Accidents Investigation Branch

Department of Transport

# Report on the incident to British Airways BV 234, G-BWFC 33 miles north of Aberdeen on 21 February 1983

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HER MAJESTY'S STATIONERY OFFICE

## List of Aircraft Accident Reports issued by AIB in 1984/1985

| *No* | *Short Title* | *Date of Publication* |
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| 5/83 | BAe HS 748 G–ASPL<br>Nailstone Leicestershire<br>June 1981 | February 1984 |
| 6/83 | Embraer Bandeirante G–OAIR<br>Hatton Nr Peterhead Scotland<br>November 1982 | January 1984 |
| 7/83 | Sikorsky S76A Spirit G–BNSH<br>Aberdeen Airport<br>October 1981 | July 1984 |
| 8/83 | DHC–6 Twin Otter 310 G–STUD<br>Flotta Aerodrome Orkney<br>April 1983 | May 1984 |
| 9/83 | Sikorsky S76A G–BGXY<br>South Kirkton Aberdeen<br>March 1981 | July 1984 |
| 1/84 | Douglas DC–8–51 RP–C830<br>London (Stansted)Airport<br>September 1982 | August 1984 |
| 2/84 | Bell 212 G–BDIL<br>14 miles from the Murchison Platform<br>September 1982 | September 1984 |
| 3/84 | Cessna 404 Titan G–OEMA<br>Over the North Sea<br>April 1983 | September 1984 |
| 4/84 | Aerospatiale AS 332L G–TIGD<br>Aberdeen Airport<br>July 1983 | |
| 5/84 | Cessna Citation 500 G–UESS<br>Isle of Lewis<br>December 1983 | February 1985 |
| 6/84 | Pilatus PC–6/H2-B2 Turbo Porter G–BIZP.<br>Yarwell, Nr Peterborough<br>December 1983 | |
| 7/84 | British Airways BV 234 G–BWFC<br>33 miles north of Aberdeen<br>February 1983 | |

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

25 January 1985

*The Rt Honourable Nicholas Ridley*
*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 incident to British Airways BV 234, G–BWFC which occurred 33 miles north of Aberdeen on 21 February 1983.

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: 7/84**
**(EW/C812)**

| | | |
|---|---|---|
| *Operator:* | | British Airways Helicopters |
| *Aircraft:* | *Type:* | Boeing Vertol 234 LR |
| | *Nationality:* | United Kingdom |
| | *Registration:* | G–BWFC |
| *Place of Incident:* | | 33 Nautical Miles North of Aberdeen<br>Latitude: 57° 45′ North<br>Longitude: 001° 58′ West |
| *Date and Time:* | | 21st February 1983 at 1117 hrs |
| | | All times in this report are GMT. |

# Synopsis


The incident occurred during a routine flight from the 'Cormorant Alpha' platform in the East Shetland Basin to Aberdeen. Following a series of No 1 engine 'chip detector' warnings the crew observed a steady increase in No 1 engine torque and shut down that engine. The crew were then alerted to a fire in the area of the No 1 engine transmission gearbox when smoke entered the passenger cabin. The smoke evacuation procedures were effective in clearing smoke from the passenger cabin and the aircraft made an emergency landing at Longside airfield where the passengers were disembarked without further incident.

The report concludes that a bearing failure in the No 1 (left) engine transmission gearbox and a resulting undetected overheat condition led to the fire and subsequent failure of the No 1 engine transmission drive-shaft.

This bearing failure is one of a series of similar failures in the same location and the report recommends that the manufacturer should reassess the loads sustained by the bearing. Recommendations are also made concerning transmission failure warning systems and the vulnerability of the Boeing Vertol 234 and other helicopters to fires in areas adjacent to transmission components.

# 1. Factual Information

## 1.1 History of the flight

G–BWFC had been on a routine flight to the East Shetland Basin and was returning directly to Aberdeen from the Cormorant Alpha Platform at a height of 6,000 feet. Take-off from the Cormorant Alpha was at 0940 hrs with 32 passengers and a crew of 3. At approximately 0955 hrs the pilots were alerted by a brief flash of the 'ENG 1 CHIP DET' caption on the annunciator panel but this did not remain illuminated for more than a second. Two minutes later the same caption again illuminated briefly and the commander instructed the cabin attendant to examine the magnetic indicators on the Maintenance Inspection Panel situated in the ramp area at the rear of the passenger cabin. The cabin attendant reported that the magnetic indicator associated with the No 1 engine transmission chip detector had 'tripped', but that he had been able to reset it.

In accordance with the flight reference cards and the normal procedures in force at the time, the flight was continued and the crew monitored the condition of the No 1 engine gearbox by reference to the oil temperature and pressure gauges on the flight deck. The temperature and pressure indications remained normal but the 'ENG 1 CHIP DET' caption continued to flash periodically and as the flight continued the time interval between flashes decreased progressively until by 1117 hrs the caption was illuminating approximately every 5 seconds. Additionally during this period of the flight the No 2 engine normal collective beep (fuel) trim system ceased to function and the emergency beep trim was selected on this engine.

At 1117 hrs the aircraft was approximately 5 miles from the Aberdeenshire coast at 6,000 feet when the first officer, who was the handling pilot, drew the commander's attention to the No 1 engine torque which was slowly rising from the matched cruise power setting of 55%.

The commander attempted briefly to prevent the torque increasing further by using the No 1 engine emergency beep trim system, however this was not successful and because the torque continued to rise he closed down the No 1 engine when the torque had reached 75%. Until the point of engine shut down the oil temperatures and pressures had remained normal and only the 'ENG 1 CHIP DET' caption was illuminated. Captions illuminated indicating primary and auxiliary transmission lubrication failure and the 'ROTOR BRAKE ON' warning light also illuminated. An immediate descent was initiated and a radio call made to Aberdeen although a formal distress call was not transmitted.

The cabin attendant was on the flight deck at this time and the commander told him to prepare the passengers for a possible ditching. When he opened the flight deck door he saw that the cabin was filling with a light coloured smoke and he immediately drew this to the attention of the commander before going into the cabin. During the subsequent investigation passengers reported that before the smoke began to appear there was a loud screeching sound from the rear of the aircraft terminating with an explosion or snapping noise. Some also reported a general increase in the level of vibration.

Having briefed the passengers from his normal position at the front of the cabin the cabin attendant walked slowly down the aisle to confirm that his instructions had been carried out. When he was adjacent to rows 10 and 11 at the rear of the aircraft he could feel heat from the area of the port cabin roof forward of the rear bulkhead. Meanwhile the commander had selected the cabin ventilation to 'RAM VENT', which was effective in clearing the smoke, and he then turned his attention to the gearbox temperature and pressure gauges. The temperature gauge which was selected to the 'SCAN' position, showed a rapid rise in temperature indication to the maximum gauge temperature. When the gearboxes were selected individually however, normal temperatures were shown. The pressure gauge indicated zero regardless of the position of the selector switch.

The commander initially intended to make an emergency landing on the beach but when the cabin attendant reported that smoke was clearing he elected to divert to Longside for a single engined landing on the 2,000 feet runway. He called Longside at approximately 1121 hrs and landed there at 1126 hrs. During the final stages of the approach the cabin attendant reported that some smoke was again coming into the rear of the cabin. When the aircraft had halted on the runway the passengers were evacuated through the forward exit and the remaining engine was shut down using the emergency 'T' handle. The rotor brake was applied normally and after the rotor had come to a stop the crew inspected the aircraft to ensure that there was no persisting fire.

## 1.2 Injuries to persons

| Injuries | Crew | Passengers | Others |
|---|---|---|---|
| Fatal | – | – | – |
| Serious | – | – | – |
| Minor/None | 3 | 32 | |

## 1.3 Damage to aircraft

Substantial fire damage in the area of the No 1 engine transmission gearbox.

## 1.4 Other damage

There was no other damage.

## 1.5 Personnel information

| | |
|---|---|
| Commander: | Male, aged 41 years |
| Licence: | Airline Transport Pilot's Licence (Helicopters) valid until 24 March 1987 |
| Helicopter type ratings: | Alouette II<br>Sikorsky S61N<br>Boeing Vertol Chinook |

| | |
|---|---|
| Instrument rating: | dated 27 January 1983 |
| Medical Certificate: | valid until 28 February 1983 |
| Certificate of test: | Boeing Vertol Chinook 27 January 1983 |
| Flying experience: | Total all types: 5,520 hours<br>Total helicopter: 5,460 hours<br>Total BV234: 860 hours<br>Total last 30 days: 45 hours<br>Total last 7 days: 14 hours |
| Duty time: | Off duty 20 February 1983<br>On duty 0600 hrs 21 February until 1500 hrs on 21 February |
| Co-pilot: | Male, aged 26 years |
| Licence: | Airline Transport Pilot's Licence (Helicopters) valid until 24 January 1993 |
| Helicopter type ratings: | Bell 47<br>Bell 206<br>Sikorsky S61N<br>Boeing Vertol Chinook |
| Instrument rating: | None |
| Medical Certificate: | Valid until 31 March 1983 |
| Certificate of test: | Boeing Vertol Chinook 7 February 1983 |
| Flying experience: | Total all types: 1,845 hours<br>Total helicopter: 1,515 hours<br>Total BV234: 377 hours<br>Total last 30 days: 54 hours<br>Total last 7 days: 13 hours |
| Duty time: | Off duty 20 February 1983<br>On duty 0600 hrs 21 February until 1500 hrs on 21 February |

**1.6 Aircraft information:**

*1.6.1 General information*

| | |
|---|---|
| Type: | Boeing Vertol 234LR |
| Manufacturer: | Boeing Vertol Company, Philadelphia, USA |
| Operator: | British Airways Helicopters |
| Airframe Serial Number: | MJ 004 |

| | |
|---|---|
| Date of Manufacture: | 1981 |
| Certificate of Airworthiness: | Transport Category (Passenger) valid until 28 May 1983 |
| Certificate of Registration: | G–BWFC in the name of British Airways Helicopters |
| Certificate of Maintenance: | Validated on 31 October 1982 at 1,934.20 flying hours |
| Next Check Due: | A4 Inspection (25 hour check) due at 2,323.50 hours |
| Total Airframe Hours: | 2,325.05 hours |
| No 1 Engine Transmission Gearbox Manufacturer: | Boeing Vertol |
| No 1 Engine Transmission Gearbox Part Number: | 234D6200-1 |
| No 1 Engine Transmission Gearbox Serial Number: | All-3520 |
| Total Engine Transmission Gearbox Hours | 1,241 hours since new |

*1.6.2 Aircraft weight and centre of gravity*

The helicopter's weight at take-off was calculated to be 17,798 kg and its centre of gravity was within limits.

The maximum approved gross weight for this helicopter is 22,000 kg.

*1.6.3 Technical Log*

Examination of the helicopter's technical log did not reveal any defects which were related to the incident.

**1.7 Meteorological information**

The area was dominated by a large anticyclone centered just to the east of Scotland. There was a layer of stratocumulus the base of which was at around 3,000 feet and the top at 5,500 feet. The visibility was generally in excess of 20 kilometres.

**1.8 Aids to navigation**

*1.8.1 On the ground*

Radar

Very High Frequency Omni Range (VOR)

Distance Measuring Equipment (DME)

Medium Frequency Non-directional Beacon (NDB)

Decca

*1.8.2 In the air*

The aircraft was equipped with:

VOR/ILS - twin installation

DME

Automatic Direction Finder (ADF)

Decca

Weather radar

**1.9 Communications**

The aircraft was in contact with Aberdeen Radar and immediately after the incident called them saying "WE'RE HAVING A PROBLEM WITH OUR ENGINE AND REQUEST DESCENT TO FLY BELOW CLOUD WE'RE HEADING TOWARDS SCOTSTOWN HEAD". Radar cleared them to descend to 1,500 feet and gave them their position as 12 miles northwest of Scotstown Head. At 1121 hrs when the aircraft was at 2,500 feet below cloud the aircraft commander decided to divert to Longside and called that airfield for clearance and requested fire cover for the landing.

**1.10 Aerodrome and ground facilities**

Longside was an unlicensed heliport with a 2,000 feet tarmac runway operated by North Scottish Helicopters. A fire truck was available which carried a selection of hand operated fire extinguishers and in addition a 20 gallon lightwater extinguisher and a 50 kg BCF extinguisher. Additional fire cover was requested from the Grampian Fire Service at Peterhead and this was available some 9 minutes after the aircraft had landed.

**1.11 Flight recorders**

The helicopter was not equipped with a flight data recorder or a cockpit voice recorder, nor were these required to be fitted.

**1.12 Wreckage and impact information**

*1.12.1 Examination of the aircraft*

When the AIB investigation was initiated at Longside airfield on 23 February 1983, the No 1 engine and transmission gearbox along with the combining gearbox and fire damaged wiring looms had been removed from the helicopter. The photographs, included at Appendix 1, were taken shortly after the helicopter landed at Longside and show the areas of damage.

Examination of the helicopter revealed that severe fire damage had affected the No 1 engine transmission gearbox fairing and associated stub fairing with lesser damage to the engine intake screen and lip fairings. The stub fairing had been disrupted by failure of the transmission cross-shaft between the engine transmission gearbox and the combining gearbox (refer Appendix 2). The mid section of this shaft was missing leaving a short section still attached to the transmission gearbox flexible coupling and some 15 cm of shaft attached to the combining gearbox input coupling. What remained of the cross-shaft was fire affected, particularly around the outboard failure where the fractured area was splayed radially and exhibited a rotational rub-type witness mark on the fractured surface.

Evidence of fire entrainment inboard from the engine transmission gearbox output shaft seal was observed. There was marked flame erosion of the aluminium alloy rib at the root end of the stub fairing and molten aluminium alloy spatter and thermal discolouration on the two adjacent steel flying control rods. The protective finish on the left rear side of the combining gearbox was blistered and two lubrication hoses in the same area showed evidence of fire induced surface craze cracking. Electrical wiring grommets at the base of frame 482 were damaged and the left mounting structure for the combining gearbox was heat discoloured and distorted.

The combining gearbox filler cap assembly had been found in the 'open' condition and the associated hinge had cracked. The internal filter-screen 'cylinder' was partially split longitudinally due to break-away of part of the soldered seam. Inspection of the left engine transmission gearbox main lubrication system pressure filter showed it to be heavily contaminated with fine steel and bronze/aluminium alloy particles, although the by-pass indicator button was found in the normal position, as were those associated with two other pressure filters for the combining gearbox and starboard engine transmission gearbox. The smaller auxiliary system pressure filter for the No 1 engine transmission gearbox was similarly contaminated. The No 1 engine transmission gearbox scavenge line filter 'screen' had trapped some six sections of bronze bearing cage and in addition a 3.5 cm long section of inner race land (or 'rail') from a large bearing had fallen out of the scavenge hose upon disconnection.

No evidence of oil level was apparent in any of the three reservoir sight-glasses, although this is normal for Nos 1 and 2 reservoirs due to drain-back into their respective engine transmission gearboxes. Small oil samples were taken from all three reservoirs (ie, the No 1 engine transmission gearbox, combining gearbox and No 2 engine transmission gearbox). In addition, approximately one litre of oil was drained from the No 1 engine transmission gearbox and some two litres from the No 2 engine transmission gearbox.

External examination of the No 1 engine transmission gearbox assembly at British Airways Helicopters, Aberdeen, showed it to be generally blackened by fire, with a particularly noticeable heat-band effect around the housing in a position outboard of the input pinion main roller bearing.

There was some localised blistering around the breather hose union on the upper forward area of the housing and the hose connection was found to be loose by half a turn. The small diameter auxiliary pressure hose exhibited a white 'frosty' appearance, caused by the Teflon inner hose exuding through the steel braided outer sheath, due to heat absorption.

The status of the Maintenance Inspection Panel in the ramp area at the rear of the helicopter had been recorded after the landing at Longside: the No 1 (left) engine transmission gearbox chip detector and the No 1 engine filter screen magnetic indicators had 'tripped'. On the flight deck the circuit breakers for the engine transmission gearbox oil pressure warning, rotor brake warning, DC power warning and engine oil level warning had also tripped.

*1.12.2* *Subsequent detailed examination*

1.12.2.1 No 1 Engine and Transmission Gearbox

The No 1 engine together with its transmission gearbox cross-shaft and the combining gearbox were removed to the operators engineering base where they were examined in detail.

Examination of the engine revealed no serious defects within the power plant. Some very light foreign object damage to the compressor rotor blade leading edges and stator trailing edges was apparent together with some acceptable light alloy 'spatter' on the stage 1 and 2 turbine blades. There was no damage to the free turbine.

Strip examination of the No 1 engine transmission gearbox revealed that the input pinion main roller bearing Part No 114DS665-1 had failed, with complete break-up of the phosphor-bronze cage, inner race aft land and a 4 cm section broken away from the front land (refer Appendix 3).

Excessive wear was evident on both races with the outer race exhibiting an approximately 60° 'arc' of break-up. All twelve rollers had a black heat-discolouration, with skid-induced 'flats' on their rolling surfaces. Some showed evidence of the rollers 'skidding' at 90 degrees to their normal axial orientation during the failure sequence.

The lubrication plate located on the aft side of this bearing was badly worn on its forward face due to roller and bearing debris contact. Bearing cage and land debris had damaged many gear teeth as well as the output bevel ring gear baffle.

The scavenge outlet at the base of the engine transmission gearbox housing was almost completely blocked with fine metallic debris, which had also accumulated on the adjacent chip/temperature detector assembly.

All four lubrication hoses associated with the No 1 engine transmission gearbox (ie, main and auxiliary pressure, common scavenge return and 'breather') were found to have suffered total loss of their internal elastomer in the region of the outboard cross-shaft failure due to the effects of the fire in this area. Tests conducted to examine this feature showed that temperatures in the region of 600-650°C were required to produce this phenomenon.

The failed input pinion main roller bearing was examined by the Royal Aircraft Establishment (RAE) Materials Department and Boeing Vertol, Philadelphia.

Neither laboratory could determine the primary cause of the bearing failure. All fractures examined were ascribed to over-stressing with the exception of a localised fracture evident on the forward land of the inner race which the RAE metallurgists thought due to low cycle fatigue caused by roller end radii contact and therefore secondary to some other problem which had allowed roller track divergence.

RAE made the point that on low ductility steels of this type (AMS 6490, 'M50', Rockwell C60 minimum) fatigue is typically difficult to identify due to the lack of fine striation detail on the fractures. The only fatigue identified by Boeing was associated with the approximately 60° arc of surface break-up (spalling) present on the outer race, where the heat and mechanical deformation of the eventual failure had also induced re-hardening of the track surface layer.

Oil samples taken from the No 1 engine transmission gearbox lubrication system were analysed by the Ministry of Defence Materials Quality Assurance Directorate. The analysis confirmed that the oil complied with the correct specification - ie, D.ENG R.D. 2497, AEROSHELL 555. Inspection of the Spectrometric Oil Analysis Programme (SOAP) results from G–BWFC before the incident showed them to have been generally satisfactory with no evidence of the impending bearing failure.

1.12.2.2 Other Components

The No 1 engine transmission cross-shaft was examined at both RAE and Boeing Vertol Material Laboratories and found to exhibit evidence of excessive thermal exposure (1100°F minimum) at the outboard end and to a lesser extent within the inboard area. Both outboard and inboard failures were consistent with over-stressing.

The output shaft sprag-clutch assembly could not be hand-rotated as found and was discoloured with a blue/brown 'shelac' appearance from over-heating in the presence of oil. Later examination by the manufacturer (Borg-Warner) indicated that it had been serviceable and showed evidence of excessive over-run wear on the sprags due to operating in a high temperature lubrication environment with fine metal particle contamination.

The main lubrication pump cylinder was removed from the combining gearbox and inspected. No failure was observed. The auxiliary pumps and filter housing were removed from the front of the combining gearbox and similarly found to be mechanically intact.

Removal of the rotor-brake, back-plate and aft bevel gear shaft from the combining gearbox and inspection of the associated bevel gears showed no evidence of any distress.

The transmission oil pressure monitoring system sensors (main and auxiliary pressure switches and main system transducer) were checked after the incident and all operated satisfactorily.

1.12.2.3 Transmission Lubrication Monitoring System: (Refer Appendix 4)

The transmission oil temperature monitoring system sensors, the combined chip/ temperature detector assembly and the associated temperature switch, were examined by their respective manufacturers. The detector had suffered damage to the three support pillars of the temperature switch housing. This damage was noted when the detector was removed and a section of bearing inner race was found lodged within the support pillars. These detailed examinations showed that the detector was serviceable at the time of the bearing failure and that the temperature switch had been subjected to severe vibration and excessive temperature which had caused a shift in its temperature response and a reduction in the switch contact spring force. The switch closed over a range of 175 - 180°C compared to the specification 200 ± 5°C. Although the contact closure spring force was found to have reduced from 10 grammes (minimum) to 4.5 grammes, switch closure was consistent on test and no contaminents were found on the contact surfaces. The examinations revealed that the switch had been subjected to temperatures in excess of 315°C. This evidence was obtained from examination of the 'O' ring seals, phenolic components and zinc plating on the detector assembly.

The fire damaged electrical wiring looms were examined in detail at the Accidents Investigation Branch Wreckage Analysis Facility. It was noted that the electrical connector to the combined chip/temperature detector was missing from the wiring looms. It was subsequently established that the connector had been removed from the helicopter along with the fire damaged wiring when the operators engineering staff commenced repairs before AIB were notified of the incident. An extensive search of the operators engineering facility failed to recover the connector, but the engineers recalled that the connector had been fire damaged and was, when first examined, separated from its wiring. Inspection and continuity tests on the burnt wiring revealed no lack of continuity in any of the wires, although several areas were apparent where all the insulation material had been destroyed by the fire and the wires were bare.

Following repairs to the helicopter which included splicing in a new section of wiring loom to replace that wiring damaged in the fire, the transmission warning systems were functioned and were all found to be serviceable.

### 1.13 Medical and pathological information

Not applicable.

### 1.14 Fire

The in-flight fire was severe though localised in the area of No 1 engine transmission gearbox fairing. The origin of the fire appears to have been associated with the ignition of transmission oil following the degradation of the seal around the gearbox output shaft. The first indication of fire was when the passenger cabin began to fill with light coloured smoke. The air conditioning system was selected to 'RAM-VENT' and this was effective in clearing the cabin of smoke.

By the time the helicopter landed at Longside the fire had extinguished.

The fire damage was limited to the No 1 engine transmission gearbox fairing, the transmission cross-shaft and its fairing and the wiring looms in the area of the combining gearbox. Some light structural damage had occurred due to thermal distortion.

## 1.15 Survival aspects

The smoke evacuation procedures were effective in clearing the smoke and no one on board suffered from the effects of smoke inhalation. The helicopter was landed normally and the passengers were evacuated through the forward exit. There were no injuries.

## 1.16 Tests and research

Tests conducted by the helicopter manufacturer to examine material decomposition and spontaneous ignition temperatures for transmission oil as a result of an accident in 1975 are included at Appendix 5.

## 1.17 Additional information

### *1.17.1 Incidence of 'Spurious' Transmission Chip/Temperature Warnings*

Following this incident, the helicopter operator carried out a survey of CHIP detector and 'OIL HOT' warnings, covering the period from the receipt of each BV 234 helicopter to the 3rd March 1983. The total number of CHIP warnings across the fleet of six BV 234's during this period was 18 (4 were engine related 'CHIPS') of which 13 (including 3 engine related warnings) were judged as spurious.

It should be noted here that the term spurious includes cases where slight contamination of the detector was found and was remedied by cleaning the detector-head. With regard to G–BWFC, four spurious chip warnings were recorded, out of a total of six, giving a rate of 1.74 per 1,000 hours compared to 3 spurious warnings each for two other helicopters, giving respective rates of 1.30 and 1.51. Therefore G–BWFC did have a slightly higher rate of spurious chip detector warnings than the remainder of the operator's Chinook fleet. The average spurious warning rate for the fleet was 1.20 per 1,000 hours.

There were 77 'OIL HOT' warnings during the same period across the fleet, and all were judged as having been spurious/unconfirmed. G–BWFC had the second highest rate of hot warnings with some 22 (a rate of 9.56) compared to some 31 warnings for the helicopter with the highest rate (13.43). The fleet rate for 'OIL HOT' warnings was averaged at 7.09 per thousand hours.

### *1.17.2 Previous cases of Engine Transmission Gearbox Input Pinion Main Roller Bearing Failure*

Between 1965 and the incident to G–BWFC on 21 February 1983 there had been 12 cases of input pinion main roller bearing failures. Details of these failures are given in Appendix 6.

### *1.17.3 In-flight Emergency Procedures*

Throughout the incident the crew complied with the In-flight Emergency Procedures current at that time and elected to maintain an altitude of 6,000 ft from the initial warning indication until the torque rise caused the crew to shut down the No 1 engine. U/CT the only information available to the crew was the 'ENG 1 CHIP DET' warning on the annunciator panel and the magnetic indicator on the Maintenance Inspection Panel which indicated that the warnings were generated within the No 1 engine transmission gearbox. The absence of other indications, particularly transmission temperature and pressure excursions or an increase in vibration, led the crew to consider the possibility of a spurious warning.

The following extracts from the Flight Reference Cards were current at the time of the incident:

"(a) ENGINE CHIPS DETECTED

INDICATION

ENG CHIP DET annunciator on.

ACTION

1. If oil temperature and pressure and other engine indications are normal and the ENG OIL LEVEL annunciator remains extinguished, continue with the ECL at FLIGHT.

2. If pressure, temperature, or other engine indications are abnormal, or if ENG OIL LEVEL annunciator is illuminated shut down and secure the affected engine.

(b) TRANSMISSION CHIPS DETECTED

INDICATION

XMSN CHIP DET annunciator on.

ACTIONS

1. Temperature and pressure - monitor

2. Land as soon as practicable

CONSIDERATIONS

1. If temperature and pressure excursions present, land as soon as possible.

2. If unusual noises or severe vibrations present, land immediately."

On 22 February 1983, the day following the incident, Flying Staff Instruction BV/6/83 was issued by British Airways Helicopters of which the following is an extract:

"CHIP DETECTORS

An engine chip detector annunciator which is seen from the maintenance panel to be caused by the engine transmission is to be treated in the same way as a centreline transmission chip; ... For all transmission chips, the flight to the nearest practicable landing site is to be continued at low altitude.

Should temperature or pressure abnormalities be present, the engine is to be shut down and the aircraft landed as soon as possible ...

Should the engine chip annunciator be caused by the engine itself, then continue according to the drill (paragraph (a) above) additional to that, however, the aircraft is to be landed as soon as practicable."

# 2. Analysis

The detailed examination confirmed that the primary failure was that of the input pinion main roller bearing within the Number 1 (left) engine transmission gearbox. However, the areas of airworthiness concern raised by this incident extend to the secondary factors of the transmission warning indications and the subsequent airborne fire.

## 2.1 The bearing failure

The only evidence of pre-existing fatigue damage found by the helicopter manufacturer was that associated with the 'spalling' damage to the outer race track, damage which was to some extent masked by subsequent mechanical deformation and thermal damage sustained during the ultimate break-up of the bearing.

The RAE Materials Laboratory report on the failed bearing stated that an isolated fracture evident on the forward land of the inner race appeared to be characteristic of low cycle fatigue. However RAE considered that the nature of this fracture suggested that it was likely to be a secondary feature associated with local overstressing resulting from roller defections within the inner race track. It would appear, then, that the fatigue induced spalling of the outer race was present well before eventual failure occurred, but whether it played a significant part in that failure remains uncertain, since such spalling of highly loaded bearings is not uncommon whereas total failure is comparatively rare. However, one could envisage such track roughness initiating or aggravating roller instability with consequent effect on land and cage stressing. The helicopter manufacturer has indicated that the roller stability, radii and cage stiffness have been areas of concern with this bearing for some time.

The history of failures to this bearing suggests that the loading spectrum may be more severe than is currently believed. It would seem appropriate therefore that the manufacturer should conduct a detailed reassessment of this bearing's loading and its operating environment.

## 2.2 The transmission gearbox warning indications

The first indication of the impending bearing failure appears to have been the 'ENG 1 CHIP DET' warning on the annunciator panel, reported by the Commander to have occurred some 15 minutes after take-off from Cormorant Alpha. It was later confirmed by the cabin attendant with his observation of the 'LEFT ENG XMSN CHIP DETECTOR' magnetic indicator indication on the Maintenance Inspection Panel in the ramp area. The crew received no other warning, and it was only the torque rise on the No 1 engine which caused the commander to shut it down.

The absence of any oil temperature or pressure warning indication during the period from the first chip detector warning until the onset of the torque rise, deprived the crew of vital information which would have enabled them to make important decisions related to the particular type of failure.

### *2.2.1 The Transmission Oil Pressure Monitoring System*

The sensors that provide transmission oil pressure indications and warnings (refer Appendix 4) were checked after the incident and operated satisfactorily. Had they sensed low oil pressure the switches would have illuminated the 'XMSN OIL PRESS' and the 'XMSN AUX PRESS' on the annunciator panel, and the transducer would have indicated main system pressure on the associated 'Scan' system indicator and illuminated the No 1 'XMSN' indicator light. However, no such indications were apparent.

This suggests that oil pressure, for both main and auxiliary systems was in fact maintained to the No 1 engine transmission gearbox during the progressive failure of the bearing. This is not entirely surprising since the main and auxiliary system pumps, located remotely in the combining gearbox were still functioning, and the main and auxiliary pressure filters although heavily contaminated with fine metallic debris, did not appear to be totally blocked.

It was surprising that the No 1 engine transmission scavenge screen magnetic indicator was not observed by the cabin attendant on the two occasions when he checked the Maintenance Inspection Panel in flight. The fact that this filter screen debris indicator was showing after the landing at Longside suggests that it did in fact come on in flight – as one would expect from the amount of debris subsequently found associated with the scavenge screen and associated scavenge line. This aspect raises questions concerning the wisdom of having such important indications on the Maintenance Inspection Panel remote from the flight deck.

2.2.2 *The Transmission Oil Temperature Monitoring System*

The relevant sensors in this system were the No 1 engine transmission temperature switch, (part of the combined chip/temp detector-probe assembly) located in the base of the left transmission gearbox, adjacent to the scavenge pipe outlet and the left system temperature bulb (combined switch and transducer assembly) located in the base of the left system reservoir within the combining gearbox. (Refer Appendix 4)

'XMSN OIL HOT' warnings should have illuminated on the annunciator panel and the accompanying temperature transducer should have illuminated the No 1 engine 'XMSN' indicator light and displayed the oil temperature on the scan system indicator. Again however, no such indications occurred up to the onset of the torque rise indication which caused the crew to shut down the left engine.

The absence of an indication from the temperature bulb at the base of the left transmission system reservoir, could be explained by the oil temperature in the transmission gearbox only rising above 130°C after sufficient debris from the failure of the bearing had partially blocked the scavenge return pipe, thereby greatly reducing the return rate of flow into the left reservoir. With the thermal dissipation from the relatively small volume of oil returning to the reservoir it is possible that the oil temperature did not exceed 130°C.

There still remains the question of why the No 1 engine transmission gearbox temperature detector switch did not illuminate the 'ENG 1 XMSN HOT' annunciator panel caption. The detailed examinations revealed that the switch had been subject to severe vibration and excessive temperature exposure which had caused 'a shift in its temperature response and reduction in switch contacts spring force'. The tests showed that the switch closed over a range of 175-180°C compared to the specification of 200± 5°C. The switch closure was consistent on test and no contaminants were found on the contact surfaces. Damage to the 'O' ring seals, phenolic components and zinc plating showed evidence of exposure to temperatures in the range 260-315°C, well in excess of the switch closing temperatures. It is considered therefore, that the switch should have operated.

The damage found on the temperature capsule support pillars of the combined chip/temperature probe had caused break-through of the self-closing valve anodising and a resultant 'short' of the circuit to the temperature switch. If this damage had occurred during the progressive failure of the bearing, this would have been a further reason to expect illumination of the 'ENG 1 XMSN HOT' annunciator panel warning. However, the orientation of the most badly deflected pillar adjacent to the lower wall of the left transmission gearbox suggests that debris impact with the pillar would have been highly unlikely. It is more probable that this damage to the pillars occurred during the operators attempted removal of the chip detector sub-assembly at Longside when partial rotation of the whole chip/temperature detector assembly occurred. A fragment of the bearing inner race land was found lodged between the pillars and gearbox housing which could have led to the observed pillar deformation.

The chip and temperature indication system wiring in the vicinity of the No 1 engine transmission gearbox had been seriously affected by the fire. The helicopter operator's engineering staff had commenced repairs to the aircraft before AIB were notified of the incident. These repairs included removing 2.5 metres of electrical wiring loom together with the electrical connector from the chip/temperature detector. Unfortunately the connector, which was reported by engineering staff to have been affected by fire with its associated wiring detached, was not retained with the burnt wiring when new wiring was 'spliced' into the loom. The operator confirmed that when a replacement chip/temperature detector was connected to the circuit after the repairs the circuit operated satisfactorily. Inspection and continuity tests on the associated burnt wiring found no lack of continuity in any of the wires, although several areas were apparent where all the insulation material had been destroyed by the fire and the wires were bare.

In this context it is worth noting the Commander's report that the No 1 engine transmission chip warning illuminated on the annunciator panel when the No 1 engine was shut down. This evidence indicates that, even at that late stage, the No 1 engine transmission 'chip' detector circuit was still functioning, strongly suggesting that the closely associated temperature circuit had not been affected by fire at that time.

The integrity of the No 1 engine transmission gearbox temperature detector circuit was checked on the Maintenance Inspection Panel in the ramp area before flight. However, selection of the 'XMSN System Test' rotary selector switch to 'left' effectively earths the temperature detector circuit, but at a point remote from the detector in the left transmission gearbox – actually some 2 metres from the connector from measurements of the associated wiring from G–BWFC. This circuit 'test' facility therefore omits the detector, connector and some 2 metres of wiring from such checking.

Since the temperature detector and wiring appeared free of a defect which could have prevented illumination of the 'ENG 1 XMSN HOT' annunciator panel warning, it must remain a possibility that the connector area of this circuit had a dormant open-circuit defect.

### 2.2.3 *Other Warning Indications*

Following the Commander's decision to shut down the No 1 engine a number of warnings illuminated on the flight deck, including primary and auxiliary transmission lubrication system failures and rotor brake 'On'. These warnings were all attributed to the effects of fire on the helicopter's wiring looms.

### 2.2.4 *Transmission Warning System Design*

This incident has highlighted a number of shortcomings in the transmission indication and warning systems. The 'ENG 1 CHIP DET' warning on the flight deck annunciator panel gave the initial warning to the crew in this instance but with the existing installation this had to be confirmed by reference to the magnetic indicators on the Maintenance Inspection Panel at the rear of the aircraft in order to determine whether the warning represents a chip on the engine or the associated transmission gearbox. The annunciator panel does however include oil temperature warnings for both engine transmissions ('ENG 1 XMSN HOT'). This arrangement would be sound if high oil temperature tended to be the initial indication of an imminent engine transmission failure. Experience from other cases of bearing failure has shown that such a 'HOT' indication has never been the initial indication and in fact only appeared at all in approximately 30% of cases, whereas a 'CHIP' warning was the first indication in 50% of instances. Adding two separate cautions to the annunciator panel for 'ENG 1' and 'ENG 2 XMSN CHIP DET' would enable the crew to identify immediately whether there was an engine transmission problem or an engine problem.

In addition, the scavenge line screen indicator for each engine transmission only activates the respective magnetic indicators on the maintenance inspection panel. There is no annunciator panel warning on the flight deck. Since such an indication will occur (if valid) due to a sizeable piece of debris being trapped against these screens, this is an indication of a major component break up in either engine transmission and should therefore be indicated on the flight deck annunciator panel as separate 'ENG 1 or 2 XMSN SCREEN DET' warnings. In this context, it is possible to envisage a large fragment passing the chip detector in the engine transmission gearbox and then being lodged on the scavenge screen. With the existing system such an occurrence would probably remain unnoticed by the crew with only the associated magnetic indicator showing in the maintenance inspection panel in the ramp area at the rear of the passenger cabin.

It is a fact that chip detector warnings on helicopters are to some extent degraded by the high incidence of spurious or non-critical detection due to very fine metallic debris being collected on the detector head. Improved chip detectors are now available which minimise spurious or non-critical detection by burning off fine debris by using a voltage (28 volts) across the electrodes, thereby only triggering the chip warning when larger debris is trapped.

## 2.3 Fire development

The severe localised fire damage to the No 1 engine transmission gearbox stub fairings and oil and breather pipes, particularly outboard of the cross-shaft failure, indicated that a radial 'torching' type of fire had occurred with entrainment inboard along the cross-shaft and stub fairing due to air-suction through the two oil coolers being induced by the large cooling fan. The origin of the fire appeared to have been from around the No 1 engine transmission gearbox output shaft 'Viton' seal, which had virtually fused away leaving a small annular gap around the shaft. There was also some lesser evidence of localised burning around the gearbox breather pipe union.

There were two reasons for the rapid increase in temperature within the gearbox. Initially the break-up of the bearing which led to excessive frictional heating, generated by the engine torque absorption observed by the crew. Secondly heat generation due to 'oil churning'. The engine transmission lubrication system is designed to operate with a high flow to maintain oil cooling. With the progressive blockage of the scavenge outlet, and the total disruption of the aluminium alloy oil-baffle located outboard of the output bevel ring gear, thermal generation due to oil churning would have been rapid and excessive. It may well be the case that at the moment of engine shut down this situation became critical due to sudden settlement of metallic debris over the scavenge outlet. All gear motion would have ceased, but oil would still have continued to be pumped into the gearbox by the lubrication system pumps located in the combining gearbox.

Under these conditions, the failure of the 'lip' seal around the gearbox output shaft to prevent venting of overheated oil fluid/vapour is not surprising, since the output shaft against which the seal makes edge contact had become excessively hot, as shown clearly by the 'shelac' type baked oil discolouration on this and associated sprag clutch assembly found during detailed examination.

The Mil-L-7808 transmission oil will generate dense white smoke when sprayed onto a metal surface heated to 255°C and will spontaneously ignite on a surface at 350°C (Appendix 5). The examination of the transmission gearbox chip/ temp detector indicated that the unit experienced temperatures approaching those where spontaneous ignition would occur. It is therefore considered that the fire was caused by a hot oil spray from the degraded transmission gearbox output seal spontaneously igniting on the flexible coupling of the cross-shaft which had been heated by conduction from the transmission gearbox.

A worrying feature of this incident was that the first indication of fire observed by the crew was when smoke appeared in the passenger cabin. This has been the experience with earlier cases of fire/smoke in this area. It appears that the ramp zone smoke detector, which is located in the roof of the ramp area, will not detect smoke from the engine transmission or combining gearbox area. The ramp zone smoke detector was fitted to meet an FAA requirement for smoke detectors to be installed in closed compartment areas. Tests have shown that smoke generated in the engine and transmission zones intially flows aft and up through the pylon structure until it reaches sufficient volume when it will enter the passenger cabin via the overhead area, it will then flow forward with the normal airflow direction in the cabin.

It would be unwise to underestimate the potential hazard of fire in such areas where flight controls and wiring looms could be affected, particularly on an aircraft that spends the major part of its flight time over water and as seen here has an ineffective airframe fire detection system and no transmission fire suppression capability.

The airworthiness requirement for fire detection and suppression in the vicinity of power plant hot zones has been established for many years. In the light of experience on this helicopter type and of similar incidents on other helicopters, it would seem prudent that the manufacturers and airworthiness authorities consider the installation of fire detection and suppression systems for transmission areas. Areas which although not designated as hot zones have shown in practice to have been the site of a number of potentially catastrophic in-flight fires.

It was noted during the investigation that the helicopter manufacturer had, as a result of earlier cases of fire, changed the flight control push pull rods in the fire affected area from aluminium alloy to stainless steel. The control system bellcranks and lever assemblies in the same area however, are of aluminium alloy. Failure of bell-cranks and lever assemblies, through the effects of fire, would be as catastrophic as failures of control rods. If the material change was designed to give the flight controls additional protection in the event of fire, then the same philosophy should apply to the bellcranks and lever assemblies.

### 2.4 In-flight emergency procedures

The helicopter was maintained at a height of 6,000 ft throughout the incident. In retrospect it can be appreciated that had the incident developed rapidly then the time taken to descend from 6,000 ft could possibly have meant the difference between making a controlled ditching or losing control of the helicopter.

The operators 'Flying Staff Instruction' issued on the day following the incident directed that in the event of a transmission chip warning, the flight to the nearest practicable landing site would be conducted at low level. The instruction was issued to ensure that if necessary a controlled ditching could be carried out without delay.

The suggested additions to the annunciator panel of separate engine transmission chip detector warnings and transmission scavenge screen indicator warnings discussed earlier in the analysis would allow the crew to determine rapidly the source of a warning and make for a more efficient monitoring of the relevant parameters. These changes and corresponding amendments to the In-Flight Emergency Procedures would provide the crew with better information on the condition of the transmission system and allow them to be better placed should a decision to ditch be necessary.

# 3. Conclusions

*(a) Findings*

(i) The crew were properly licensed and adequately experienced to conduct the flight.

(ii) The helicopter had been maintained in accordance with an approved maitenance schedule and the Certificates of Airworthiness and Maintenance were valid at the time of the incident.

(iii) The No 1 engine transmission gearbox input pinion main roller bearing broke up in flight. The mode of failure could not be determined due to the damage sustained by the bearing during the failure sequence.

(iv) The bearing failure generated excessive temperatures within the gearbox causing failure of the output shaft seal and spontaneous ignition of the gearbox lubrication oil.

(v) The engine transmission 'OIL HOT' temperature warning system failed to indicate the rapid rise in oil temperature possibly due to a dormant fault in the systems electrical circuit.

(vi) The inboard entrainment of the fire led to softening and the ultimate failure of the No 1 engine transmission cross-shaft and marked thermal damage to the structure, transmission lubrication system and electrical wiring in the area.

(vii) The fire was not detected by the ramp area smoke detector despite the close proximity of the fire and large volumes of smoke in the passenger cabin.

(viii) There was no requirement or provision for a fire detection and/or a suppression system in the transmission zones despite previous incidents of fire in these areas on similar helicopter types.

(ix) Warning indications that would enable the crew to identify the source of an engine chip warning, determine its significance and take the appropriate action were located in the rear of the helicopter on the Maintenance Inspection Panel and not on the flight deck.

(x) Throughout the incident the crew acted in accordance with the In-Flight Emergency Procedures current at that time.

(xi) This and other cases of bearing failure cited, indicate that the loading spectrum of the bearing may be more severe than is currently believed.

*(b) Cause*

The incident was caused by the failure, in-flight, of the No 1 engine transmission gearbox input pinion main roller bearing.

# 4. Safety Recommendations

It is recommended that:

4.1 The helicopter manufacturer and certificating authority reconsider the design of the engine transmission gearbox input pinion main roller bearing in the light of the evidence that suggests that the bearing loading spectrum may be more severe than is currently believed.

4.2 Airworthiness authorities review the fire detection and suppression requirements for helicopter transmission areas which are currently not designated as 'hot zones'.

4.3 The helicopter manufacturer and the certificating authority review the adequacy of the current flight deck transmission warning indications and expedite the introduction of the new generation of chip detectors in order to reduce the numbers of non-critical chip warnings.

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