AIRCRAFT ACCIDENT REPORT 1/90

Air Accidents Investigation Branch

Department of Transport

Report on the accident to Sikorsky S61N, G-BDES in the North Sea 90 nm north east of Aberdeen on 10 November 1988

LONDON: HMSO

First published 1990

ISBN 0 11 550965 8

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Department of Transport
Air Accidents Investigation Branch
Royal Aerospace Establishment
Farnborough
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20 April 1990

The Right Honourable Cecil Parkinson
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr D F King, an Inspector of Accidents, on the circumstances of the accident to Sikorsky S61N, G-BDES which occurred in the North Sea 90 nautical miles north east of Aberdeen on 10 November 1988.

I have the honour to be
Sir
Your obedient servant

D A COOPER
Chief Inspector of Air Accidents

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GLOSSARY OF ABBREVIATIONS

AAIB	Air Accidents Investigation Branch
ADELT	Automatically Deployed Emergency Locator Transmitter
AGC	Automatic Gain Control
BCAR	British Civil Airworthiness Requirements
CAA	Civil Aviation Authority
CAM	Cockpit Area Microphone
CVR	Cockpit Voice Recorder
dB	decibels
FAA	Federal Aviation Administration
FILO	Flight Information Liaison Officer
HUET	Helicopter Underwater Escape Trainer
HUMS	Health and Usage Monitoring Systems
IAM	Institute of Aviation Medicine
IAS	Indicated Air Speed
NR	rotor speed
OIM	Offshore Installation Manager
PA	Public Address
RAE	Royal Aerospace Establishment
RC	Rockwell$_C$
RCC	Rescue Co-ordination Centre
SAR	Search and Rescue
SARBE	Search and Rescue Beacon Equipment
ULB	Underwater Locator Beacons
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

SIKORSKY S61N

Air Accidents Investigation Branch

Aircraft Accident Report No: 1/90
(EW/C1090)

Registered Owner and Operator:	British International Helicopters Ltd
Aircraft:	
Manufacturer:	Sikorsky Aircraft, USA
Type	S61N
Nationality:	British
Registration:	G-BDES
Place of Accident:	In the North Sea 90 nautical miles north east of Aberdeen
	Latitude: 58° 25' North
	Longitude: 000° 14' West
Date and Time:	10 November 1988 at 0850 hrs
	All times in this report are UTC

SYNOPSIS

The accident was notified to the Air Accidents Investigation Branch (AAIB) on 10 November 1988 at 1010 hrs and an investigation began the same day. The AAIB team comprised Mr D F King (Investigator in Charge), Mr C I Coghill (Engineering), Mr B M E Forward (Operations) and Mr R J Vance (Cockpit Voice Recorder).

The Sikorsky S61N, G-BDES, was tasked on a non scheduled public transport service from Aberdeen to three oil installations in the North Sea 100 nm north east of Aberdeen and return. The outbound and two short inter-rig sectors were completed without incident and, after refuelling, the aircraft was prepared for the return to Aberdeen.

With a crew of two and eleven passengers on board G-BDES was lifted to a low hover and the engines and controls checked before commencing the climb. Whilst established in the cruise the crew and passengers became aware of an unusual, initially slight, buzzing noise. This noise increased in volume and the commander decided to land as soon as possible and turned towards a suitably equipped platform. The noise continued to get louder associated with increasing vibration. Following loss of the main transmission oil pressure, restored by use of the Emergency Lubrication Pump, a sudden change in the level of both noise and vibration associated with rapidly fluctuating engine indications forced the commander to execute an immediate ditching. Shortly afterwards G-BDES inverted.

The crew and passengers evacuated the aircraft and were rescued without serious injury.

The following causal factors were identified:-

i) Progressive damage within the main transmission went undetected.

ii) Failure of the main transmission was initiated by fatigue failure of the helical combiner gear (part no. S6135-20620).

iii) The fatigue origin was associated with aluminium oxide inclusions, the aluminium oxide being a by-product of the steel production process.

iv) The steel used for the manufacture of the combiner gear was single air melt and only subject to a cleanliness inspection based on a small sample at the poured ingot stage.

1 Factual Information

1.1 History of the flight

On the morning of 10 November 1988, G-BDES was tasked on a non scheduled public transport flight to three oil installations in the North Sea, 100 nm north east of Aberdeen. These destinations were the Sedco 707, the Smit Semi 2 and the Sedco 703. The weather for the operating area was forecast as surface wind 200°/35 kt, surface temperature +10°C, visibility generally 15 km with local reductions to 3,000 metres in rain. The cloudbase generally was forecast as 2,000 feet with scattered stratus at 1,000 -1,500 feet and local stratus patches down to 300 feet. The sea temperature was +10.5°C.

The crew, consisting of two captains, one of whom was to act as aircraft commander, reported for duty at 0600 hrs for a scheduled 0700 hrs departure. The commander had had a 36 hour rest period and the co-pilot 13½ hours.

G-BDES departed Aberdeen at 0704 hrs. The flight to the Sedco 707 was unremarkable and the engine power assurance checks done en-route were satisfactory. At the Sedco 707 passenger transfer and unloading of freight was supervised by the co-pilot, who then carried out an external check of the aircraft which revealed nothing untoward. The subsequent short flight to the Smit-Semi 2 was uneventful. On arrival the commander supervised the unloading of a small amount of freight. Again nothing amiss was revealed by the external inspection. For the next short leg to the Sedco 703 the co-pilot was the handling pilot but, because of the wind direction on the helipad, the commander carried out the landing. The commander then remained at the controls while the co-pilot supervised the transfer of passengers and the rotors running re-fuelling. A fuel sample from the rig fuel supply was examined before the start of re-fuelling and proved satisfactory. Having satisfied himself that the re-fuelling had been completed correctly, the co-pilot entered the passenger cabin and checked that the passenger baggage was correctly stowed in the under floor compartment and that the passengers were correctly distributed and secure in their seats. He then left the cabin and carried out a further external check of the aircraft. There were no fluid leaks and all panels were secure.

The aircraft was then prepared for take-off using the full check list rather than the approved abbreviated checklist that had been used on the inter-rig stages. After clearing the return route to Aberdeen with the Claymore Flight Information Liaison Officer (FILO), G-BDES was lifted to a low hover and the engines and controls checked before commencing the climb. While established on the Aberdeen 059° radial and at 1,500 feet on the Aberdeen QNH, the commander became aware of a slight buzzing noise which he initially thought might have been a rough bearing in the heater fan motor. The noise was not so compelling as to cause him any concern and he handed control to the co-pilot so that he could eat his breakfast. The co-pilot then became aware of the noise, which he could not identify but thought that it was emanating from the transmission. A passenger who had heard a 'thump' then came to the flight deck and indicated his wish to speak to the pilot. The commander removed his headset and leant to his left to hear what the passenger was saying. With his head in this position, the commander realised that the noise that he had been hearing was coming from the passenger cabin and was of significant volume. The passenger had come forward to report the noise to the crew.

The commander considered that the nature and volume of the noise dictated a landing as soon as possible and decided that the Claymore A platform, which was 18 nm downwind, was the best place to land. He therefore took control of the aircraft and turned onto a direct track for the Claymore A while the co-pilot informed them of their problem and intentions. Highland radar was then informed that G-BDES was descending and transferring flight watch to Claymore. While descending to low level VFR, the commander attempted to diagnose the source of the noise. He considered that the noise might be associated with AC generator bearings but decided not to attempt selective switching because of the possibility of loss of the Automatic Flight Control System. The speed control levers were advanced to increase rotor speed (N_R) from 100% to about 102%. This resulted in an increase in the noise level and N_R was reselected to 100%.

In anticipation of arriving at the Claymore A in a few minutes, the commander called for the landing checks and briefed the passengers. The aircraft was now at about 500 feet VMC and travelling at 110 kt IAS. All engine and transmission temperatures and pressures were normal but the noise was getting steadily louder and there was now a perceptible level of vibration.

When at a range of about 8 nm from Claymore A, the transmission oil pressure was seen to fall and the Emergency Lubrication Pump was operated which restored the oil pressure to 25 psi. Claymore were informed of the deteriorating situation and of the commander's decision to land on an adjacent vessel, the Uncle John located 170 metres north west of the Claymore A, because it had a lower pad height. The noise and level of vibration were steadily increasing. The commander instructed the passengers to prepare for ditching and subsequently confirmed visually that his instruction was being actioned. The crew now began to doubt their ability to cover the remaining 6 nm to the Uncle John and armed the flotation gear in anticipation of a possible ditching. At a range of just under 3 nm, when at a height of about 250 feet, there was a sudden and substantial increase in the levels of both noise and vibration. This increase was accompanied by rapid fluctuations of both torque and engine speed on both engines. The changes in the indications from both engines were reported as being in phase with a period of about 1 Hertz.

The commander announced his intention to ditch the aircraft and the co-pilot transmitted an abbreviated MAYDAY. There was insufficient height to turn into wind. Speed was reduced to below 20 kt IAS at which point the commander felt that he was losing yaw control. The ditching was cushioned by use of collective control and the aircraft contacted the water in a slightly nose-up attitude with no bank. On impact the commander lowered the collective lever; the co-pilot shut down the engines and attempted to deploy the flotation system. The ditching had occurred in a trough between two very large waves. The front of the aircraft was immediately engulfed by a wave and shortly afterwards G-BDES rolled to the right and inverted. A summary of pre-impact timings is at Appendix 1.

The crew and passengers evacuated the aircraft successfully despite their inability to open some emergency exits. Six survivors including the crew boarded a life-raft which was launched after opening the rear door from the outside. They were rescued 53 minutes after ditching. Seven passengers were unable to reach the life-raft and were in the sea for 41 minutes before being rescued. One of these passengers was later found to be suffering from mild hypothermia.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	-	-	-
Minor/None	2	11	-

There were no significant injuries caused by the impact but one passenger suffered mild hypothermia due to prolonged immersion in the sea and one broke a bone in his hand while escaping from the helicopter.

1.3 Damage to aircraft

The helicopter was severely damaged by the impact with the sea and the subsequent roll over.

1.4 Other damage

There was no other damage.

1.5 Personnel information

1.5.1	*Commander:*	Male, aged 41 years.
	Licence:	United Kingdom Airline Transport Pilot's Licence (Helicopters/ Gyroplanes) valid until 4 August 1993.
	Helicopter type ratings:	Sikorsky S61N, Boeing Vertol 234, Westland 30.
	Certificate of test:	dated 15 August 1988 valid until 14 March 1989.
	Instrument rating:	renewed 16 February 1988 valid until 15 March 1989.
	Last medical examination:	4 July 1988 valid until 3 January 1989.
	Flying experience:	
	Total hours as pilot:	5,295 hours.
	Total hours in command:	955 hours.
	Total hours on type:	3,351 hours.
	Total hours in last 28 days:	70 hours.
	Total hours in last 7 days:	21 hours.
	Rest period before 10 November 1988:	36 hours.
	Last wet life-raft drill:	21 October 1988.
1.5.2	*Co-pilot*	Male, aged 41 years.
	Licence:	United Kingdom Airline Transport Pilot's Licence (Helicopters/ Gyroplanes) valid until 24 April 1989.
	Helicopter type ratings:	Sikorsky S61N, Boeing Vertol 234, Aerospatial 332, Sikorsky S76, Bell 47, Hiller 360.

Certificate of test:	dated 14 June 1988 valid until 13 January 1989.
Instrument rating:	renewed 18 December 1987 valid until 17 January 1989.
Last medical examination:	29 July 1988 valid until 28 February 1989.

Flying experience:

Total hours as pilot:	7,250 hours.
Total hours in command:	6,700 hours.
Total hours on type:	3,660 hours.
Total hours in last 28 days:	56 hours.
Total hours in last 7 days:	21 hours.
Rest period before 10 November 1988:	14 hours.

Last wet life-raft drill: 4 November 1988.

1.6 Aircraft information

1.6.1 Aircraft details

Manufacturer:	Sikorsky Aircraft, USA.
Type:	S61N.
Airframe serial number:	61-747.
Date of construction:	July 1975.
Maximum all-up weight:	20,500 lbs.
Engines:	Two General Electric CT58-140-1 turboshaft engines.
Certificate of Airworthiness:	Transport Category (Passenger) Valid until 11 Nov 1988 Cert. No. 6742-2.
Certificate of Registration:	British International Helicopters Ltd
Total airframe hours:	16,224 hours.
Main transmission time since last overhaul:	1,085 hours.
Certificate of Maintenance Review:	Dated 30 Sept 1988 Valid until 30 Jan 1989.

1.6.2 *General description*

The Sikorsky S-61N is a large single rotor, twin engined commercial transport helicopter. It was designed in the late 1950s, received its American civil type certification in September 1963 and its British type certificate validation in April 1964. The S-61 is related in its structural, aerodynamic and mechanical components to a range of military variants which have, in total, some 5 million operating hours to date.

The S-61N features a sealed hull and stabilizing sponsons, which on G-BDES were supplemented by inflatable air-bags, to give a measure of flotation stability in moderate sea states. In this form the S-61 has been used extensively in support of North Sea oil operations.

G-BDES was equipped with two Dukane Underwater Locator Beacons (ULB), one on the Cockpit Voice Recorder (CVR) and the other on the main transmission.

1.6.3 *Engines and main transmission*

The engines are mounted in front of the main gearbox and the two drives are combined in the front compartment of the gearbox. The front compartment comprises a magnesium alloy housing with integral front airframe mounting feet and a front cover. The gearshafts are supported in bearings fitted in the front cover and the housing which are a matched pair.

Each engine drives an input pinion gear which meshes with the larger diameter spur gear of one of two 'camshaft' assemblies.(Appendix 2) Each camshaft assembly contains a freewheel device (ramp and roller type). An output helical pinion on each camshaft assembly drives onto the helical combiner gear (part no. S6135-20620) which is mounted on the same shaft as the input bevel pinion, which in turn drives the main bevel gear in the main gearbox housing. The helical combiner gear had been designed for an unlimited fatigue life using standard gear design rules and fatigue properties for the specified steel obtained from laboratory coupon tests, factored to allow for the measured variability in fatigue strength. The engine input drives run at a nominal speed of 18,966 RPM which is reduced to a speed of 3,195 RPM at the helical combiner gear. The teeth of the combiner gear experience two load cycles from the meshing gears during each rotation resulting in 383,400 tooth load cycles per hour.

A fibreglass/nomex guard partially covers the input gear train. Oil scavenge from the input housing is by gravity through an aperture in the bottom of the rear wall of the front compartment. The aperture decants oil into a gallery. The gallery conducts input housing oil and main casing oil towards the oil strainer and magnetic chip detector, which were in a combined unit on G-BDES as a result of incorporation of Customer Service Notice 6135-1A. The chip detector was designed to operate by signalling a short circuit between an insulated central stack of magnetic elements and the surrounding half cylindrical earthed strainer. The distance between the central magnetic assembly and the strainer mesh is 0.35 inches (*ie* the gap that must be bridged by magnetic and conductive material). The length of the magnetic stack is 1.5 inches so that it effectively spans the whole width of the oil scavenge gallery. Small particles or slivers of magnetic material can therefore be distributed along the magnetic stack before building to sufficient thickness to bridge the gap. On G-BDES, in common with the rest of the operator's fleet, the electrical connector on the outside of the chip detector was not connected to a cockpit indicator but was checked for electrical continuity at certain maintenance inspections (see *1.6.4*).

The main lubrication pump scavenges oil through the strainer and chip detector described above. The pressurized oil then passes through a fine pressure filter and a cooler before being fed through a manifold to a system of jets. The torquemeter, which is operated by gearbox oil, has a similar scavenge strainer, pump and pressure filter system. For emergency lubrication, oil is taken from a lower sump which is continuous with the main sump but is separated from it by a mesh screen. When emergency lubrication is selected the electrically driven pump draws oil from the lower sump (no input strainer) and feeds it through the emergency lubrication filter into the main manifold. The manufacturer states that typically, debris will migrate from the front compartment to the magnetic chip detector or strainer in about 20 minutes.

1.6.4 *Maintenance and component history*

The component histories which are relevant to the investigation are the history of the main gearbox, from the last overhaul which had been carried out by British Airways Engineering, and the history of the helical combiner gear, from the manufacture of the steel, through the production of the gear itself, to its service in two main rotor gearboxes.

1.6.4.1 *Gearwheel identification and service history*

The combiner gearwheel which was extracted (1.12.2) from gearbox serial number 566 in G-BDES had identifying numbers etched on its rim. However, some of the letters and numbers were indistinct and, in particular, one digit of its serial number (the second) could not be read. As this gearwheel did not have a prescribed service life it was not required that its serial number be recorded in the aircraft's documentation. The 'Time Life Control/Inspection Record' completed at the previous overhaul of gearbox 566, in 1987, showed that the combiner gear (serial number not recorded) had been replaced. In the documentation pack for that overhaul an inspection report and repair worksheet for gearwheel serial number 1117 were found. This number, with a certain doubt concerning the second digit as mentioned above, fitted the number etched on the failed gearwheel from box 566. The indistinct indications of the second digit were consistent with it being a '1'. The other identifiers on the gearwheel rim, particularly the manufacturer's identification 'IGW' (Indiana Gear Works) and the heat treatment (carburization) lot number (K827) were also consistent with a serial number of 1117, and only 1117, given the three positively identified digits. The identification of the gearwheel as being number 1117 in heat treatment lot K827 was therefore confirmed.

Further information on the history of helical combiner gear serial No 1117 was then sought. The documents for 1117 in gearbox 566's records showed that the wheel had had a plating repair carried out in one of its central bores (Dia 5.254 - 5.253 inches). One of the two documents cited the wheel as having a 'Time Since Overhaul' of 2,790 hours. The operator's technical records were searched for the records of a gearbox which had returned for overhaul or repair after 2,790 hours service, at a date somewhat before 1117's appearance as a replacement in gearbox 566. It was discovered that gearbox 1037 fitted these requirements. Its Inspection Report on receipt from service for overhaul by British Airways Engineering in January 1987 recorded the helical-combiner gear, serial number 1117, as requiring a plating repair in the 5.254 - 5.253 inches central bore because of the presence of a score mark on the surface. Gearbox 1037 had been rejected from service when metal had been found in the filters and a loud 'clunking' noise was heard from the No 2 freewheel unit. As part of the gearbox's strip inspection the helical gear was subjected to magnetic particle crack detection and was certified as clear of crack indications.

The British Airways plating repair scheme, BXR 26, applied to the gear, was a Civil Aviation Authority (CAA) approved scheme which was cited as being similar to the equivalent repair instructions in the Sikorsky Overhaul Manual, Chapter 65-13-00. The repair scheme required the wheel to be centred and the subject bore to be ground oversize before plating and then ground to size after plating. It also included post plating heat treatment (de-embrittlement) and crack inspection by magnetic particle. However, the stress-relieving and de-embrittlement treatments (190°C ± 10° for 4 hours) differed from those in the Sikorsky document (135°C ± 5.5°C for 5 hours). The manufacturer expressed concern about the difference and carried out a test using the British Airways process. This showed that there was no change in surface hardness or case thickness, as a result of the variation in processing.

Three other anomalies were found in the documentation of this repair process. The material specification on the job sheet was recorded as 'Hardened and Tempered' whereas properly it should have been 'Surface Hardened (Carburized)'. This did not affect the subsequent processing in any way. The job sheet proforma specified 'CRACK DETECTION Steel part magnetic particle checked'. This had been certified as 'not applicable'. The full repair scheme, however, makes it clear that only the local area of the repair is to be checked in this way and, therefore this omission is irrelevant to the detection of defects in the gear teeth. Finally, the scheme requires that 'BXR 26/1' be etched on the component. Such marking was not found, but it was possible that it had been obscured by damage.

Gearwheel 1117 was recorded as being removed from gearbox 1037 at overhaul in December 1986 and the records show that it had not been changed since the previous build in 1983. At that previous build the combiner gear had not been recorded by serial number in the relevant documentation but by its 'Approved Stores Serial Number', under which it was certified as conforming to appropriate aviation quality assurance standards. Its accompanying approval certificate was also a shipping notice from the manufacturer, and it covered three other gearwheels of this type. None of the serial numbers were recorded. Overall these records did confirm that gearwheel 1117 had been installed in gearbox 1037 as new and had therefore performed 2,790 hours of service since new when it was repaired and built into gearbox 566. Gearbox 566 was installed in G-BDES in November 1987 and operated for 1,085 hours before the accident on 10 November 1988. At the time of its failure wheel 1117 had therefore completed a total of 3,875 hours of operation.

Following its rebuild by British Airways Engineering, gearbox 566 was transported to Westland Aerospace Ltd for rig test and running-in in August 1987. On completion of its test run the magnetic chip detector and filters were checked and it was recorded on the test sheet that there was debris on the magnetic plug. A second test log sheet was found in the gearbox's records which showed that the gearbox had been subjected to a second full test run and that, following that run, the filters and chip detector had been satisfactory on inspection.

Westland report that it is not unusual for some metal to be found in the filter system on the first test after a rebuild. Any metal that is found is subjected to comparison with criteria set by the manufacturer for acceptance or rejection. If the type and amount of contamination falls within these criteria the gearbox can be re-tested and, if there is no further contamination, as would appear to have been the case here, the gearbox can be released to service. However, of the documents which would have been generated in connection with the test running, only the two test log sheets were found with the rest of the overhaul documents. In particular, the 'Inspection History Record' was not found, and this should have contained information about the assessment of the debris found and the action taken. The documentation was normally returned with the gearbox to British Airways Engineering who retained the overhaul records. Part of the documentation, the test log sheets, had been so returned but the checklist of overhaul documentation carried a note that one of the assembly worksheets, which normally accompanied the gearbox when it was dispatched for test, had not been returned. Investigations at both British Airways Engineering and Westland failed to unearth the missing documents.

1.6.4.2 *Combiner gearwheel manufacturing history*

The aircraft manufacturer supplied such information on the manufacture of the combiner gearwheel as was available, beginning with the steel, 'melt' No 68966 of 90 tons, produced by Copperweld in 1981. This was a single air-melt steel to AMS 6260 specification (equivalent to AISI 9310) and complying with AMS-2301, 'Aircraft Quality Steel Cleanliness'. In AMS 2301, acceptable cleanliness is defined in terms of the average frequency of indications greater than 1/16 of an inch in length per square inch under magnetic particle inspection of prepared sample surfaces and also in terms of a cumulative total length per square inch of the indications. The sample surfaces are on machined cylinders 3 inches in diameter and 6 inches long. The indications are factored according to size before the summation; the larger features carrying a larger 'severity' factor. Specimens containing an individual indication greater than 1.5 inches are rejected.

The 'melt' was poured (top poured) into 17 ingots and samples for magnetic particle inspection were taken from the first, middle and last ingots. Two ingots were rolled to make 16 bars which were delivered to Fountaintown Forge, where they were cut and forged into 62 'cheeses' for gear manufacture by Indiana Gear Works. The records available do not allow individual continuity to be traced from the ingots, through the bars, to the individual gear forgings, so the material from the 2 ingots could be randomly distributed amongst the individual forgings. It is not known whether either of the 2 ingots used to manufacture these gears was amongst those which had been sampled for conformity with specification AMS 2301. The quality records for the melt were reported as showing a frequency density of 0.04 per square inch for the average of the test cylinders against a limit of 0.37 and a severity (factored cumulative length per square inch) of 0.03 against a limit of 0.28.

From the 62 cheeses, 49 finished gearwheels are recorded as being manufactured, the rest having been rejected for unrecorded reasons during the manufacturing process.

The 49 gearwheels were carburized in 3 batches as follows:-

Batch K825	4 gearwheels
Batch K826	16 gearwheels
Batch K827	29 gearwheels

Each finished gearwheel was subjected to inspection by the magnetic particle method to MIL-1-6868.

Sikorsky Aircraft provided information from their own overhaul and repair records, available from 1983 onward, which showed that of 300 helical combiner gears examined, 84 had been rejected for a variety of causes (28%). Gears from heat-treatment lot K827 had suffered a rejection rate of 40% to date from all causes. Six out of the 12 rejected (not including 1117) had been classified as 'capping' failures. The expression 'capping' had been used to describe a geartooth failure, where a portion of tooth had detached in a manner which appeared to be related to the residual stresses generated by the presence of the case hardened surface layers on the tooth flanks. An example is reported in 1.17.5. There had been 5 other capping failures identified outside lot K827, none of which were in the related lots K825 and K826. The manufacturer pointed out that many wheels were examined for overhaul or repair at the overhaul facilities of approved agents and detailed information on such damage was not routinely available.

1.6.4.3. *Maintenance history*

The condition of the main gearbox was monitored during scheduled maintenance by examination of its two fine-gauge pressure filters and its combined scavenge strainer and magnetic chip detector. The inspection regime was as follows:-

Check	Period	Requirement
A	15 hrs/2 days	Electrical continuity of magnetic chip detector.
B	27 hrs	Visual check of scavenge screen.
P_1	50 hrs	Electrical continuity of magnetic chip detector.
P_3	150 hrs	Pressure and torquemeter filters removed and inspected.

The final checks in each category were as follows:-

Last P_3 check	11 Oct '88 at 16,134 hrs	Pressure & torquemeter visual.
Last B check	5 Nov'88 at 16,205 hrs	Scavenge, visual.
Last P_1 check	9 Nov '88 at 16,215 hrs	Chip detector electrical continuity.
Last A check	10 Nov '88 at 16,224 hrs	Chip detector electrical continuity.

Neither in these checks, nor in any of the checks recorded in the maintenance worksheets or the technical log (A & B checks) were any cases noted of significant metal in the filters. The manufacturer's maintenance manual gives guidance on the significance and acceptability of any metal debris found in the filters. The operator's Type Engineer stated that it was the company's policy to refer to the Engineering Department any indications of metal fragments and showed a current example where a few fine slivers had been found by maintenance personnel and had been referred for engineering consideration.

The technical log and scheduled maintenance records were examined for the period between gearbox 566's installation in G-BDES and the incident. Events were sought which could have had relevance to the operation of the main transmission. There were two sequences of entries in the technical log concerning cases of vibration. However, one appeared to have been resolved by blade tracking adjustments (the onset of vibration had coincided with the replacement of a main blade which had suffered erosion of its leading edge abrasion strip) and the other series of reports were resolved when a worn tail rotor bearing was identified and the tail rotor hub replaced.

No other defects or incidents were recorded which could have affected or been related to main transmission operation.

1.7 Meteorological information

1.7.1 Synoptic situation

A strong to gale south-westerly airstream covered the area with frontal troughs lying north-south over western Scotland and moving east at about 25 kt.

1.7.2 Forecast weather

Surface wind:	200°/35 kt.
Visibility:	15 km, locally 3,000 metres in rain.
Cloud:	3-5 oktas stratocumulus base 2,000 feet with scattered stratus base 1,000 feet.
Air temperature:	+ 10°C.
Sea temperature:	+ 10°C.

1.7.3 *Actual weather conditions*

An aftercast by the Meteorological Office gave the following conditions for the ditching area:-

Surface wind:	190°/25-30 kt with gusts to 40 kt.
Visibility:	15 km reducing to 6 km in rain.
Cloud:	8 oktas stratocumulus base 3,000 feet with 2-4 oktas of stratus base 1,200 feet in rain.
Sea temperature:	+ 10.5°C on the surface.
Sea state:	Wave height 15 feet.

1.8 Aids to navigation

The helicopter was navigating using Decca. When the decision was taken to proceed direct to the Claymore A, the commander requested that the Claymore Non Directional Beacon be switched on. This beacon operates on 397 MHz and has a coding of CE. The helicopter's weather radar was also used to aid in the location of Claymore A.

1.9 Communications

External communications were not a factor in this accident.

1.10 Aerodrome information

Aerodrome characteristics were not a factor in this accident.

1.11 Flight recorders

1.11.1 *Description of Installation*

The aircraft was equipped with a 30 minute duration, 4-channel CVR, Fairchild Model A100A, and a Fairchild model A152 Cockpit Area Microphone (CAM). The CVR channel allocation was as follows:-

Channel 1	Cabin Address and N_R signal.
Channel 2	Co-pilot's 'hot microphone'.
Channel 3	Pilot's 'hot microphone'.
Channel 4	CAM.

The CVR was located in the rear fuselage and the CAM in the cockpit centre console.

A Flight Data Recorder was not required and none was fitted.

1.11.2 *Recovery of the CVR*

The CVR was recovered from the sea, with the aircraft's rear fuselage, approximately 6 days after the accident. It was taken, immersed in water, directly to the AAIB at the Royal Aerospace Establishment (RAE), Farnborough. The CAM was not recovered.

1.11.3 *CVR replay*

The tape was removed from the CVR, cleaned and dried. Replay of the tape revealed that the aircraft lifted off from the Sedco 703 rig at 0825 hrs and that, after approximately 8 minutes of flight, an unusual noise was audible on the CAM channel. The amplitude of this noise progressively increased with time.

Approximately 16 minutes into the flight there was a change in the noise signature and about 1 minute later a passenger was heard telling the commander about a noise in the cabin, which he described "... as a bearing like sound". The crew discussed the situation and the commander decided to divert and descend to low level. The commander briefed the passengers on the situation.

After establishing that there were no abnormal cockpit indications the crew varied N_R and confirmed that the noise was associated with the transmission system. Four minutes later the transmission oil pressure fell and emergency lubrication was selected. Some 2½ minutes later there was a sudden change in the recorded noise. The N_R fluctuated markedly and the crew decided to ditch. The last recorded speech on the tape was the co-pilot confirming "Harness locked".

Appendix 3 is a time history of the recorded N_R with appropriate events from the CVR record annotated.

1.11.4 *Interpretation of the CVR record*

Analysis of the CAM channel revealed that the unusual recorded sound had a fundamental frequency corresponding to the once per revolution frequency of the main input bevel pinion shaft (approximately 53 Hertz). This was below the frequency response envelope of the CVR CAM channel and the signal was therefore identified and analysed from the recorded harmonic frequencies.

The '-' annotations on Appendix 3 refer to the frequency spectra plots shown in Appendix 4a to h. These spectra plots are snapshots of the CAM channel at intervals throughout the flight.

The recorded signals were compared with those from other S61 aircraft in similar stages of flight and it was concluded that until approximately 3 minutes into the flight the recorded transmission sounds were normal.

Appendix 4c shows the situation 9 minutes after lift off just as the unusual noise becomes audible on the CAM channel. It can be seen that the amplitude and number of the harmonics had increased compared to the signatures in Appendix 4a and b. The spacing between adjacent harmonics identifies the fundamental frequency as approximately 53 Hertz.

At 14 minutes into the flight the noise was louder. Appendix 4d shows the increased number and amplitude of the harmonics. One minute later a passenger came forward to the flight deck and Appendix 4e shows a significant increase in noise amplitude. The harmonics moved in sympathy with the varying N_R confirming that they were a product of vibration from within the transmission.

Appendix 4g shows the spectrum as emergency lubrication was selected and Appendix 4h is immediately before the N_R became uncontrolled. Although not shown, harmonics are present throughout the entire frequency range of the CAM channel during the last minutes of the flight. This indicates that the amplitude of the noise had saturated the CVR and that therefore many of the recorded harmonics were a product of total harmonic distortion within the CVR amplifier rather than being present in the incoming noise. Furthermore the increases in the recorded signal amplitude throughout the flight would have been more dramatic had a CVR Automatic Gain Control (AGC) not been limiting the CVR record amplifier.

1.11.4 Limitations of the CVR

Until Health and Usage Monitoring Systems (HUMS) with appropriate frequency response, bandwidth and signal conditioning are available, the CVR is the only source of recorded information on noise and vibration during a flight. However, the CVR was designed as a speech recording system and as such is not ideally suited to recording the very low frequency signals associated with helicopter main rotor systems. These signals are outside the bandwidth of the CVR amplifiers and analysis is therefore carried out using those harmonics of the input signal that fall inside the frequency response envelope of the CVR. The CVR also has an AGC to prevent saturation of the tape with loud sounds.

This poses three significant problems with the analysis:-

(a) The harmonics of a signal are weaker than the fundamental and it is often difficult to extract them from the overall CAM signal.

(b) Without the fundamental frequency a meaningful assessment of the power density spectrum of a signal is impossible.

(c) Operation of the AGC is difficult to model, therefore it is not possible to establish a correlation between the recorded signal and the source sound pressure level. A further limitation is that any electronic amplifier is subject to harmonic distortion which results, in the case of the CVR, in harmonics not present in the incoming signal being recorded on the tape. Total harmonic distortion becomes a significant factor in the CVR when sound pressure signals above 100 decibels (dB) are present, such sound levels are common in helicopters in normal cruise. However, provided these limitations, which can only be rectified with the installation of specialist vibration monitoring equipment, are recognised then the CVR is a most valuable tool in identifying the source and nature of transmission noises.

1.12 Wreckage and impact information

1.12.1 Salvage and recovery

When G-BDES had been abandoned it remained afloat inverted. The Multifunctional Support Vessel (MSV) Tharos was engaged by the operator's insurers to monitor the helicopter and to effect salvage if possible, but during the period in which G-BDES remained afloat the sea conditions made it impossible to get lifting equipment attached to it. At 1616 hrs a report was received from MSV Tharos that the aircraft's tail had broken off and had sunk at a position 58° 27.4'N and 000° 9.2'W. The Tharos continued to track the drifting hull until 0516 hrs on 11 November when it was seen to sink. The Tharos recorded a sinking position of 58° 29' 06.227" N, 000° 03' 48.142" E the precision of which was to facilitate later salvage.

The survey vessel North Sea Commander was engaged by Wimpol Ltd on behalf of AAIB for the salvage task, with diving support being provided by Oceaneering Limited using 'Wasp' submersibles. The Wasp submersible is a one man vehicle (Appendix 5) in which the diver stands and operates tools through manipulators at the extremities of two flexible arms. The diver has full vision through an hemispherical dome and manoeuvres the vehicle using its own thrusters though it is tethered to a crane on deck which deploys it into the sea. The crane's line also contains the umbilical supplies of power and communication. While lacking the full manipulative freedom of free divers it can be rapidly deployed to any depth within its operating range and divers can be rapidly returned to the surface for reporting and consultation.

The Wasp equipment, 'Syledis' precision navigation equipment and sidescan sonar were installed on the North Sea Commander at Peterhead and following installation checks, the vessel sailed at 1337 hrs on 14th November and arrived on site at 2310 hrs. Initially the ship's 'Simrad' system was used to search for the 37.5 KHz signals from the ULB's on the aircraft but no signal was received. Pre-diving checks were carried out and, with the North Sea Commander's position stabilized by its dynamic positioning system a Wasp was lowered into the sea at 0200 hrs on the 15 November. The Wasp's Dukane receiver immediately detected two ULB signals and the North Sea Commander was moved towards the source. G-BDES was located at 0240 hrs at a position 170 metres southeast of the sinking position in a depth of 130 metres.

A visual inspection showed that, with the exception of the tail pylon and the main rotor blades, the aircraft was intact but threequarters inverted with the rotor head buried in soft mud. Initially an attempt was made to lift the fuselage and rotate it into an upright position. Considering the equipment available and following discussions with the divers about the access around and under the wreck it was decided to attempt this by putting steel hawsers around the fuselage with the lifting point offset so as to rotate the fuselage as it was being lifted. As the lift started the sea bed mud was stirred up obscuring G-BDES from the diver's view. As the mud cleared it could be seen that the fuselage was taking damage because of the rise and fall of the ship. Before it could be set down again the fuselage had broken into three parts.

The tail section with the accident recorder inside was then recovered. Because it was suspected that there had been a major mechanical failure in the main gearbox it was decided not to load the rotor head or gearbox during recovery as the casing might have been damaged and, being a magnesium alloy, further corrosion might have taken place. On the second attempted lift, the centre section was recovered with the main gearbox and rotor head by lifting from the sponson attachments. Attempts were then made to recover the cockpit section but the diver's attempts to grapple with it and manipulate it proved very difficult and time consuming as its airframe structure had been disrupted. Eventually it was abandoned as the most significant parts of the aircraft had been retrieved.

On deck the wreckage was washed down with fresh water and the main gearbox and rotorhead sprayed with a water repelling and corrosion inhibiting agent. North Sea Commander docked at Aberdeen at 0945 hrs on 17 November and the wreckage was unloaded and transported to the operator's facility at Aberdeen for initial disassembly and examination.

1.12.2 *Initial examination*

The main gearbox showed little external sign of damage and there had been no disruption of the casing. The gearbox was removed from the aircraft and taken into the operator's engineering facility for initial strip and investigation. Disassembly was later completed at British Airways Engineering facility at Heathrow where a full set of special tools were available.

A continuity check across the magnetic chip detector proved negative. The oil was drained and collected and was found to be contaminated with sea water. The scavenge strainer was found to be congested by what was later to be recognised as glassfibre and nomex debris from the splash-guard in the input section of the gearbox.(Appendix 6A) This debris also contained metal fragments. The main pressure filter and the torquemeter filter were lightly contaminated by fine fibreglass/nomex debris with a small number of bright metal particles. The emergency lubrication filter was heavily contaminated by the fibrous material along with some small metal particles. A functional test of the chip detector using a simple bell tester showed that it was serviceable.

The main disassembly was started by removing the input drives, torquemeters and the input housing. As the input drive sections and torquemeters were removed they were seen to be heavily contaminated by magnesium corrosion products, some cavities being completely filled. Two anomalies were found in that the anti-rotation pins in the torquemeter pistons were loose and the locking ring on the No 2 torquemeter piston was found to be displaced out of its groove. These features were later taken to have been a result of the severe vibration that the gearbox had suffered.

When the input housing cover was removed it was seen that the helical combiner gear (part no. S6135-20620-3) had failed and a section of its rim had detached.(Appendix 6B) The input section of the gearbox was partially filled with debris comprising magnesium corrosion products, remnants of the composite material splashguard and metallic fragments, some of the larger pieces of which were recognisably parts of the helical gear but much of which was small and swarf-like. The splashguard had been almost completely destroyed but all of its attachment nuts and bolts were found in a condition which showed that it had been correctly secured. Two outer race retention tangs on the No 1 camshaft assembly rear bearing had been broken in overload (shear).

Much of the metallic debris had come from the destruction of gearteeth on the combiner gear and its meshing input gears. The two input helical pinions had not suffered equal damage.(Appendix 6C and D) On the No 1 wheel the teeth had been almost completely stripped whereas on the No 2 wheel there were only localised areas of damage. The damage to the helical combiner gear teeth was progressive, in a direction counter to its rotation, from complete stripping at one end of the missing section to only superficial damage at the other side of the gap in the rim. The input helical pinions were later examined for any evidence of pre-existing failures in their teeth but none was found and their damage was taken to be entirely secondary.

The ring nut which secures the helical combiner gear on the input bevel pinion shaft was found to be tight and secure. Its releasing torque was measured at 3,200 ft lbs (specified assembly torque 2,300 to 2,800 ft lbs).

All the loose debris in the input housing was collected and examined for recognisable pieces. Almost all of the elements released from the helical combiner gear were recovered in this way and fragments from inside the two freewheel units were also found. The small amount of debris collected from the magnetic chip detector and strainer was also examined microscopically but none was found that could be identified as originating in the area of primary failure in the helical combiner gear. The remains of the helical combiner gear, including recognisable fragments, were dispatched for detailed examination. While the nature of its failure was being considered by the metallurgists of the RAE Farnborough and the aircraft manufacturer the rest of the gearbox was examined for other possible contributory defects or failures.

The two freewheel assemblies, of which the helical pinions are the output, were dismantled and both were found to be heavily damaged. The No 1 freewheel was most severely damaged (Appendix 7A), a condition which reflected the damage to its helical pinion. Its roller cage had been disrupted and the rollers had suffered gross damage and overheating. The No 2 freewheel was somewhat less damaged with the cage being only partly destroyed.(Appendix 7B) All the fragments of the disrupted cages were found and their fractures examined at RAE Farnborough. Although there was some secondary damage on these fractures they were found to be typical of fast ductile rupture signifying overload conditions.

The gearbox was completely dismantled but no significant defects or anomalies were found which could have been related to the damage in the input section. The main bevel gear and the meshing input bevel pinion, which is co-axial with the helical combiner gear, were examined for any unusual wear condition but none was apparent. All areas of the gearbox were heavily contaminated by corrosion products (mainly magnesium) and pulverized debris from the input gearing splashguard. The fibreglass and nomex debris was found pressed between gearteeth and in bearings. Such debris was also found congesting the mesh which separates the main gear chamber from the oil sump below. This contamination contained relatively little steel, the steel debris having remained for the most part in the input housing. The steel was separated from the other debris and corrosion product and searched for fracture material from the helical gear but nothing was found which could be identified as such.

1.12.3 *Input gear alignment*

The main gearbox input housing (PN S6135-20606-013) and cover (PN S6135-20638-8) are manufactured as a matched pair. The input gearing is supported in bearings mounted in the housing and cover and precise alignment is necessary to prevent non-design loading on the gears. At the last overhaul prior to the accident the original cover and housing had been rejected for distortion, as measured in terms of the locations of the bearing holes, and a new matched pair were fitted. It is known that such distortion can develop in service.

Following strip and cleaning of the input section the bearing locations were measured using the jig borer used for this purpose by British Airways and the check was repeated at RAE Farnborough. The two sets of results were essentially similar and both showed some deviations beyond the specified limits. However, when the data was subjected to analysis it was determined that the deviations taken together would not have caused excessive tooth loading.

1.12.4 *Metallurgical investigation of the helical combiner gear*

The failed helical combiner gear was examined and reported on by metallurgists of the Materials and Structures Department of RAE Farnborough with the participation of a metallurgist from Sikorsky Aircraft. Sikorsky Aircraft also supplied a detached geartooth from another gearwheel for comparison of failure modes. On completion of the work at RAE Farnborough the gearwheel parts were passed to the Sikorsky Aircraft Metals Laboratory for further examination. The results of both examinations are summarised below.

1.12.4.1 *Examination of the helical combiner gear*

From the debris recovered from the input housing a reconstruction of the helical gear was made and, with the exception of one small area described below, the reconstruction was complete in what was found to be the critical area.

Examination showed both of the wheel's central bores to be slightly oval. As the axes of ovality of both bores were similarly aligned, and only one had been subjected to the plating repair already detailed (1.6.4.1), it seemed likely that this distortion was the result of the trauma suffered by the wheel during the break-up of the rim. The nickel plating of the repair appeared satisfactory and of uniform thickness though there was some fretting on its surface adjacent to the destroyed rim. It was not clear whether such fretting was the result of some pre-failure condition, the failure process or a normal service phenomenon and no especial significance could be attached to it in relation to the fatigue failures in the gear tooth. The only further dimensional checking of the gearwheel which could be carried out was a measurement of the rim thickness and this was within specification.

There were clear indications of progressive crack growth from an area in the rim below a tooth which had fragmented.(Appendix 8 Ref A) The adjacent tooth (counter rotation) had detached with only light damage to the tooth surfaces.(Ref B) The next adjacent portion of detached rim comprised most of 14 teeth.(Ref C) This portion was in places heavily damaged, having been almost straightened but, despite having lost some rim and tooth material, some of its tooth surfaces were almost undamaged and the driven flanks of these teeth showed a light contact pattern which was similar to that seen on other gears returned from service. A further detached portion of rim contained parts of 8 teeth.(Ref D) These were heavily damaged but notably less so than the teeth on the adjacent attached rim, which had been virtually wiped off.(Ref E)

In gross terms, the failure of the wheel had developed from the area in the rim mentioned above out to either side of the rim and downwards into the web.(Appendix 9) The crack's inward and pro-rotational development had been arrested by one of the four lightening holes in the web but the crack had also developed counter rotation and had so released the two large pieces of rim. This phase of the crack development had been in high strain, low cycle fatigue from one side of the web, the web being subjected to excessive bending loads once the rim's integrity had been destroyed. This development was clearly secondary to the fatigue associated with the fragmented tooth and the adjacent released tooth. This area of fatigue within the rim was examined for evidence of an origin. It was eventually determined that fatigue cracking had progressed into this area from a feature within the tooth.

When the tooth fragments had been re-assembled (Appendix 10A) it was seen that a small amount of material was still missing from the crown of the tooth.(Appendix 10B) Its absence left a complex feature, occupying about 1 cm of the tooth's crown at about the mid-span position. The surfaces of the feature, made up of facets on different tooth fragments, and the other areas closely related to it were subjected to examination by scanning electron microscope, electron probe, microsection and energy dispersive x-ray's for metallurgical and chemical analysis. The possibility was considered that the feature was some form of impact damage but the examination showed this not to be the case. The local tooth surfaces showed no sign of spalling or surface breakdown.

The surfaces of the tooth fragments were examined and there could be distinguished an oval area of unusual surface texture which extended into the tooth.(Appendix 10C and D) The oval measured approximately 5 mm by 10 mm. Its long axis was angled to the tooth spanwise direction such that it was almost parallel with gearwheel axis and it descended into the tooth at about 40° to the tooth crest line. The oval feature probably did not extend into the tooth's carburized surface layer. A small zone of fatigue was identified extending from the oval area through to the surface of the undriven flank of the tooth near its crown. Other areas of development to the tooth surface showed evidence of ductility and were not clearly identified as fatigue. The missing material had probably therefore been released by cracking from the oval feature where it extended towards the crown of the tooth. The oval feature also, however, extended into the tooth where the larger and more significant areas of fatigue had developed.

Identifiable fatigue, as mentioned above, had developed from the oval feature, downward into the rim.(Appendix 10E) The plane of this fracture surface was roughly parallel to the driven flank. Deep within the tooth, fatigue began to progress laterally as well as radially within the rim from an area delineated by an almost circular crack front visible at Appendix 10E. Within the circle the crack surface was smooth and indicative of slow crack growth rate. Beyond the circular crack front the crack surface had a banded appearance. These bands may signify flights or some other major load cycle but progress in this area was more rapid than before. From the point at which fatigue had started to grow within the rim it also developed back through to the undriven side of the tooth on either side of the location of the oval feature. This contributed to the fragmentation of the tooth. High strain, low cycle fatigue had also developed from the driven face of the tooth at its root through to the main crack and had thus completed the fragmentation and release of the tooth. A representative section is shown in Appendix 11. The next adjacent tooth was also released, intact, by high strain, low cycle fatigue from the root of its driven face through to the main crack. These relatively rapid fatigue cracks were evidently secondary to, and a result of, the primary crack developing within the fragmented tooth. Because of the damage to the fracture surfaces and the complexity of the development of the failure no estimate could be made of the time or number of cycles taken from initiation to failure.

Metallographic sections were made through the oval feature.(Appendix 12A) The normal tempered martensitic microstructure was seen but two types of distinctive feature were found at a number of locations. Groups of inclusions were found at or below the surface of the oval feature which x-ray examination showed to be pre-dominantly aluminium oxide.(Appendix 12B) Other areas, which etched white on the microsections appeared to be very close in composition to the base steel but were hard (70.5 to 73.5 $Rockwell_C$) by comparison with surrounding areas ($48R_C$).(Appendix 12C and D) Cracks were also seen below the oval feature's surface and also undercutting the metal at the edge of the feature. In some of the sections isolated inclusions with associated white etched areas and cracks could be seen extending into the metal in line with the surface of the oval feature.

1.12.4.3 *Heat treatment*

At the time of manufacture of 1117, final heat treatment for gearwheel S6135-20620 after machining was specified to produce a carburized surface layer 0.025 to 0.040 inches thick of hardness 58-64 R_C with a core hardness of 30 to 45 R_C.

Subsequently this was modified to a case thickness of 0.015 to 0.030 inches with the same case hardness but a somewhat reduced core hardness of 30 to 40 R_C. This change was made following a number of 'capping failures' and was intended to reduce the probability of residual stresses in the transition between the case and core producing fatigue damage in combination with cyclic running loads.

RAE Farnborough conducted micro-hardness measurements across a metallographic section of the failed tooth close to the failure origin and also remote from it. These showed a high case thickness, 0.060 inches, where the thickness was defined as the depth at which an R_C of 50 was obtained. The core hardness was high at 48 R_C but the hardness of the case itself was within limits.

Sikorsky carried out case quality checks on the two teeth in the area of the fracture initiation and also elsewhere on the gearwheel. These examinations showed surface hardnesses of 58/59 R_C and they assessed case thickness to be 0.032 to 0.037 inches on the driven flanks. Core hardness was measured at 32 to 36 R_C. These were, therefore, within the applicable specification but were in contradiction of results obtained by RAE Farnborough. The two laboratories had used different equipment to carry out their tests each converting their results to the Rockwell standard of the specification.

The RAE Farnborough considered that, though its results showed a higher thickness, the generally higher level of hardness in the core mitigated this effect and they concluded that there was "no evidence to suggest that residual stresses associated with the case provided an abnormal impetus to the growth of the defect".

1.13 Medical and pathological aspects

The crew were medically fit to carry out their duties and only two occupants suffered minor injuries. (Para 1.2)

1.14 Fire

There was no fire.

1.15 Survival aspects

1.15.1 Evacuation

1.15.1.1 Emergency exits

The aircraft was fitted with seven emergency exits which could be either opened or jettisoned after being unlocked manually.(Appendix 13) These were:-

(a) the pilots' side windows.
(b) the cargo door forward on the right side of the cabin.
(c) the door stairs aft on the right side of the cabin.
(d) the rear door on the left side of the cabin which incorporated a life-raft.
(e) exits mid-way along the cabin, one on each side.

In addition, eleven of the fifteen passenger windows could be removed by pulling a rip-out beading and pushing the window.

1.15.1.2 Crew evacuation

The pilot in the right hand seat, who was a strong swimmer, was unable to locate the jettison handle for his emergency exit from his inverted position under water and proceeded aft to the cargo door. After some difficulty, he located the operating handle by feel, again under water, and rotated it to the unlocked position. However, he was unable to push the door outboard, which is a necessary action before sliding the door to the rear to provide an escape path. Following this attempt, he surfaced for air but the airspace of approximately two feet which had existed before he tried to open the cargo door, had gone. When he was on the point of drowning, his hand touched a window recess, probably window C (Appendix 13). His initial attempt to push out the window only resulted in him moving bodily backwards. A second attempt during which the window was punched, was successful. His subsequent egress was accomplished without further difficulty.

The pilot in the left hand seat had ditched with his left hand on the front frame of his side window for support. On coming to rest inverted and completely submerged, he slid open his side window and then attempted to locate the jettison handle for his emergency exit but was unsuccessful. He therefore decided to exit through the now open side window which he did with some difficulty. This window is 29 inches high and tapers from 11 inches wide at the base to 10 inches wide at its top. The edges of the opening are not smooth and present several projections which could snag clothing or safety equipment during egress.

1.15.1.3 *Passenger evacuation*

The passengers were all experienced travellers on North Sea helicopters who had completed the appropriate survival course, including a practice underwater escape. All eleven passengers escaped, some encountering minor difficulty. One used the left hand escape exit midway along the cabin and the others used push-out windows. Seven of the available eleven push-out windows were used for escape. All passengers commenced their escape from the inverted position although one had released his lap strap on initial impact before the helicopter rolled over. Three passengers reported some difficulty in releasing their lap strap buckle. All the push-out windows functioned correctly but one passenger, who had donned his survival gloves, reported that he could not grip the fabric tag attached to the rip-out beading until he had removed a glove. At least two passengers experienced some difficulty in escaping through push-out windows. One passenger sustained a broken bone in his hand while punching out a window.

1.15.2 *Sea survival*

Having escaped from the inverted helicopter, six survivors including the crew managed to either climb onto or cling to the hull. Some were washed off by waves but managed to regain the hull and retain a hold on either the sponsons, the high frequency aerial support or the safety rope. The co-pilot instructed a passenger at the rear of the hull to open the aft door containing the life-raft. This was accomplished using the external handle, which at this time was above water, and the life-raft deployed. The life-raft was then boarded by four passengers who were clinging to the rear of the hull. Both pilots then made their way aft using the safety rope and boarded the life-raft. The life-raft was still attached to the hull by the short painter and was bumping against the Very High Frequency Omni Range aerial and the rear of the left sponson. After some confusion, both the short and long painters and possibly the sea anchor attachment were cut and the life-raft drifted under the tail pylon and clear of the hull.

The commander had activated his Search and Rescue Beacon Equipment (SARBE) before boarding the life-raft and subsequently used the speech facility to direct an approaching helicopter to his position. The co-pilot checked his SARBE to ensure that it was ready for use should it be required. The survivors in the life-raft could see another group of survivors in the water and used the life-raft paddles in an attempt to reach them. In the conditions prevailing, this proved to be a fruitless exercise and was abandoned. A decision was taken not to erect the life-raft canopy since it was feared that this action would further reduce the stability of the life-raft which in the high sea-state prevailing was giving some cause for concern. All six survivors were winched from the life-raft within 53 minutes of ditching, the actual winching exercise having taken 9 minutes.

On emerging from the inverted helicopter, seven survivors were unable to secure themselves to the hull and were swept away. In accordance with their survival training they managed to group together for mutual support and although aware that a life-raft was being launched from the ditched helicopter, they were unable to make headway towards it against the wind and waves. After 42 minutes in the sea, all seven survivors were picked up by a rescue boat from the Grampian King and transferred to the Maersk Cutter, which they boarded with some difficulty using scramble nets. The last survivor was on the Maersk Cutter 51 minutes after the ditching. A summary of post-impact timings is at Appendix 14.

1.15.3 Search and rescue (SAR)

At 0841 hrs, the pilot of G-BDES informed Highland Radar on the frequency in use that he had a strange noise from the transmission and was diverting to Claymore A. Shortly after this transmission, G-BDES checked in with Claymore A Flight Watch stating the problem and requesting permission to land on the Claymore. No 'PAN' call was made. At 0850 hrs when approximately 3 nm from Claymore A, G-BDES transmitted a 'MAYDAY' call. Some 27 seconds later having transmitted a further 'MAYDAY', G-BDES ditched 2 nm short of Claymore A.

The radio station aboard Claymore A was manned by a FILO who was responsible for providing a Flight Information Service to aircraft in the area, together with a marine operator with similar responsibilities for marine traffic. Incoming radio traffic on all networks was received via loud speaker and communication between the operators was by direct voice. There was no intercommunication channel available to those co-ordinating the rescue. With the arrival of the Offshore Installation Manager (OIM) and other essential personnel, the small radio room became very crowded. There were no dedicated co-ordination aids available, such as situation display boards, and space was very limited. The number of air, marine and shore based units involved in the SAR operation resulted in extremely high levels of both radio and telephonic traffic.

In response to the 'MAYDAY' message, the FILO aboard Claymore A requested an S76 helicopter, callsign G-BHYB, aboard the safety vessel Tharos to proceed to the last known position of G-BDES. Having failed to re-establish radio contact with G-BDES, the FILO despatched the rig support vessel Nautica to the presumed ditching position. At 0852 hrs an S61 helicopter callsign 53C which was 20 nm from Claymore heard the 'MAYDAY' call and proceeded to the last known position of G-BDES. Another helicopter callsign 98P which was 11 nm from Claymore also diverted to the search area. None of the helicopters involved at this stage were equipped with a rescue winch.

At 0853 hrs the FILO informed Aberdeen Coastguard by telephone that G-BDES had transmitted a 'MAYDAY' message. The Aberdeen Coastguard informed the Rescue Co-ordination Centre (RCC) at Edinburgh who stated that they would act as co-ordinators for the incident. The RCC then dispatched three units to the ditching area.

1 A Nimrod from RAF Kinloss as Rescue 01.
2 A Sea King from RAF Lossiemouth as Rescue 137.
3 A Coastguard S61 from Sumburgh as Rescue 117.

A summary of the timings relating to these units is at Appendix 15.

Meanwhile, the Forties Field SA 365N helicopter, which was engaged on a local shuttle was recalled, prepared for SAR duties and dispatched to the accident scene.

At 0859 hrs, a distress beacon operating on 121.5 MHz was heard by Claymore Radio. This signal was also received by 98P which commenced tracking the signal on its VHF homer. At 0904 hrs 98P reported overhead the distress beacon and at 0905 hrs reported seven survivors in the water and six in a life-raft at a position 1.6 nm south of Claymore A.

At 0913 hrs the Ocean Victory standby vessel, Grampian King, advised Claymore Radio that she "was 3 miles from the datum and proceeding". At 0926 hrs having been directed to the survivors' location by G-BHYB, she was positioned ½ mile from the survivors from where she launched a fast rescue boat.

At 0928 hrs the Forties SA365H, now using the Callsign 143, arrived from the Forties Field and commenced winching survivors from the life-raft. By 0932 hrs the seven survivors in the water had been picked up by the rescue boat from the Grampian King and transferred to the Maersk Cutter which was positioned half a mile from the datum. By 0943 hrs, Rescue 143 had completed its winching operation and was proceeding to Claymore A where it landed at 0946 hrs with six survivors.

The rescue was completed by North Sea based assets, shore based assets arriving too late for active participation.

1.15.4 *Public Address (PA) system*

The PA system on G-BDES comprised a series of loud speakers mounted along each side of the cabin 12 inches above the heads of the seated passengers. The system was operated by either pilot's microphone through the appropriate selection on the pilot's intercommunication and station box. The safety briefing video seen by all passengers before each flight stresses the importance of hearing protection and strongly recommends that ear plugs or ear defenders are worn throughout the flight. In practice it has been observed that many passengers wear both.

All the passengers on G-BDES reported that they could not understand messages passed on the PA system and they were prepared for ditching only because one passenger heard the single word "life-jacket" and assumed that an instruction to prepare for ditching was being passed. It is not known how much the noise from the failing transmission contributed to this problem but a flight in another S61, with a similar PA system, confirmed that the PA system could not be readily understood in cruising flight when wearing ear defenders.

1.15.5 *Emergency lighting*

The main emergency exits are identified by lights which are illuminated be either:-

a) Manual selection at each exit.
b) Inertia switches which operate at 1-1½g.

Both the main emergency exits and the push-out windows are illuminated by edge lighting which is operated by either:-

a) A pilot operated switch.
b) Through immersion of the CVR float switch.
c) By immersion of a saline switch.

There was no evidence from survivors that any of the emergency exit lighting had operated. A technical investigation of the system was inconclusive due to severe corrosion resulting from immersion in the sea.

1.16 Tests and research

1.16.1 Survival suits

In general the survival suits performed satisfactorily. Two passenger suits were found to have holes in them, one was probably pre-existing, the other was damaged during egress from the helicopter. All passenger suits, including the one worn by the passenger who suffered mild hypothermia, passed the standard leak rate test. The suit worn by the commander was satisfactory but that worn by the co-pilot was in poor condition having perished and torn seals and a damaged zip. In addition it was damaged at the hip probably when the co-pilot escaped through his side window. The co-pilot had a suit on order that was to the same standard as that worn by the commander but fitting problems had delayed its delivery.

1.16.2 Life-jackets

Some passengers reported problems with their life-jackets. Three reported having difficulty locating the inflation tag and two reported that their jackets inflated correctly but then went flat.

Inspection by the Institute of Aviation Medicine (IAM) indicated that all eleven inflation bottles had operated and their lanyards and toggles remained connected to the firing mechanism. Three of the jackets had been cut in order to remove them from the survivors. The remaining eight jackets were subjected to an inflation check. Three were found to be punctured, one torn at the attachment point of the inflation bottle, another with an abrasion and hole on the right side of the stole and the third having a pinhole in the front neck of the stole. Three jackets were found to have no reflective patches and no evidence of their ever having been applied.

The crew life-jackets functioned correctly and were not subjected to tests.

1.16.3 Pilot evacuation

Tests were conducted in an intact S61N cockpit to establish why neither pilot could locate the operating handle for his emergency exit. These tests established that when a pilot in the left hand seat reaches for the side escape exit operating handle with the collective in the fully raised position, his hand would naturally fall between the collective and the side of his seat. The IAM was also consulted on the problem of disorientation under conditions of sensory deprivation. Research into disorientation of subjects inverted under water has demonstrated that their perception of the vertical can be seriously in error. The results of these tests are discussed in para 2.3.

1.17 Additional information

1.17.1 Automatically Deployed Emergency Locator Transmitter (ADELT)

The ADELT installation was examined at the AAIB facility at Farnborough. Most of the system wiring, the control panel, the two forward frangible switches, the saline switch and the lithium battery were not recovered and could not therefore be examined. The ADELT unit was badly disrupted; examination revealed that the pyrotechnic squib had not fired. An acceptance and firing check carried out on the squib proved it to be serviceable. The rear frangible switch was found to be serviceable but had not operated. The crew did not attempt to deploy the ADELT using the flight deck ADELT DEPLOY switch. A service Bulletin (CAS/CPT 600/SB-01) had been issued by the ADELT manufacturer to provide alternative deployment activation means in the event of failure of the aircraft power supply or system wiring. This was made mandatory by CAA Airworthiness Directive 058-12-88 for compliance not later than 31 March 1989 and had not been implemented on G-BDES.

1.17.2 Metallographic examination of geartooth from combiner gear 1094

RAE Farnborough were given the opportunity by Sikorsky to examine one geartooth which had suffered a 'capping' failure.(Appendix 16A and B) The gearwheel from which the tooth had come was serial number 1094 and was from the same heat treatment batch as 1117.

On examination, its surface hardness was found to be slightly lower than that measured for 1117 but the thickness of the carburised layer was similar. The fracture was seen to have run from near the middle of the tooth out to one end. The fracture origin, at its inboard end, was seen to be associated with a plane oval feature. Diagonally across the oval area ran an irregular line or fissure. Numerous inclusions were found on the oval surface and along the fissure. These were identified as both aluminium and iron oxides. It appeared that the oval region was, in fact, defined by the presence and distribution of these inclusions and that it was, therefore, similar to the larger oval feature at the origin of the primary fatigue in the failed gear from G-BDES but lying in a different plane.

1.17.3 *Gear tooth failure in Canadian Armed Forces CH124 helicopter*

While the investigation was in progress information was received from the Canadian National Defence Directorate of Flight Safety of a tooth failure in a helical combiner gear in a Canadian Armed Forces CH124 helicopter. The gear's part number was S6135-20620-3 and its serial number 499. It was therefore identical to the failed gear from G-BDES but it did not belong to the same or any related heat treatment batch.

The Directorate of Flight Safety made available to the AAIB a copy of the metallurgical report on this failure. The failure appeared typical of a capping failure with about 40% of one tooth having been released with no catastrophic failure or damage. Metallographic examination revealed a (normal) tempered martensitic microstructure with minor oxide inclusions. The core and case hardnesses and case thickness were within specification. Indications of progressive crack growth were found emanating from a small area within the fracture which was parallel to the gear tooth crown and about 2mm below it. In this area were found inclusions rich in aluminium but non-conducting, probably therefore, in oxide form.

1.17.4 *Steel quality and certification*

The steel used for the manufacture of wheel 1117 was a single air-melt steel as used when the S-61N obtained its original certification approval. The manufacturer has stated that a double vacuum melt steel has hitherto been an alternative for this component and will in future be used for new production gears.

The present British Civil Airworthiness Requirements (BCAR Section G or BCAR 29) do not specify a particular standard or quality of material to be used in a 'critical' component in a helicopter's transmission. It is required that the manufacturer demonstrate by analysis and test that the failure of any such individual component, shall be "extremely remote" (less than once per 10^7 hrs of operation), within the declared "safe life" applied to the component, where such a failure could prevent flight to the intended destination with a power-on landing. The material used in production components must then conform to the design specification and be obtained from an approved source. Procedures under US Federal Aviation Regulations are similar in principle.

Since the S61N was designed and certificated, steels of improved quality have become available in the shape of 'vacuum remelted' or 'double vacuum melt' products. The aluminium found in oxide form in gear 1117 was probably present as a result of the normal steel-making process, where aluminium is introduced into the melt to absorb oxygen preferentially and reduce oxidation of the iron. Normally the aluminium oxide migrates to form a slag or is dispersed in very fine form in the steel to form very small inclusions when the steel solidifies. Vacuum remelting enhances the dispersion of impurities. Double vacuum melting further reduces the oxygen level and again enhances dispersion of the impurities. Both of these processes reduce the volume fraction and size of inclusions of the type found in gear 1117.

The steel used in gear 1117 was checked for quality at the ingot stage by a sampling process, samples being taken from the first, middle and last ingots (of 17) and examined by the magnetic particle method to AMS 2301. Present techniques allow about 80% of the total volume of typical round cornered rectangular rolled or forged stock to be checked ultrasonically for defects. A further improvement in the control of steel quality comes from the use of prepared, circular forged stock which can be inspected ultrasonically through 100% of its volume.

These improved processes cannot entirely eliminate defects but they do provide a very large improvement over single air-melt steels in the consistency of steel available for critical aircraft components and therefore in the predictability of their behaviour under fatigue loading. In practice, today, such parts as main transmission gears would be designed to be manufactured from a vacuum remelt or double vacuum melt steel.

1.17.5 *Safety actions*

On 15 December 1988, as a result of preliminary metallurgical results and information received from Sikorsky Aircraft, AAIB made the following two Safety Recommendations to the CAA:-

"1) *As a preliminary step, that subject gear wheels from heat treatment K827 be traced and withdrawn from service".*

"2) *So that further safety measures can be considered, every effort be made to identify the source of the steel used in the gear wheels in lot K827, and to identify the distribution of that batch and any other batches of steel which may be suspect, so that aircraft components manufactured from such steel can be traced and, if necessary, withdrawn from service".*

AAIB also drew attention to a previous recommendation (No 10 in report 4/83) which called for the recording of serial numbers of all critical parts in gearbox transmissions even where there was no declared service life.

On 21 December 1988 Sikorsky Aircraft issued an Alert Service Bulletin 61B35-66 specifying an increased frequency of inspection and functional checks of magnetic chip detector and strainers in the main gearbox as a precautionary measure while the investigation was proceeding.

On the 9 January 1989 Sikorsky Aircraft communicated the full manufacturing history of gearwheel 1117 as far as could be established and confirmed that gearwheels in two further lots, K825 (4 gears) and K826 (16 gears), had been manufactured from the same batch of steel. On the same date Sikorsky Aircraft provided the CAA with a method for identifying the helical combiner gear serial and heat treatment lot numbers on installed combiner gears by inspection using boroscope equipment. This was necessary in implementing Recommendation 1 above as a gearbox's documentation would not always contain that information. On 13 January CAA circulated this instruction in a letter to operators together with the request that gear wheel identifying numbers so obtained be forwarded to the CAA.

On 26 January the CAA issued an Emergency Airworthiness Directive, number 030-01-89 requiring gearwheels from heat treatment batch K827 to be removed from service within 100 flight hours as a prudent measure pending the final results of the AAIB investigation.

On 19 January Sikorsky Aircraft wrote to the U.S. National Transportation Safety Board (copied to AAIB, Federal Aviation Administration (FAA) and CAA) expressing reservations about the AAIB's preliminary conclusions which had resulted in the initial recommendations.

On 14 February CAA wrote to AAIB giving its full response to the two initial recommendations and other points in the AAIB letter of 15 December. Recommendation 1 had been accepted and Recommendation 2 had been partially fulfilled by information provided by Sikorsky Aircraft. CAA also considered that Recommendation 10 in report 4/83 had been accommodated in BCAR 29 (para 29.917(a)) which was in the process of being amended to encompass the service history and manufacturing history of critical parts. The CAA also pointed out that BCAR Section A, Chapter A8-1 para 3.17(e), also similarly A8-2 para 3.15(e) and A8-3 para 3.13(e), states that for UK primary companies, suppliers and overhaulers:-

"3.17 Technical records shall be maintained and shall be such that proper correlation of all work carried out is established with relevant documents including the following, as appropriate:-

> (e) Test and inspection records including a record of each identified (*ie* by serial number) component and item of equipment".

On 23 June following completion of metallurgical examination of the failed gear by RAE and Sikorsky Aircraft AAIB wrote to CAA summarizing the findings and making a further recommendation:-

"Helical gearwheels of part number S6135-20620 in Sikorsky S61 helicopters which are identified as being from manufacturing heat treatment batches K825 and K826 be withdrawn from service".

The CAA indicated its acceptance of this recommendation on 27 June and undertook to amend CAA EAD 030-01-89. From the information which had been collected from operators the CAA could report that none of the relevant serial numbers (from the three batches) was in operation on a British registered aircraft. The FAA was reported as not following suit at that stage but was awaiting definitive information from the manufacturer.

Of the four gearwheels which the operator had received under one approval certificate he managed to locate two in addition to 1117. One was a gear which was recorded as having suffered a capping failure. Another was still in service and was removed when it had been identified. The fourth was not traced and may have been in a gearbox which had been sold.

The manufacturer has stated that a double vacuum melt steel which has previously been an alternative manufacturing material for the helical combiner gear will in future be used for new production gears.

AAIB recommendations remaining in place are listed at chapter 4.1.

2 Analysis

2.1 General

The accident resulted from a progressive failure in the main transmission initiated by a fatigue fracture of a single tooth on the main combiner gear wheel. Despite prompt and correct actions by the crew, the loss of the transmission occurred at a point where a ditching into wind was impossible. The subsequent down-wind ditching was successfully carried out by the crew in difficult conditions and all occupants escaped from the inverted hull despite the crew's inability to complete the ditching drills and to operate three of the designated escape exits. The SAR operation was well conducted, given the limited facilities available, and all occupants survived until rescued despite various failures of survival equipment.

2.2 Conduct of the flight

The crew were properly briefed, qualified and well rested for the flight. Both crew members were wearing the correct survival equipment but the co-pilot's immersion suit was of dubious serviceability at the start of the flight. The passengers were all experienced travellers on North Sea helicopters who had completed the appropriate survival course including a practice underwater escape.

The first indication to the crew of an abnormality was a slight buzzing noise. Although both pilots could hear the noise neither of them considered it of sufficient significance to warrant immediate action and, at this stage, there was no suspicion of anything amiss with the transmission. On removing his headset to listen to the passenger who had come forward to report the same noise, the commander realised that the noise was coming from the cabin area and was of significant amplitude. Despite the fact that there were no other indications of a problem, the commander decided to divert to the nearest available landing site which was the Claymore A oil production platform. When informing Highland Radar and Claymore Radio of the nature of his problem, the commander did not declare a state of urgency, *ie* he did not use the prefix 'PAN' in his radio transmissions. The commander of a helicopter with transmission problems over the North Sea in poor weather conditions has few options open to him and the use of the prefix 'PAN' would ensure that all relevant agencies are at the appropriate level of readiness should the situation deteriorate.

Reference to the check list and flight deck instrumentation provided no additional information to help the commander in determining the source of the noise and it was not until he changed N_R, which changed the amplitude of the noise, that he was convinced that the noise was emanating from the main transmission. Post crash examination of the chip detector, which was not wired to the flight deck, revealed that it was contaminated with fibreglass and metal but would not have given an indication on the flight deck because the nature of the contamination was such that it did not cause a short circuit across the chip detector contacts.

At this stage, the commander considered that a routine landing could be made and configured the aircraft and briefed the passengers accordingly. In view of the steadily increasing noise level however, he requested a priority landing. This was the first indication to the FILO aboard Claymore A that the diversion was other than routine.

Shortly after this request, the failure of the transmission oil pressure confirmed that there was a severe problem with the aircraft. The commander's reaction to this failure was both prompt and positive. Although he was only some 5 nm from Claymore A and had it in sight, he judged that a ditching was a distinct possibility and instructed the passengers to prepare accordingly. The reaction of the passengers to this instruction is discussed in para 2.8. From this point on, the situation deteriorated rapidly. The sudden increase in noise and vibration accompanied by major fluctuations of the engine instrument indications convinced the commander that he could not safely fly the remaining 2½ nms to the Uncle John which he had nominated as his landing point because of its lower deck height. As the aircraft was by now at 250 feet with a major transmission problem, the commander decided that there was insufficient height to turn into wind for a ditching and elected to land down-wind. It is probable that at this stage the condition of the input gears was such that No 1 engine was no longer driving the rotors and No 2 engine was doing so intermittently. As the commander raised the collective lever to cushion the landing the N_R fell rapidly causing a related fall in tail-rotor rpm which would explain the commander's impression that he was losing yaw control just before impact.

2.3 *Evacuation*

The evacuation was successful in that all 13 occupants escaped from the inverted hull without serious injury. It is quite clear that the comprehensive training and briefing given to the passengers was a major contribution to their survival. All adopted the correct procedures and there was no panic. However, the pilots were unable to escape by the easiest route, through their cockpit escape hatches, and had to improvise under very difficult circumstances.

The commander states that on contacting the water, he lowered the collective lever fully. However, since the collective lever friction was set low for the landing to allow easy movement, it is possible that when the helicopter inverted, the lever migrated to its fully up position. Tests established that when a pilot in the left hand seat reaches for the side escape exit operating handle with the collective in the fully raised position, his hand would naturally fall between the collective and the side of his seat. This problem would be exacerbated by the weight of the inverted pilot raising him from his seat cushion, although this effect would be reduced somewhat by the buoyancy provided by air trapped in his survival suit. The combination of these factors would make it difficult for a pilot who was inverted under water with no visual reference to locate the handle. The pilot in the right-hand seat would not have been faced with the problem of obstruction by the collective lever since this is inboard of his seat. However, the effect of raising the pilot 2 inches from his seat is to put the emergency lever near the limit of normal reach, whereas when seated normally, the lever falls readily to hand. Research into disorientation of subjects inverted under water has demonstrated that their perception of the vertical can be seriously in error. The combination of these two factors probably explain why the commander failed to locate his emergency handle; they would also have contributed to the co-pilot's problems.

Although the degree of disorientation will vary from pilot to pilot, it is felt that a simple modification to the 'Helicopter Underwater Escape Trainer' (HUET) which would require the pilot to operate an emergency lever, correctly positioned for his aircraft type, as part of his escape drill would help to prepare pilots for the situation in which the crew of G-BDES found themselves. This matter has been drawn to the attention of the operators of the HUET.

Passenger evacuation was accomplished without difficulty. All exits that were used functioned properly. No firm conclusions can be drawn from the fact that no survivor can recall seeing the emergency lighting. The lights may well have been illuminated, but due to the ambient light conditions and contamination of the water by bubbles and debris, survivors may not have been conscious of them. The use of the 'push out' windows prevented congestion at the major escape exits and speeded the evacuation considerably. Some passengers were surprised by the force required to unlatch their harnesses when inverted and this should be emphasised during training. This matter has also been drawn to the attention of the training organisation.

Since any future ditching of a helicopter in the North Sea will often, given the predominance of high sea states in the area, result in evacuation from an inverted aircraft, greater emphasis should be placed on this condition during training and when formulating drills. The design requirements for future helicopters approved for operation over the North Sea should also take account of the problems of egress from the inverted position. It is recommended that the CAA give further consideration to the problems of escape from inverted helicopters, given the likelihood of rapid capsize following ditching, when approving helicopters for offshore operations.

2.4 *Search and Rescue (SAR)*

The SAR operation was completed in 53 minutes from the time of ditching. Although land based dedicated SAR aircraft were alerted promptly they did not arrive at the rescue scene in time to take an active part in the rescue. The rescue was directed and co-ordinated by a small team based in the radio room on board Claymore A with the OIM acting as scene-of-search commander. None of the personnel involved had been formally trained in SAR procedures but despite this, the operation was conducted efficiently.

Although this operation was handled well, it is felt that under different circumstances the outcome may have been less favourable. It is therefore recommended that the Department of Transport and the Ministry of Defence jointly co-ordinate with the operators of fixed offshore installations for the provision of facilities and specific training of personnel to provide for the control of SAR operations pending the arrival of shore based units.

2.5 *Sea survival*

All occupants of the helicopter survived their period in the sea without significant deterioration in their condition, apart from one survivor who spent 42 minutes in the water and suffered mild hypothermia. It was clear that the survival training and briefing provided for both crew and passengers had stood them in good stead, enabling them to overcome minor equipment problems and ensuring a high level of morale throughout the incident. The co-pilot was fortunate in having the protection of the life-raft; had he not been able to enter the life-raft then the damage to his survival suit may well have led to advanced hypothermia in the conditions prevailing.

2.6 *Survival suits*

The IAM report concludes that although the passenger survival suits had been repaired and showed some signs of wear, they passed the standard leak test and were adequate for the task. The co-pilot's survival suit was in a poor condition before the ditching and sustained further damage while he was escaping through the small side window. Although in the prevailing conditions it was not mandatory for the flight crew to wear survival suits, it is felt that it is incumbent upon flight crews to be at least as well protected as their passengers so that they may fully discharge their duties relating to passenger well-being following an accident. The operator should review survival equipment procedures to ensure that aircrew are properly protected so that they may be of maximum assistance to their passengers following a ditching. This matter was raised with the operator.

2.7 *Life-jackets*

The performance of the passenger life-jackets gave cause for concern in three areas.

2.7.1 *Location of inflation toggle*

Three passengers reported having difficulty in locating the inflation toggle on their life-jackets. Passengers are taught to place both hands on their chest and then run them down over the inflation bottle towards their waist where they will find the toggle. This drill works very well if the toggle is in its correct position. Two passengers were unable to say how they eventually found the toggle but the other stated that it was lodged in the area of the inflation bottle. He also states that one other passenger had the same problem. It is felt that the failure to immediately locate the inflation toggle in four cases out of twelve is indication of a design and/or packing deficiency. It is recommended that the CAA review the design and packing procedures relating to approved life-jackets to ensure that the inflation toggle is correctly presented to the survivor.

2.7.2 *Damage to life-jackets*

All passengers exited the helicopter through approved exits which on the S61 are of generous size and have smooth edges. However, the IAM report states that damage resulting in puncture of two of the life-jackets probably occurred during escape from the helicopter.

2.7.3 *Servicing procedures*

One of the three life-jackets found to be punctured had a hole that was unlikely to have been caused by snagging or abrasion during escape. This jacket had undergone an annual service only days before the ditching. Examination by the manufacturer identified the most likely cause of this damage to have been due to a cross folded part of the fabric chafing against a knot in the whistle securing line. The rate of leakage that resulted could easily be compensated for using the oral inflation tube. Three of the life-jackets were found to be without reflective patches and the IAM report suggests that they had never been fitted. The absence of these patches would jeopardize the location of survivors in the sea at night.

2.8 *Public Address system*

In helicopters carrying less than 20 passengers where the flight deck is not separated from the passenger cabin by a door, there is currently no requirement for a PA system to be fitted. G-BDES came into this category. The poor performance of the PA system in this case cannot therefore be criticised on the grounds that it did not meet laid down requirements. Because of its existence however, it was used not only for passing routine information but also information vital to passengers in an emergency. In this accident this method of communication proved to be virtually useless because all the passengers were wearing ear protection as advised in their pre-flight briefing. Had it not been for one passenger hearing the single word "life-jacket", it is conceivable that the passengers would have entered the sea unprepared for a ditching. While it is acknowledged that in this case the ability of the passengers to hear the PA was probably reduced by the noise of the failing transmission, the practice of passing vital safety messages via a loud speaker based system to passengers who are wearing ear protection is clearly unsound. The situation is exacerbated by the fact that many passengers will have just finished a 12 hour shift and may well be sleeping.

Since passengers on North Sea helicopters are required to wear survival equipment, it follows that they should be alerted to situations when they might have to invoke the protection it affords. Despite the lack of a regulation requiring it, there is clearly a need for a reliable means of communication between crew and passengers. Such a system should cater for such situations as:

1. Passengers wearing ear protection.
2. The need for continued communication after the full donning of survival suits.
3. The probability that some passengers will be asleep.
4. High ambient noise and vibration associated with aircraft malfunctions.
5. The probability that headsets will be worn by passengers to receive in-flight entertainment.

The cordless infra-red PA systems that are currently in use on some North Sea helicopters may have the potential to meet these requirements. Alternatively, such a system could be based on the system of lights and claxons used aboard off-shore oil installations to indicate the safety state existing on the installation. All passengers would be familiar with this system and therefore require the minimum of training. It is recommended that the CAA produce a requirement for an effective means of communication between flight deck crew and passengers for public transport helicopters.

2.9 *ADELT*

Examination of the ADELT beacon unit indicated that it would have deployed had it received the correct electrical signal. Since the crew did not attempt to deploy the beacon manually and the available evidence indicates that the three frangible switches probably did not operate, it is possible that a fault existed in either the immersion switch or in the ADELT wiring loom. This was the third consecutive ditching of an S61 where the ADELT failed to operate. (see AAIB reports 3/89 and 1/90 on G-BDII and G-BEID respectively) Since the accident to G-BDES modifications have been made to the ADELT installations in helicopters required to carry such equipment. However, it is recommended that the CAA review the design and installation of the ADELT system on helicopters in order to ensure reliable operation.

2.10 *Damage within the input housing of the main rotor gearbox*

While it appeared that a cause for the transmission failure had been clearly identified in the subsurface fatigue within the helical combiner gear, the damage suffered by the components within the input housing was considered to see whether there were any preceding failures or other contributory factors.

Anomalies were found within the torquemeters and freewheel units (loose anti-rotation pins, sheared bearing retention tags and a displaced piston ring) but these could not be related to the gear failure other than as consequences of the massive vibrations and overloads experienced during the event. Again, though the composite material splashguard had been destroyed the evidence was that it had been properly secured and had, therefore, most probably been shattered by the fragmenting gears.

The outside surfaces of the tooth which contained the fatigue fracture, the adjacent released tooth and the next adjacent section of rim segment which had detached all showed less damage than the remainder of the gear rim. The pattern of progressive tooth damage on the remaining rim was consistent, therefore, with having been sustained once these rim pieces had been lost. In traversing the gap in the rim of the combiner gear each input gear and its power unit oversped and became desynchronised with the combiner gear. Repeatedly, on re-engaging, the two gears had suffered damage to their gearteeth but evidently they had become synchronised again as rotation continued creating the progressive pattern of damage seen.

Although the helical combiner gear along with the freewheel assembly units and their helical pinions had suffered gross damage nothing was seen within the damage that could have been the initiator of the whole failure sequence. It was concluded that all this damage was consistent with being secondary to the rupture of the helical combiner gear from the position of the fragmented tooth. The release of the rollers in the freewheel unit and the gross damage sustained by them may have allowed some lateral movement of the helical pinion for which each freewheel unit was a partial support (together with two ball bearings). The damage which each helical pinion sustained was probably related, therefore, to the damage in its freewheel unit and the more severe damage suffered by the No 1 helical gear was probably the result of its freewheel unit having progressed further towards complete failure than the No 2 unit.

2.11 *Fatigue initiation*

The early results from the metallurgical examination identified the origin of the fatigue cracking in gearwheel 1117 as an area within the fragmented tooth which contained aluminium oxide and other inclusions. Microcracks had developed from the inclusions leading to the development of a single subsurface crack, from which identifiable fatigue had developed down into the tooth and gear rim. The position and orientation of this subsurface crack and the development of fatigue from it were not obviously related to the stresses resulting from normal tooth loads, e.g. tooth bending loads. A finite element analysis of the gear stresses by the manufacturer found one vibration mode, near gear tooth meshing frequency at normal operating speed, which could have produced high tensile stresses in the teeth in the required location near the crown. However, it was not known whether that mode did in fact occur or how high the stresses would be in absolute terms. The driving stresses behind the crack development, further discussed below, were, therefore, obscure.

The actual progression of the complex crack development had been made clear by careful metallurgical examination and the area of initiation was identified as the well-defined zone containing the inclusions. Also within that zone were seen features which etched white on the metallurgical micro-sections. These were considered to be similar to a phenomenon seen in bearings in association with surface spalling and signifying sub-surface plastic deformation. Here they were probably associated with the aluminium oxide inclusions though this could not be confirmed in every case. The white etched areas were, therefore, taken to be a secondary effect resulting from intense stress fields around the inclusions and related cracks.

Because of a number of 'capping' failures that had been experienced in the helical combiner gear, modifications had been introduced in 1983 to the heat treatment of the finished gear to alter the carburized layer on its loaded tooth surfaces. The surface hardening process does result in inbuilt tensile stresses in the transition zone between the hardened 'case' and the core material. If the residual stresses are sufficiently high they can, in combination with the hoop loads in the rim and the cyclic tooth loads, result in fatigue damage. Of the numerous capping failures which had occurred very few had apparently been returned to the manufacturer for laboratory examination. However, it would appear that it had been assessed that the basic cause, of at least the majority of such cases, was such a residual stress problem related to the heat treatment. However, all three cases for which detailed information was available to this investigation, two capping failures and the catastrophic failure of 1117, show a different phenomenon to be implicated in the failures - aggregations of non-metallic inclusions, mainly aluminium oxide. This phenomenon relates to the manufacture of the steel and not to the heat treatment of the finished product.

The manufacturer identified 1117 as belonging to a heat treatment batch which had suffered a high rate of 'capping' failures. Any relationship between the rupture of 1117 and these failures could have been associated with the stock material properties as suggested by the RAE Farnborough's results, or with the heat treatment. As it was thought probable, though unconfirmed at first, that all gearwheels in lot K827 had come from the same batch of steel it was decided that it would be prudent to remove related gearwheels from service and a recommendation was made to the CAA in the letter of 15 December 1988. A second recommendation was also made as a supporting move to further investigation. (see paragraph 1.17.5)

Together with the concentration of 'capping' failures in heat treatment lot K827 there was some other evidence to suggest that the heat treatment was implicated in this failure; *ie* the anomalies in the measured tooth hardness and case thickness. The metallurgical analysis, however, did not identify any connection between these effects and the development of the fatigue. The main fatigue development from the area of inclusions occurred remote from the hardened zone but it remains a possibility that the conditions at the case transition were influential in the development of the oval zone around the inclusions, where at one end of its extent it was close to the transition zone. This could, however, be the case with such a group of inclusions adjacent to a hardened layer, whether the layer was within specification or not. The statistical information, showing six possibly related failures in lot K827 and none known in lots K825 and K826, was suggestive of a heat treatment problem but no more than that as the statistical record was known to be incomplete. The samples were small and any relationship between the fractures in lot K827 might equally have been due to the material as to the heat treatment.

It was therefore concluded that, though there were other anomalies found in the gearwheel, the most significant was the presence of aluminium oxide inclusions within a zone of the fracture surface. This one feature, the group of inclusions, even though it may not have constituted a defect in terms of the original material quality criteria, may well have been the sole initiator and cause of the failure of gearwheel 1117. As it could not be demonstrated that the type of failure seen in gearwheel 1117 would be restricted to that gearwheel alone, or to its heat treatment batch, and as there had been the other probably related occurrences, it was decided that it should be recommended that all other gearwheels related to 1117 by material source *ie* heat treatment lots K825 and K826, should be withdrawn from service.

2.12 *Sequence and timescale for the helical combiner gear failure*

The tooth loads in the helical combiner gear would vary in magnitude depending on the applied torque from each engine, which in turn would vary with flight condition and aircraft loading. If, through some effect such as the existence of a stress raiser, fatigue damage were being caused by tooth loading it might be that initially only higher loads would cause accruing fatigue damage. However, with the development of a crack, lesser tooth loads would begin to cause damage because of the notch effect of the crack. Once normal cruise loads became damaging at a cyclic rate of over 380,000 per hour, development could be rapid. Unfortunately, although the metallurgists were able to assess relative rates of growth of the fatigue fractures they were not able to assess any absolute rate of development in terms either of cycles or time.

Gearwheel 1117 completed 2,790 hours service in gearbox 1037 and was crack checked using a fluorescent magnetic particle technique after removal from that gearbox. At that time, therefore, a sub-surface defect may have existed but may not have been detectable by magnetic method. Less likely, but not impossible, a crack to the surface of the crown of the tooth from the 'oval feature' may have been present but undetected. Following that inspection the gearwheel completed another 1,085 hours before failure. At some point the material from the crown of the tooth which was not recovered was released. This could have happened during the initial test run following overhaul, when some metal was found in the strainer, or later in service but the test record which might have described the metal found after test was not recovered and there were no reports of metal being found on the chip detector or in the filters during service. Finally, this small amount of debris might have been amongst the debris recovered from the gearbox during the investigation but not recognised for what it was.

The release of the single tooth and the fragments of the tooth which contained the primary fracture must have occurred only shortly before the rupture of the wheel itself. The manufacturer states that, typically, steel debris from the front housing will take about 20 minutes to migrate to the chip detector. All the significant debris was found still inside the front compartment. The loss in oil pressure 3 minutes before ditching was evidently caused by the blocking of the scavenge strainer by a relatively small amount of material from the composite splashguard. As this light material could have migrated very quickly with the oil flow it would seem that disintegration of the splashguard had begun only shortly before and would not have played any significant part in preventing steel fragments from being transported to the strainer and chip detector.

The first detectable sound on the CVR recording which can be related to the failure of the combiner gear occurred 18 minutes before ditching. This must signify some mechanical change to the wheel; either the development of the crack to an extent which at least altered the stiffness of the wheel, or the loss of some material. The fact that this sound was detected on the CVR through its sixth harmonic indicates that it signified a major mechanical change to the gearwheel. If there had been previous distress indicating only at its fundamental frequency at 2 per revolution (of the helical combiner gear) the CVR's response characteristics, and the limitations imposed by the use of an area microphone rather than a dedicated gearbox mounted transducer, would have suppressed the signal and it would not have been recorded on the tape.

At 12 minutes before ditching there was a marked increase in noise, the passengers, who were already aware of an unusual noise, reported it as a "thump", and this may have signified the release of material from the wheel, most probably either fragments of the 'primary' tooth or release of the adjacent complete tooth, the primary tooth having already broken up. By that time the noise and vibration were very marked but the continuing increase in noise and vibration from that point seems consistent with the circumferential development of the crack into the gear's web. This allowed increasingly large movement of the rim and ultimately the release of the two large segments of rim which, without doubt, was the cause of the gross noise and vibration which motivated the commander to initiate ditching.

A crack obviously existed in the helical combiner gearwheel for some time before the first indication of a fault was detectable on the CVR recording but unfortunately this time cannot be estimated. It seems likely that there had been sufficient alteration to the wheel's mechanical properties, before its registration as a noise on the CVR, to make it detectable by a vibration/audio monitoring system optimised to detect changes in the characteristic noise emitting from the transmission, but again the time at which this level of damage was reached cannot be defined. It is recommended that the CAA require, for all public transport helicopters, the provision of a facility to continuously monitor the vibration/audio 'signature' of all high speed rotating equipment whose integrity is critical to flight safety.

2.13 *Steel cleanliness*

The evidence of contamination found at the failure origin in gearwheel 1117 cannot easily be compared with the cleanliness requirements applied during the steel manufacture. A comparison cannot be made between the observed accumulation of inclusions seen in a section of one tooth and the cleanliness requirements of the steel (AMS 2301) expressed as an average density of indications on a test sample area of 56 square inches. The cleanliness inspection would have been carried out on ingot samples before the major manufacturing forging processes had been carried out. Forging would have altered the configuration of the group of inclusions, perhaps redistributing the material from a single conglomeration into the string of individual fragments seen in the manufactured gear.

It is accepted that it cannot be demonstrated that the material used did not conform to the required cleanliness standard and the second part of Recommendation 2 in the letter of 15 December 1988 is withdrawn.

While it cannot be questioned that melt No 68966 met the requirements of AMS 2301 as recorded, it is observed that the low sampling rate specified must permit a distinct possibility of unacceptable amounts of non-metallic included material being present in a batch of steel where such contamination may be very unevenly distributed. The finished gearwheel was tested for defects by magnetic particle inspection but this technique has a limited ability to detect sub-surface defects. The service history of the helical combiner gear, with the exception of the non-catastrophic capping failures, shows it to have been a reliable component as originally designed given the materials and techniques available at that time but the standards originally used for metal cleanliness and inspection fall well short of what is now possible. For this reason the manufacturer has decided to use a steel from a more modern double vacuum melt process for future production. It is significant that such a change to the material specified for this or a similar component can be readily accomplished as the material properties are not fundamentally altered but the incidence and magnitude of conglomerations of impurities are reduced.

This investigation has highlighted a situation which affects successful designs of aircraft which have been in service for a long period of time and which may continue to operate commercially for a further considerable period. During their operating life manufacturing and certification standards, in at least some respects, have developed and improved so that standards acceptable in the original manufacture and certification would not be employed today. The mature design has the assurance of safety and reliability, beyond that provided by the development and certification procedures, of a long service history. In the case of the S-61 and related types this amounted to some 5 million operating hours, and this should more than compensate in safety terms for differences between earlier and present standards of manufacture and certification.

The report of the Helicopter Airworthiness Review Panel, CAP 491, published in June 1984 commended the concept of "VITAL" components where critical parts of the helicopter design could not be made damage tolerant and whose quality control would be handled with the "utmost seriousness". BCAR 29, Paper G778 and BCAR sections A and G do now recognise "CRITICAL" components according to this concept. In the case of the type of failure seen in gearwheel number 1117, a modern manufacturing standard, bearing in mind that this component would be a 'CRITICAL' part, would reduce the probability of such a failure recurring.

The failure sequence appears to have begun with the occurrence of inclusions, probably acceptable according to the specified material cleanliness requirements, at a particular location in the component. The present airworthiness requirements, as in the past, recognise the possibility of catastrophic failure through such a conjunction but a very low probability for such an occurrence is set as a design target to be used together with component stress levels and the known scatter of material fatigue properties. The current UK airworthiness requirement for the possibility of a failure such as that in gearwheel 1117 to be "extremely remote" is a minimum requirement (less probable than 10^{-7} per hour of flight). It also assumes an autorotative descent to a landing. While this is hazardous on land it is significantly more hazardous in the type of operation for which G-BDES was being used over the North Sea.

No investigation has been carried out into the basic data and calculations used in the original S-61 design and certification and it is not known, for instance, how present single air-melt steels compare in cleanliness with the material used in the laboratory tests which produced the mean and worst case fatigue characteristics used in designing the gearwheel part number S6135-20620. The cleanliness requirement AMS 2301 allowed relatively large amounts of contamination (only features over 1/16 of an inch to be recorded) and imposed a low quality sampling rate for each melt of steel. There was, therefore, a distinct possibility of overall steel quality varying considerably over time. If a steel batch were lower in average cleanliness than that assumed in certification the sampling process of AMS 2301 would not necessarily identify this but even if such a batch were acceptable on cleanliness throughout its bulk to AMS 2301, there would remain the possibility of an inclusion, or a group of inclusions, occurring in a critical position in the finished component.

Given that what is available is not a change of material but an improvement in the manufacturing and quality control of the material in present use and that a marked reduction in the risk of mechanical failure is possible, it is recommended that the CAA should review and reconsider, with manufacturers, the use of single air-melt steels in 'CRITICAL' transmission components in helicopters and the practice of 'small sample' inspection of materials destined for use in the manufacture of such components.

3 Conclusions

a) Findings

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

(ii) The helicopter had a valid Certificate of Airworthiness in the Transport Category (Passenger) and had been maintained in accordance with an approved maintenance schedule.

(iii) The passengers were properly briefed and trained to cope with the ditching and subsequent sea survival.

(iv) The passengers were all experienced travellers on North Sea helicopters who had completed the appropriate survival course, including a practice underwater escape.

(v) The crew were not provided with sufficient warning of the impending transmission failure to allow a ditching to be avoided, or even planned to the extent of alighting into wind.

(vi) The Passenger Address system proved to be inadequate for passing vital safety information to the passengers.

(vii) On ditching, the front of the aircraft was immediately engulfed by a wave, it rolled to the right and inverted.

(viii) The crew and passengers evacuated the aircraft successfully despite their inability to open some emergency exits.

(ix) Most of the passengers survival suits leaked to some extent despite being serviceable.

(x) The co-pilot's survival suit was in a poor condition at the start of the flight.

(xi) Two passenger life-jackets were damaged during escape from the helicopter and a further one had a pin-hole puncture that was unlikely to have been caused by snagging or abrasion during the escape . It may have come about due to chafing against a knot in the whistle line within the valise.

(xii) Several passengers failed immediately to locate their life-jacket inflation toggle because it was 'trapped' within the life-jacket/valise combination.

(xiii) Neither pilot was able to locate the operating lever for his escape exit.

(xiv) The provision of passenger escape windows made a fundamental contribution to the survival of the commander and passengers.

(xv) The Search and Rescue operations, both shore based and in-field were well co-ordinated and executed inspite of limited facilities and a lack of specific Search and Rescue training for the in-field personnel involved.

(xvi) The Automatically Deployable Emergency Locator Transmitter failed to operate but it was not possible to establish a reason.

(xvii) The helicopter suffered a catastrophic failure of the helical combiner gear (part number S6135-20620) within its main transmission input gear train.

(xviii) The failure of the helical combiner gear, which did not have a prescribed service life, occurred after 3,875 hours of total operation, 1,085 hours on G-BDES since last rework.

(xix) The history of the gear was difficult to establish and could have proved impossible because its serial number had not been recorded on all of the relevant maintenance documents as it was not a 'lifed' component.

(xx) The failure occurred as a result of fatigue cracking which originated in a geartooth and developed into the gearwheel's rim and web.

(xxi) The fatigue originated within a zone in the tooth containing non-metallic inclusions which were composed mainly of aluminium oxide, a by-product of the steel manufacturing process.

(xxii) Nothing was identified, other than the aluminium oxide inclusions, as a causal factor in the initiation of the fatigue.

(xxiii) Some evidence was presented of excess depth of carburised layer on the gearwheel's teeth and a relationship between this condition and the initiation of the fatigue could not be discounted.

(xxiv) The failed gearwheel was one of a heat treatment batch (K827) which appeared to have suffered a high incidence of geartooth failures.

(xxv) Information on two such geartooth failures, one from heat treatment batch K827, also showed there to be aluminium oxide inclusions associated with the initiation of the failures.

(xxvi) Two other heat treatment batches (K825 and K826) were identified which had been manufactured from the same steel melt.

(xxvii) The steel melt conformed to the required cleanliness specification.

(xxviii) The steel was a single air-melt steel, the cleanliness inspection employed a low sampling rate and there was no other inspection of the sub-surface quality of the steel throughout the manufacturing process.

(xxix) The Cockpit Voice Recorder provided some useful information on the audible progression of the failure but the Cockpit Voice Recorder/Cockpit Area Microphone combination is not optimised for the frequencies involved.

(xxx) A vibration/audio monitoring system optimised to detect changes in the characteristic 'noise' emitting from the transmission might have been able to provide the crew with a warning early enough to have avoided a ditching or a least to have permitted a more controlled one.

b) Causes

The ditching which resulted in the loss of the aircraft was due to the following causal factors:-

i) Progressive damage within the main transmission went undetected.

ii) Failure of the main transmission was initiated by fatigue failure of the helical combiner gear (part no. S6135-20620).

iii) The fatigue origin was associated with aluminium oxide inclusions, the aluminium oxide being a by-product of the steel production process.

iv) The steel used for the manufacture of the combiner gear was single air melt and only subject to a cleanliness inspection based on a small sample at the poured ingot stage.

4 Safety Recommendations

The following safety recommendations were made during the course of the investigation:-

4.1 The Civil Aviation Authority give further consideration to the problems of escape from inverted helicopters, given the likelihood of rapid capsize following ditching, when approving helicopters for offshore operations.

4.2 The Department of Transport and the Ministry of Defence jointly co-ordinate with the operators of fixed offshore installations for the provision of facilities and specific training of personnel to provide for the control of Search and Rescue operations pending the arrival of shore based units.

4.3 The Civil Aviation Authority review the design and packing procedures relating to approved life-jackets to ensure that the inflation toggle is correctly presented to the survivor.

4.4 The Civil Aviation Authority produce a requirement for an effective means of communication between flight deck crew and passengers for public transport helicopters.

4.5 The Civil Aviation Authority review the design and installation of the Automatically Deployed Emergency Locator Transmitter system on helicopters in order to ensure reliable operation.

4.6 Sikorsky S61 helical combiner gearwheels (part no. S6135-20620) from heat treatment batches K825, K826 (recommendation made 23 June 1989) and K827 (recommendation made 15 December 1988) be withdrawn from service.

4.7 The Civil Aviation Authority require, for all public transport helicopters, the provision of a facility to monitor continuously the vibration/audio 'signature' of all high speed rotating equipment whose integrity is critical to flight safety.

4.8 The Civil Aviation Authority should review and reconsider, with manufacturers:-

a) the use of single air-melt steels in 'critical' transmission components in helicopters.

b) the practice of 'small sample' inspection of materials destined for use in the manufacture of such components.

The Civil Aviation Authority response to these Recommendations is contained in 'Follow-up Action on Accident Reports' (FACTAR) No 1/90, to be published concurrent with this report.

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April 1990