AIRCRAFT ACCIDENT REPORT 4/85

Accidents Investigation Branch

Department of Transport

Report on the accident to British Airways S-61N G-ASNL in the North Sea 75 NM North East of Aberdeen on 11 March 1983

LONDON
HER MAJESTY'S STATIONERY OFFICE

List of Aircraft Accident Reports issued by AIB in 1985

No	*Short Title*	*Date of Publication*
4/84	Aerospatiale AS 332L G–TIGD Aberdeen Airport July 1983	March 1985
5/84	Cessna Citation 500 G–UESS Isle of Lewis December 1983	February 1985
6/84	Pilatus PC–6/H2–B2 Turbo Porter G–BIZP Yarwell, Nr Peterborough December 1983	March 1985
7/84	British Airways BV 234 G–BWFS 33 miles north of Aberdeen February 1983	March 1985
8/84	British Airways Sikorsky S–61N G–BEON In the Sea near St Mary's Aerodrome Isles of Scilly July 1983	March 1985
1/85	Britten-Norman Islander BN 2A–26 G–BDVW At Sanday Island Airfield, Orkneys June 1984	July 1985
2/85	Aerospatiale Puma 330J G–BJWS Aberdeen Airport October 1982	August 1985
3/85	SA 318B Alouette Astazou G–AWAP Gat Sand, The Wash June 1983	October 1985
4/85	British Airways S–61N G–ASNL In the North Sea, 75 nm north east of Aberdeen March 1983	

First published 1986

ISBN 0 11 550724 8

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

27 January 1986

The Rt Honourable Nicholas Ridley
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr K P R Smart, an Inspector of Accidents, on the circumstances of the accident to British Airways S–61N, G–ASNL, which occurred in the North Sea 75 nm North East of Aberdeen on 11 March 1983.

I have the honour to be
Sir
Your obedient Servant

G C WILKINSON
Chief Inspector of Accidents

Contents

Accidents Investigation Branch

Aircraft Accident Report No. EW/C815

Registered Owner:		British Airways Helicopters
Operator:		British Airways Helicopters
Aircraft	*Type:*	Sikorsky
	Model:	S–61N
	Nationality:	British
	Registration:	G–ASNL
Place of Accident:		75 nautical miles North East of Aberdeen Latitude 58.14N Longitude 00.42W
Date and Time:		11 March 1983 at 14.43 hrs

Synopsis

The accident occurred during a routine flight from the Piper and Claymore platforms to Aberdeen. Shortly after departure from the Claymore Platform the crew heard a loud bang, and experienced vibration from the main rotor transmission. At the same time the crew observed that the No 1 engine had run down and stopped. The crew transmitted a MAYDAY distress call and announced their intention to make a precautionary landing alighting on the water. A controlled ditching was completed without incident and the helicopter floated in a stable manner with the emergency flotation gear inflated. During deployment, both liferafts carried on board the helicopter were punctured and rendered unusable by sharp projections on the hull of the helicopter. A Royal Air Force Sea King helicopter arrived on the scene one hour after the ditching and the passengers and crew were winched on board and flown to Aberdeen. An attempt at recovery of the helicopter by an oil company support vessel resulted in the helicopter being damaged and subsequently sinking. It was later recovered from the sea bed and examined at the Accident Investigation Branch, Farnborough.

The report concludes that the accident was caused by a failure, in fatigue, of a spur gear in the main rotor transmission gearbox which resulted in a rupture of the gearbox casing and loss of the transmission lubrication oil.

1. Factual Information

1.1 History of the flight

The helicopter was returning to Aberdeen as part of a charter flight to the Piper and Claymore platforms. Fifteen passengers were on board but no flight attendant was required for the flight and none was carried. The aircraft departed the Claymore platform at 1440 hrs following a routine turn-round during which, in accordance with normal practice, the rotor was kept turning. As the aircraft was approaching its planned altitude of 1500 feet there was a loud bang accompanied by a high frequency vibration and noise from the main gearbox. At the same time the crew observed that No. 1 engine had run down and stopped. The co-pilot, who was flying the aircraft from the left-hand seat, established that there was sufficient power to maintain height. While the pilots were completing their emergency actions they noticed that a transmission oil pressure failure was indicated, that the transmission oil pressure had dropped from a steady 50 pounds per square inch (psi) to 30 psi, and that the emergency lubrication system had come into operation automatically. Unknown to them but observed by the passengers, oil was beginning to stream across the windows on the righthand side of the cabin.

At 1443 hrs the commander changed frequencies from the Piper Platform to Highland Radar on 134.1 MHz and transmitted a 'Mayday' distress call informing them that an engine had failed and that there were indications of gearbox problems. While this was going on the co-pilot briefed the passengers on the public address (PA) system and alerted the Piper Platform to the situation. He also passed the information to an AS 332L (Tiger) helicopter which was known to be in the vicinity. A gradual descent was commenced during which the pilots came to the conclusion that there was a serious problem within the main gearbox. Because the sea state was slight the commander decided to make a precautionary alighting on the water and Air Traffic Control (ATC) and the Tiger were informed accordingly. The commander took control of the aircraft and made a successful power-on ditching at approximately 1456 hrs. The landing was made into a light southerly wind and against a long regular swell of 6 to 10 feet in a position approximately 043° (T) 75 nautical miles (nm) from Aberdeen.

Once in the water the helicopter floated satisfactorily. The commander decided to keep the rotor turning in order to assist with the stability of the aircraft and the flotation gear was deployed, the sea anchor streamed, and the undercarriage lowered. Because of the favourable conditions the commander decided not to abandon the aircraft immediately and the passengers were told of the decision. At this time the fire warning lights illuminated and the remaining engine was shut down and the rotor allowed to stop rotating.

The ditching had been observed by the Tiger and the position established by a Nimrod aircraft which was in the vicinity but unable to descend because of its fuel state. These aircraft were able to maintain two-way communications with the ditched helicopter. A detailed description of the rescue is contained in Section 1.15 and only an outline of what happened is included here. As a precaution the commander ordered that the rear liferaft should be deployed. This was launched through the rear left emergency exit and inflated. However, it drifted behind the aircraft where it came into contact with an aerial and was punctured and deflated. The second liferaft was therefore launched through the righthand freight door but on inflation it rolled over into the inverted position and could not be righted. This liferaft was also punctured after coming into contact with the hull. Both liferafts were therefore completely unusable.

After the arrival on the scene at approximately 1540 hrs of a British Airways Helicopter's S61 and an RAF Sea King, both winch-equipped and dispatched from the shore, it was decided that the Sea King would lower its own liferaft. This was hauled alongside the ditched helicopter and using two loads the occupants were winched aboard the Sea King which returned to Aberdeen with the S61 in attendance. No injuries were suffered during the evacuation.

An attempt was made to recover the helicopter by one of the ships which had arrived on the scene but the aircraft became damaged and sank. It was later recovered from the sea bed and brought ashore for a detailed examination.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	–	–	–
Serious	–	–	–
Minor/None	2	15	

1.3 Damage to aircraft (see Appendix 1)

The main rotor gearbox input casing and the adjacent fairing were ruptured and one main rotor blade pitch horn was damaged as a result of debris being ejected from within the gearbox. The aircraft alighted on the sea without further damage. Following the successful evacuation of the passengers and crew, attempts were made to recover the aircraft onto a ship. During this recovery attempt the tail boom and tail rotor assembly were severely damaged and became detached from the fuselage. The aircraft subsequently broke away from the recovery vessel and sank to the sea bed.

1.4 Other damage

None.

1.5 Personnel information

1.5.1	*Commander:*	Male, aged 37
	Licence:	Airline Transport Pilot's Licence (Helicopters) valid until 10 March 1990
	Helicopter type ratings:	Westland S-55 series 111 Sikorsky S–61N
	Instrument rating:	Renewed 31 May 1982

	Medical certificate:	Class 1 valid until 31 July 1983
	Flying experience:	Total all types: 4435 hours Total helicopters: 4250 hours Total Sikorsky S–61N: 2141 hours Total flying last 28 days: 4.05 hours
	Duty time:	Off duty 1700 hrs 10 March until 0900 hrs 11 March (16 hours) On duty 0900 hrs 11 March (5 hours 56 minutes duty up to time of ditching)
1.5.2	*Co-pilot:*	Male, aged 35
	Licence:	Airline Transport Pilot's Licence (Helicopters) valid until 20 November 1988
	Helicopter type ratings:	Sikorsky S–61N Westland 60 Whirlwind 111 Bell 206A and B Bell 47
	Instrument rating:	Renewed 24 January 1983
	Medical certificate:	Valid until 30 April 1983
	Flying experience:	Total all types: 6428 hours Total helicopters: 6200 hours Total Sikorsky S–61N: 3346 hours Total flying last 28 days: 64.40 hours
	Duty time:	Off duty 1705 hrs 10 March until 0900 hrs 11 March (15 hours 55 minutes) On duty 0900 hrs 11 March (5 hours 56 minutes duty up to time of ditching).

1.6 Aircraft information:

1.6.1 Aircraft details:

Manufacturer:	Sikorsky Aircraft Division of United Technologies Corporation
Type:	S–61N
Airframe serial number:	61220
Date of construction:	31 December 1963

Engines	Two General Electric CT58–140–1
Seating configuration:	3 crew (two pilots, one cabin attendant) plus 24 passengers in a conventional forward facing arrangement
Maximum all-up weight:	20500 lb
Certificate of Airworthiness:	Issued on 27 September 1973 in the Transport Category (Passenger); renewed on 12 November 1982 and valid for 12 months until 11 November 1983.
Certificate of Registration:	Certificate valid; registered in the United Kingdom as G–ASNL on 2 October 1969 with the registered owner listed as British Airways Helicopters Limited, Bealine House, London (Gatwick) Airport South, Horley, Surrey
Radio Station Approval Certificate:	Valid issued by UK CAA on 15 November 1982

1.6.2 *Aircraft description*

1.6.2.1 *General*

The Sikorsky S61N helicopter is a large commercial transport helicopter powered by two turbo-shaft engines driving conventional articulated main and tail rotor systems. The S61N has a sealed hull giving it an amphibious capability in calm waters.

The S61N and the S61L, which for practical purposes is a non-amphibious equivalent of the S61N, have been in worldwide service since 1961 and the model S61N has been used extensively in the North Sea.

1.6.2.2 *Main rotor gearbox – description (See Appendix 2)*

The drive from the engines is reduced from 18966 rpm at the engine output shafts to 203 rpm at the main rotor in 4 stages, with the two drive lines being combined at the output gear of the second stage. The first stage reduction is achieved by a pair of straight cut gears which reduce the input rpm to approximately 8,100 rpm. A ramp/roller type of freewheel unit is carried on each first stage output shaft to provide an overrun capability in the event of a failure of either, or both engines. The helical second stage gears drive a common output gear, the third stage bevel reduction gears, and the final epicyclic reduction stage. The tail rotor power take-off is provided by a gear meshing with the large third stage bevel gear, driving an output shaft through a separate freewheel unit, to permit the tail rotor to overrun the gearbox. Further gears, driven by the tail rotor take-off shaft, drive various accessories mounted on the rear of the gearbox.

The output from the No. 1 main freewheel unit also drives a through-shaft via an additional freewheel unit, which meshes with the accessories drive train on the input side of the tail rotor freewheel unit. The through-shaft rpm is 310 rpm lower than the equivalent rotational speed of the auxiliary drive train, thus ensuring that in normal operation the through-shaft is operating in the freewheel mode and is not transmitting load, but is available to maintain tail rotor and auxiliary drive in the event of a failure in the tail rotor and auxiliaries main driveshaft.

The main gearbox casing is a magnesium alloy tub which carries the third stage bevel gears and the epicyclic fourth stage. A separate magnesium alloy housing is attached to the forward end of the main gearbox casing and carries the first and second stage reduction for both the No. 1 and No. 2 drive lines, the free-wheel units and the common output gear from the second stage reductions. A similar magnesium alloy housing is mounted on the rear of the main gearbox casing and carries the tail rotor take-off freewheel unit and the accessories drive train. Both the front and rear casings have two integrally cast mounting feet, which provide the gearbox and main rotor assembly with a four point attachment to the fuselage structure on the cabin roof.

1.6.2.3 Main rotor gearbox input casing - description

The main gearbox input casing carries the No. 1 and No. 2 power input shafts, the 1st and 2nd stage reduction gears, the engine freewheel units, the No. 1 and No. 2 torquemeter assemblies and the rotor brake shaft. Each engine drive train is identical, for all practical purposes, up to the point where the drives combine onto the common second stage output gear.

Each engine output shaft drives a straight cut involute pinnion running in plain bearings at 18,966 rpm. The output gear from this first stage reduction is mounted directly upon the camshaft of the freewheel unit, which it drives at 8,100 rpm. The second stage input pinion is integrally machined on the outer race (driven section) of the freewheel unit.

The second stage reduction gears have a helical involute tooth form which, when under load, produce an axial thrust on the gears tending to move the output shafts forwards, i.e. towards the front cover of the input casing. The camshafts are supported on roller bearings which allow a small degree of axial freedom. The axial positions of the camshafts are controlled by hydraulic servo cylinders, utilizing lubricating oil from the main transmission, which react the torque induced thrust on the shafts. The hydraulic pressures acting on each of the servo cylinder pistons are thus proportional to the torques being transmitted by their respective drive lines, and are used to drive, via transducers, the torque indicators on the flight deck.

The plain bearings which support the high speed input pinions are very vulnerable to oil starvation, but the remainder of the gearbox is claimed by the manufacturer to have a dry run capability. G–ASNL was fitted with a manufacturer's modification providing an emergency supply of lubricating oil, drawn from a reserve section of the oil reservoir via a separately mounted electrical pump, which is designed to cut-in in the event of a loss of gearbox oil pressure.

1.6.2.4 Spur gear – description (See Appendix 3)

The spur gear is 8.9 inches diameter carrying straight cut involute teeth 2.125 inches wide on an annular rim 0.25 inches thick. The gear web, which is approximately 0.25 inches thick, is cranked back in cross section forming a shallow cone. The mounting flange at the hub is approximately in line with the edge of the rim. The gear was shaped in this manner in order to provide clearance to mount the freewheel components on the camshaft within the dimensional constraints of the input housing. Twenty four 5/16 inch diameter bolts secure the gear to a mounting flange on the camshaft.

The gear was manufactured in AMS 6260 steel and hardening of the teeth was effected by quenching the whole component from 1700°F after gas carbonising, followed by an initial temper, a deep freeze to fully transform the martensite, and, finally, a second tempering treatment. A phosphate surface treatment was employed to inhibit corrosion and produce a porous surface to improve oil retention.

1.6.2.5 Main gearbox – design history

The main gearbox used on the S61N helicopter is essentially the same as those used on other commercial S61 variants as well as the various military versions of the S61, including the Westland Sea King. Detail differences exist in certain components within the gearbox, depending upon the specific aircraft type. So far as the input casing is concerned, there are two major differences; these affect the detail design of the 1st stage spur gear and freewheel unit. Later versions of the US military, Coastguard, and all non-United States military aircraft, including the Westland Sea King, have a 1st stage spur gear with a small helix correction introduced on the nominally straight cut tooth, together with crowning of the tooth profile and a thicker gear flange. This type of gear is used in conjunction with a freewheel unit utilising 16 rollers instead of the 12 roller unit originally employed.

A further standard of 1st stage spur gear, on which the helix corrections and crowning were introduced but not the thicker flange, had been the subject of tests by the manufacturer but had not been introduced into service prior to the accident.

On certain military aircraft the lefthand freewheel unit is servo operated to permit running of the accessories without rotation of the main rotor, to facilitate the operation of the blade fold mechanism.

All commercial S61 aircraft, including G–ASNL, have the original straight cut spur gears with 12 roller freewheel units, and do not have the servo operated freewheel.

The emergency gearbox lubrication system was an in-service modification to reduce the vulnerability of the 1st stage input pinion bearing to oil starvation.

1.6.3 History of G–ASNL

The construction of G–ASNL was completed in December 1963 and the aircraft was registered to British European Airlines (BEA) that same month. The aircraft remained in the hands of BEA, latterly British Airways Helicopters, from its initial registration until the time of the accident. G–ASNL was the first S61N delivered to British Airways (BEA) and, as such, would have been involved in the normal company operating trials carried out when a new type is brought into operation. However, there are no indications that any events occurred during the aircraft's history which may have had a bearing on this accident.

1.6.4 *Maintenance history*

1.6.4.1 *General*

The aircraft has been maintained in accordance with a United Kingdom CAA approved maintenance schedule, based on the progressive maintenance philosophy, with a 50 hour or 31 day period between each check. The main rotor gearbox is not the subject of a separate maintenance programme but is incorporated into the overall maintenance schedule for the aircraft.

The most recent airframe check (check number 461) was carried out on 3 March 1983 at 17,492.05 hours.

The records indicate that the aircraft was serviceable at the start of the accident flight and that it has accumulated a total of 17,522.20 hours at that time.

1.6.4.2 *Main gearbox Serial No. 912*

Attempts to obtain a precise history of the main gearbox overhauls, inspections and rectifications were frustrated by incomplete and obscure entries on the main gearbox component history and modification record card. The best estimate that could be made is that the gearbox had been in regular service since before April 1972 and had been the subject of a regular series of overhauls and inspections, together with approximately four additional removals for the purposes of carrying out unscheduled inspections and/or repair. During its period of service with British Airways Helicopters, the main gearbox had been fitted to a total of nine different aircraft on twelve different occasions. The gearbox was last fully overhauled in July 1981 and was subject to a mid-life inspection in May 1982. At some stage subsequent to the mid-life inspection it is believed that the gearbox was removed for the investigation and rectification of metal contamination, subsequent to which it was fitted in G–ASNL: no record is made on the component record card for this removal. Subsequent to its being fitted in G–ASNL, which was carried out at 17,143 aircraft hours, the gearbox continued in service for a total of 379 hours until the accident occurred at aircraft total time 17,522 hours.

1.6.4.3 *Main gearbox input housing (Serial No. 1275)*

The input housing fitted to main gearbox serial number 912, which was installed on G–ASNL at the time of the accident, had been in service since 1974 when it was received from Sikorsky aircraft, as part of main gearbox serial number 789, at a total gearbox time (Serial No. 789) of 5,571 hours. The input housing subsequently had the following history:

January 1976	–	Removed for overhaul at 1,437 hours since overhaul, total time 7,008 hours
October 1977	–	Routed to Westland Helicopters, Yeovil for male pilot (input casing/main casing location) repair
January 1978	–	Fitted to main gearbox serial number 997, zero hours since overhaul, total time 7,008 hours

February 1979	–	Mid-point inspection carried out at 1,364 hours since overhaul
July 1979	–	Routed to Jetwain Ltd for male pilot repair at 1,687 hours since overhaul, 8,695 hours total
October 1980	–	Routed to Jetwain Ltd for liner replacement at left and right hand freewheel bores at 2,758 hours since overhaul, 9,766 hours total
July 1981	–	Fitted to main gearbox Serial number 912 at zero hours since overhaul, 9,766 hours total time
May 1982	–	Mid-point inspection carried out at 1,078 hours since overhaul, 10,844 hours total time
October 1982	–	Investigation and rectification of 'metal contamination' at 1,622 hours since overhaul, 11,388 hours total (contamination attributed to heavily worn bearing on right hand freewheel unit). Right hand freewheel unit bearings replaced.
November 1982	–	Gearbox re-fitted in G–ASNL at 1,622 hours since overhaul, 10,649 hours total, and continued in service on NL until the time of the accident at 2,003 hours since overhaul, 11,769 hours total.

The repairs to the input casing referred to above were carried out by Jetwain Ltd, a company specialising in high precision re-machining of aircraft components. The procedures adopted for the repair of the subject input casing had been established previously, after problems had been encountered on the first of the S61 input casings submitted by British Airways for repair. At that time, it was found that the input casings suffered distortion during service, which left a significant twist in the casing, and resulted in the location of the gear shaft bearing liners migrating out of limits by significant margins. Following consultations between British Airways Helicopters and Sikorsky, it was concluded that concentricity and squareness of the liners was the critical factor, and providing that this criterian could be met re-machining of the bearing liner locations on the distorted casings to bring them within limits, was deemed acceptable.

1.6.4.4 No. 1 spur gear (Serial No. 776)

The spur gear fitted to the lefthand freewheel unit on G–ASNL at the time of the accident, Serial number 776, was originally fitted in the lefthand free wheel unit of gearbox Serial number 1003 as delivered to British Airways Helicopters in 1975 on aircraft Serial number 61747. Although the spur gear is a serialised item, it is not a lifed component and it has not therefore been possible to trace precisely the component's history.

1.6.4.5 Overhaul period and summary

The maintenance records do not indicate any history of significant problems associated with the main gearbox, or any other problem which might be considered relevant to the gearbox failure. The technical log entry for a flight carried out some 48 hours prior to the accident makes reference to an observed oil leak on the port side of the aircraft, which was rectified by the fitment of a new main gearbox filter seal. No reference was made to any replacement or replenishment of the main transmission oil associated with this rectification.

Several references were found in the technical log on the subject of spurious illumination of the engine fire warning light. On 3 March 1983 an entry was made in the technical log indicating that both fire warning lights had illuminated at 70% rpm after start-up. The aircraft was subsequently cleared for flight but there was no apparent rectification of the spurious fire warning indications, nor was there any indication that a positive reason had been found for the problem.

1.7 Meteorological information

An aftercast of the weather for the area and the time of ditching prepared by the Meteorological Office, Bracknell, gave the following information:

General situation:	At 1200 hrs an anticyclone was centred at about 54° N 01° E with a ridge of high pressure extending northwards along the meridian. By 1800 hrs this ridge axis lay along a line 62° N 05° E to 55° N 02° E
Winds:	Surface 180° (T) at 10 knots 2,000 feet 190° (T) at 10 knots 5,000 feet 240° (T) at 15 knots
Visibility:	Greater than 20 kilometres
Cloud:	Scattered thin strato-cumulus at around 4,000 feet. Broken to overcast alto-cumulus, alto-stratus 12,000 feet or above
Weather:	Nil

1.8 Aids to navigation

Not relevant.

1.9 Communications

When the problem with the main rotor gear box and No. 1 engine appeared, the commander changed frequencies from the Piper Platform to Highland Radar on 134.1 MHz and transmitted a 'Mayday' which was acknowledged by Highland Radar. At the same time the co-pilot, using the second VHF radio, passed details of the emergency to both the Piper Platform and a Tiger helicopter which was in the vicinity. 134.1 MHz was established as the communications frequency between G–ASNL, ATC and the rescue aircraft until approximately 1504 hours when all those concerned with the rescue changed to the emergency frequency 121.5 MHz. Throughout the rescue two-way communications were maintained between G–ASNL and the aircraft overhead.

1.10 Aerodrome and ground facilities

Not relevant.

1.11 Flight recorders

The aircraft was not required to be fitted with either a flight data recorder or a cockpit voice recorder and neither were fitted.

1.12 Wreckage and impact information

1.12.1 Salvage

The wreckage of G–ASNL was recovered from the sea bed by the diving support vessel 'Shearwater Aquamarine', under the supervision of the Accidents Investigation Branch.

The approximate location of the wreckage was provided by the Master of the 'Maersk Retriever', which had made the unsuccessful initial attempt to recover the helicopter shortly after its evacuation. The 'Shearwater Aquamarine' arrived on station, 58° 16.7′ north; 00° 39.7′ west, at 1742 on 13 March 1983. The sea state prevented the deployment of the ship's boat for the purposes of carrying out a search, using the specialist equipment capable of detecting the 'Underwater Location Beacon' that is attached to all helicopters operating off-shore. (It is normally necessary to operate the locator equipment away from the high background noise caused by the ship's onboard equipment and the thrusters, which formed a part of the vessel's dynamic positioning system). Initial attempts to receive signals from the helicopter's beacon by operating the locator equipment from the stern of the ship were unsuccessful, and it was evident that the high background noise with the dynamic positioning system in operation was such as to swamp any signal which may have existed. A second attempt to receive a locator beacon signal from the stern of the ship with the dynamic positioning system shut down resulted in positive contact with a locator beacon on the correct frequency of 35.5 kHz, but the pulse repetition rate was approximately two per second instead of the expected one per second. However, in the light of previous experience of recovering a helicopter from the North Sea, when a similar doubling of frequency occurred, a decision was made to proceed with the search for the signal source.

The ship was manoeuvred into a series of different positions and allowed to drift. A series of cross cuts were obtained and an initial search area defined.

Following a search of the area using a small remote control vehicle (RCV) fitted with a TV camera, during which small pieces of debris and paper from the aircraft were found, a further series of cross cuts were obtained to refine the search area. During the early hours of the 15th March increasingly large pieces of debris were found, including the airstair door. By 10.40 hours the weather had moderated sufficiently to allow a work boat to be launched and, following a series of locator equipment readings from the work boat, the main wreckage was located.

A preliminary examination of the wreckage was carried out using the RCV. The fuselage section was in one piece but the tail boom and tail rotor were missing, together with the airstair door and four of the five main rotor blades. Both undercarriage sponsons were securely attached to the fuselage and both flotation bags were deployed. The fibreglass nose fairing of the port undercarriage sponson had been broken, and approximately half of the fairing was missing. Both of the clear vision flight deck roof panels were broken and the radome was missing. The single remaining rotor blade was bent downwards through approximately 90° just inboard of the aerofoil section.

A large rupture was observed in the forward starboard quarter of the mesh section of the main rotor gearbox fairing which encloses the lower section of the rotor mast and swash plate. The edges of the fairing around the periphery of the rupture were distorted outwards in a manner suggesting that the rupture had occurred as a result of something being ejected out through the fairing from the vicinity of the main gearbox.

Upon completion of the RCV survey a pre-arranged lifting procedure was put into effect using two lifting wires; one wire from a deck mounted winch to the aircraft's belly lift attachment points and a second wire, from the ship's crane, attached to the main rotor mast. The lift was accomplished by first raising the wreckage just clear of the sea bed using the belly attachment points and then lifting on the main lift point at the rotor head so as to roll the helicopter into the upright position for the main lift. The belly lift attachment wires were kept slack during the main lifting process. The helicopter reached the surface at 1740 hours and at 1747 hours was landed safely on the deck of the support vessel. Fresh water hoses were immediately deployed to de-contaminate the wreckage, so far as possible, with particular emphasis being placed on the main gearbox and power plants.

Following the recovery of the wreckage onto the ship, the area around the ruptured main rotor gearbox fairing was examined in more detail and a hole was observed in the upper edge of the main gearbox input casing. The gearbox contents were drained into a container using the standard drain point on the starboard lower fuselage side. Examination of the container contents did not reveal the presence of any mechanical debris from the gearbox; the contents were found to be a mixture of water and magnesium corrosion material. The gearbox was re-filled with oil to the level of the input casing rupture and all exposed areas of magnesium gearbox casing, which were rapidly corroding, were sprayed with inhibitor and coated with grease.

On the basis of the known circumstances of the accident and the results of the initial examination of the main gearbox it was decided that further efforts to recover the tail boom tail rotor, and airstair door were not justified and the vessel sailed for Aberdeen, docking at 0700 hours on Wednesday 16 March.

1.12.2 *Initial examination of the wreckage*

The wreckage was initially transported to Aberdeen Airport, where the main gearbox, engines, and undercarriage sponsons were removed to facilitate transport to the AIB facility at Farnborough. During this work an interim examination of the gearbox revealed that the outer portion of the number one first stage spur gear had become detached, although the precise nature of the apparent gear break up could not be determined at that stage. No fragments of gear or other loose debris were visible through the aperture of the input casing. Deep tooth shaped imprints, evidently made by a segment of the broken gear, were observed on one of the main rotor blade pitch arms at a radial position which corresponded with the rupture in the input casing.

It was noted that the hydraulic line to the rotor brake caliper unit had fractured at the 'tee' union fitting, at the point where it is screwed into the caliper body. The fractured union had remained in position, supported by the hydraulic pipework, with only a small gap separating the fracture surfaces. There was no evidence of any mechanical damage to the union or its attached pipework and the general characteristics of the failure were indicative of fatigue.

Following the work to facilitate transport the wreckage was removed to Farnborough where the detailed examinations were conducted.

1.12.3 *Detailed examination of the wreckage*

1.12.3.1 *Aircraft – general*

The aircraft as a whole was examined for any evidence of abnormality or other features which might have had a bearing upon the gearbox failure and the events which followed.

The gearbox lubrication system mounted externally to the gearbox casing, including the oil cooler and associated pipework, was intact and displayed no evidence of leakage or abnormality.

The engine fire detection systems had been affected by the ingress of sea water, which prevented a positive assessment of their pre-accident serviceability from being made. However, there were no visible signs of damage or abnormality and all those system components which could be checked responded normally. Neither engine bay displayed any signs of fire or overheating and all plastic coated components within the bays were in a normal condition. Both engine fire extinguisher systems had discharged fully into their respective engine bays.

The aircraft was examined in some detail in those areas having a bearing on survivability of the occupants following a ditching. The results of this examination are incorporated in paragraph 1.15, which deals specifically with survival aspects.

1.12.3.2 *Main gearbox*

The external condition of the gearbox was normal except for the hole in the upper edge of the input casing, caused by the ejection of a segment of broken input gear, and corrosion caused by sea water. Further extensive corrosion of the casing and internal components, caused by sea water immersion, was found throughout the gearbox. The input casing was progressively dismantled and the input housing and cover removed from the main casing.

The No. 1 first stage reduction spur gear was found to have broken up, leaving only the hub section of the gear remaining on the shaft. A large quantity of break-up debris was found inside the input casing, including two segments of the toothed outer rim of the No. 1 spur gear, which in total comprised approximately 30% of the gear circumference, numerous shards of gear teeth from the No. 1 input pinnion, a small piece of the gear web displaying signs of fatigue and a small segment of tooth, also displaying evidence of fatigue.

No. 1 input pinnion, which meshes with the failed spur gear, had been extensively damaged as a result of the spur gear break-up and debris had also become caught between the No. 2 first stage reduction gears and between both No. 1 and No. 2 second stage gears, producing significant damage. This damage, however, had not prevented the affected No. 2 driveline gears from continuing to transmit power to the main rotor.

The No. 1 camshaft, freewheel unit and torquemeter assembly were carefully disassembled revealing further secondary damage to the shaft and its forward location bearing.

The freewheel unit was removed from the camshaft, and it was found that one of the freewheel roller cage thrust rings had been broken into six segments. However the fracture surfaces were clean with no rubbing or bruising, indicating that the fracture had not been a long term feature. The freewheel rollers, ramps, and outer race were examined microscopically for evidence of slippage or snatch. In general terms all the components were in good condition and the condition of the ramps was also well within limits, so far as surface indentation of the ramps was concerned. However, freewheel units of this type are notoriously difficult to assess visually as to their performance under load. The opportunity was taken to examine the freewheel units from an S61 which was known to have suffered a transient fall off in load transmission (freewheel slip) and these units were compared to the unit from G–ASNL. It was found that the unit which was believed to have slipped showed, under the microscope, very slight skid marks on some of the rollers. However, there were no positive indications of malfunction and although no similar marks were found on the rollers from G–ASNL, the comparative examination cannot be regarded as conclusive. A general survey of the freewheel components from other gearboxes passing through the British Airways Helicopters overhaul factory showed that the condition of the components from G–ASNL was, if anything, better than average.

The condition of the remaining input casing internal components was normal except for minor damage caused by break-up debris and salt water corrosion.

1.12.3.3 *Spur gear failure – general features*

The following pieces of the No. 1 spur gear were recovered:

(i) The hub portion, still attached to camshaft and comprising the mounting flange and the inner part of the web,

(ii) two adjacent segments of rim and outer web, which had separated from the hub and were recovered from the bottom of the input casing,

(iii) one small piece of web displaying signs of fatigue,

(iv) one small tooth segment displaying signs of fatigue.

The hub remains comprised the mounting flange together with approximately 1.5 inches wide of the conical section of the gear web. It was evident that the toothed outer rim had peeled outwards from the web producing a tear type rupture of the web, which ran circumferentially around the web at an approximately constant radius. However, at one position on the circumference, the tear line stepped inwards towards the inner bend radius of the web for about 30° of arc and then stepped back out to its original radius. A radial fracture extended inwards from a position approximately mid way along this step to the inner edge of the gear mounting flange. This fracture bore signs of fatigue growth over the outer regions with final overload of the inner portion.

There was considerable distortion evident in the web and mounting flange, consistent in its general nature with the loading which could be expected on this part of the gear during a break-up of the rim. The gear mounting bolts were also distorted by varying amounts and some were loose. This damage was also compatible with the expected loads during a rim break-up and a microscopic examination of gear retention bolts confirmed that the damage was secondary.

The two sections of gear rim found inside the input casing were adjacent sections comprising approximately 30% of the gear outer circumference: these were the only sections of rim recovered. The two sections of rim had broken apart from each other as a result of the segment being driven into the adjoining input pinion as the rim peeled back from the gear hub. This contact extensively damaged the radial fracture surface at the leading edge of the segment and caused the severe damage noted on the No. 1 input pinion.

The damaged radial fracture on the leading rim segment formed an extension of the radial fracture line noted on the hub remains, and there were signs of fatigue growth in this area.

The loaded flanks of the gear teeth on the separated rim segments were damaged as a result of gross misalignment and the consequent high local tooth contact pressures, caused by gear distortion during the break-up. This damage was clearly distinguishable from the normal tooth contact marks, produced by the polishing action of mating teeth during normal operation prior to the break-up. These polish marks were noticably uneven, taking the form of a wedge shaped pattern, indicating misalignment of the first stage input gears over a significant period of operation. (Similar uneven tooth contact marks were found on the No. 2 spur gear and were also observed on the majority of available spur gears from serviceable gearboxes).

The small fragment of web bore clear signs of fatigue and matched the short area of web fracture at the leading edge of the smaller of the two rim segments.

The small segment of tooth showing fatigue markings could not be positively fracture matched to the No. 1 spur gear. However, the physical characteristics of the fragment were incompatable with the damage suffered by the input pinnion and there is little doubt that it was originally a part of the No. 1 spur.

1.12.3.4 Metallurgical examination of failed spur gear.

Following a careful matching of the fractures in the rim and hub remains, the principle fracture leading to gear break up was found to be radial crack propagating inwards from the rim which bifurcated as it approached the outer edge of the gear mounting flange. The radial branch continued inwards towards the inside edge of the wheel, forming the radial crack observed on the hub remains. The second branch ran circumferentially around the web leading to the separation of the rim from the wheel. (For the sake of brevity the cracks have been described as either radial or circumferential; the actual direction of the fractures changed significantly whilst still falling within these general definitions. Appendix 5 Figures 1 and 2 clearly indicate the precise fracture directions).

Examination of the fractures was considerably frustrated by the extent of mechanical damage affecting the outer regions of fracture 'a', Figure 2. There were clear indications of stable fatigue crack growth extending into the web from region 'A' Figure 4, at the junction of the outer web and rim, to region 'B'. Evidence of fatigue growth over the innermost part of the inclined web region of the smaller segment, region 'C', was obscured by mechanical damage, but the nature of the adjacent undamaged fatigue area 'B' was such as to suggest strongly that the fatigue had extended inwards through the damaged portion of web into region 'C'. This fatigue growth clearly continued inwards through the web and into the radial branch of the crack (fracture 'b' Figure 2) towards the mounting flange. The outer part of fracture 'b' displayed course fatigue-like markings which suggested a low cycle extension of the more recognisable high cycle fatigue in the outer web. In contrast, the inner half of this crack, which traversed the flat mounting flange and its associated bolt hole, exhibited signs of extensive plastic deformation before fracture, and considerable bruising of the fracture surfaces. The extent of the plastic deformation was such as to prevent the fracture surfaces of the outer part of the crack from being brought together, and it was clear that this part of the failure was caused by overload prior to the final gear break-up.

The circumferential branch of the primary crack, fracture 'c' Figure 2, turned outwards at point 'D' midway across the inclined web before turning to run circumferentially around the whole gear, leading to separation of the outer web and rim. The initial regions of this branch exhibited very coarse markings which suggested that the crack had propagated as a result of very high cyclic strain loading conditions; heavy rubbing and bruising of the fracture surfaces in this region indicated significant relative movement of these surfaces during the cyclic loading prior to final separation of the rim from the hub. The fatigue-like features evident in the initial region of this branch continued for approximately 4 inches from the point of bifurcation, beyond which the fracture exhibited features consistent with a fast tear type rupture of the web, in tension and shear. It was not possible to make any quantitative assessment of the rates of fatigue growth associated with these cracks, nor the number of load cycles involved.

The fracture at the junction of the two rim segments, fracture 'd' Figure 1, and at the trailing edge of the larger segment at fracture 'e', occurred as a result of bending loads arising from end loading of the gear segment whilst still attached at its trailing edge. Severe bruising and damage to the fracture surfaces 'a' at the leading edge of the segments suggest that this end loading was the result of the leading edge striking the input pinion whilst being driven with the segment peeled back from the hub.

Short cracks were found in the roots of seven teeth, three in the short rim segment and four in the longer segment. The cracks were typically 0.8 inches length and confined to the root ends in the vicinity of the over stressing fracture 'd', separating the two rim segments. Plastic deformation was observed at the outer surface of these small cracks which, after a sample crack had been opened for examination, was found to be caused by the formation of a small shear lip. No fatigue damage was present and these small cracks were clearly caused by the bending strain associated with the major overload fracture separating the two rim segments.

A number of teeth on the larger rim segment contained transverse cracks, some of which were associated with other cracks running longitudinally along the lower part of the tooth flank. A sample crack was broken open and it was found that the crack exhibited features consistent with growth as a result of a stress corrosion mechanism. No fatigue indications were present. The distribution of these cracks, their general characteristics, and the absence of fatigue growth suggested strongly that they were not present prior to the gear break-up. They appeared to be post accident features brought about by the action of sea water, or possibly the post accident treatment in the laboratory of some surfaces with an inhibited acid to remove corrosion, in combination with locked-in stresses caused by the distortion of the gear segment during the break up.

A number of teeth were sectioned and the etched sections examined. The case hardened layer and core structure were visible and a satisfactory hardened and tempered micro-structure was evident. Hardness tests on a sectioned gear tooth showed that the total core depth was approximately 0.06 inches and that the hardness values were within expectations.

Numerous small oxide filled pits were evident in the roots and lower flanks of the teeth, the largest of which was 0.00085 inches deep. The appearance of the pits suggested that they were present prior to the accident and were not a result of sea water immersion. No evidence of fatigue crack growth was found from any of the pits examined in the sectioned specimens.

Examination of the small fragments containing fatigue damage did not contribute significantly to an understanding of the primary fatigue crack initiation. The web fragment displayed a pattern of fatigue growth strikingly similar to that observed on the section of web attached to the smaller rim segment, region 'B' Figure 4, and it is likely that this fragment contained the other half of that fracture. The tooth fragment displayed clear signs of fatigue crack growth in a plane approximately parallel with the driving flank of the tooth, growing along the unloaded flank of the tooth, (see Appendix 5 Figures 5 and 5a). Because of the extent of the damage sustained by the gear, it was not possible to match this fragment to the gear rim and, consequently, no positive evidence could be found to locate the tooth circumferentially on the gear. It was evident, however, that the fragment was not from an end of a tooth, and the polish marks on the loaded flank indicated that it was from somewhere within the centre 50% of the tooth width. It was considered significant that the plane of the fracture was radially inwards without any indications of the plane turning to undercut the tooth in the manner associated with typical scallop type fatigue failures.

To summarise the results of the metallurgical examination, it was found that failure of the gear occurred after the growth of a stable, high-cycle fatigue crack which probably originated in the vicinity of a tooth flank or root. This fatigue crack grew inwards through the rim and web before bifurcating, with one branch continuing inwards through the web and the other branch running circumferentially around the web. The radial branch terminated in an overload fracture of the hub mounting flange. The circumferential branch propagated as an increasingly rapid fatigue fracture developing, eventually, into a fast rupture leading to detachment of the gear rim and subsequent break up of the outer part of the gear. No evidence of the primary fatigue crack origin could be found because of subsequent damage. A number of corrosion pits were observed, but none of these pits had fatigue cracks growing from them. A tooth fragment, possibly from the vicinity of the primary fracture, was found with a fatigue fracture in a plane approximately along the tooth flank and radially inwards. The available evidence indicated that the gear met the design specification for material and heat treatment.

1.12.3.5 Dimensional accuracy

During the course of the investigation it became apparent that the majority of commercial S61 main gearboxes had undergone one or more repairs to the input casing, which have the potential to affect the alignment of the input pinion and spur gears. Further dimensional inaccuracies affecting the positioning of the camshafts and input shafts were known to occur because of permanent distortion of the input casing arising from loads in service.

In order to assess the magnitude of any such effects on the main gearbox from G–ASNL, the positions of the input shaft bearings and camshaft bearings were measured in terms of X and Y co-ordinates relative to reference axes on the housing. The manufacturing limits were ± 0.001 inches in the X (horizontal) and Y (vertical) directions. Up to the time of the accident no alternative limits had been defined for gearboxes which have been in service. The measurements were carried out using a three axes measuring machine equipped with a sensing probe driving a micro computer, which resolved the x, y and z co-ordinate positions with respect to machine reference axes to X, Y and Z co-ordinate positions with respect to reference axes on the housing. The overall accuracy of measurement was assessed as ± .0005 inches.

It was found that there was considerable variation in the accuracy of location of the bearings in the housing and cover. Four of the system co-ordinate positions were within limits but the remainder varied from between – 0.001 inches to + 0.0106 inches outside limits. Full details and dimensions are listed in Appendix 6 together with corresponding data from measurements carried out on a number of nominally serviceable input casings.

1.13 Medical and pathological examination

Not applicable.

1.14 Fire

Not applicable.

1.15 Survival aspects

1.15.1 Rescue

Following the transmission of the distress message a non-rescue Aerospatiale (Tiger) AS332 helicopter diverted to intercept G–ASNL (NL). An RAF Nimrod also diverted to the scene and established the position of the helicopter from its transponder. This aircraft became "on-scene commander" but was unable to descend below Flight Level (FL) 170 because of its fuel state. However, the Tiger, having made visual contact with NL, accompanied the helicopter until it ditched and then remained in the vicinity. By doing so it was able to provide a valuable link between the ditched helicopter and the rescue services.

As soon as the distress call was received, three rescue helicopters were dispatched from the shore. An RAF Sea King took off from Lossiemouth and two Sikorsky S-61's, one belonging to British Airways Helicopters and the other to Bristow Helicopters, departed from Aberdeen. The Sea King and the Bristow S-61 gave its estimate as 1600 hrs. While these helicopters were en-route a second Nimrod arrived in the area, assumed control as incident commander, and descended to low level.

The Sea King and the British Airways S-61 arrived overhead NL at approximately the same time. Because of problems with NL's liferafts it was decided to lower one from the British Airways S-61. However, the downwash from the helicopter created problems for the ditched aircraft and after discussions it was agreed that the Sea King would lower its own liferaft on a long line. The passengers and crew of NL were loaded into this liferaft in two batches, and were then winched into the Sea King. On completion of the rescue the Sea King accompanied by the British Airways S-61 proceeded to Aberdeen, where they landed at approximately 1740 hrs.

1.15.2 Emergency equipment

After the helicopter had alighted on the sea the landing gear was lowered, the flotation gear deployed, and the sea anchor streamed. The sea anchor did not immediately jettison when activated by the co-pilot and its cover had to be removed by hand after which it fell into the water. Although the commander decided not to carry out an immediate evacuation since the aircraft appeared to be in a stable situation after the second engine had been shut down, he decided to prepare the rear liferaft so that it would be ready when required. The co-pilot operated the flight deck jettison switch for the rear left emergency exit but the door remained in its aperture. He therefore went aft in the cabin, found that the pins had withdrawn and pushed the door free. He then inflated the rear liferaft and secured it to the aircraft cleat so that it floated close to the emergency exit.

Some while later, one of the passengers drew the co-pilot's attention to the condition of the liferaft, which appeared to be deflating. It had been punctured apparently after coming into contact with part of the aircraft's structure, believed to be the VOR aerial, having floated aft of the door aperture in the slack in its securing line.

It was decided to prepare the front liferaft and this was launched through the cargo door exit at the front of the cabin. In spite of great care it inflated in the inverted position and all efforts to right it from the doorway were unsuccessful. A small puncture then appeared in the footstep in the lower chamber after it had come into contact with the lower cargo door rail. Unfortunately the leak stoppers were contained in the emergency pack which was secured to the floor of the inverted liferaft, and therefore inaccessible. While an attempt was made to obtain the stoppers from the deflated rear liferaft a large wave swept the front raft against the cargo door rail, and the upper chamber received a six to nine inch tear in the fabric. Both liferafts were thus rendered unusable by damage sustained from coming into contact with the aircraft's structure.

1.16 Tests and research

1.16.1 Main rotor gearbox, input casing measurements:

In order to assess the possible significance of the dimensional inaccuracies affecting the positioning of the camshaft and input shaft support bearings on G–ASNL, measurements were made of nominally serviceable input casings passing through the overhaul facility at BAH Gatwick. Similar measurements were made by the manufacturer of input casings passing through their overhaul facility in the USA. A total of 13 input casings were measured, and a summary of the data is tabulated in Appendix 6.

1.16.2 Assessment of measurements programme results

The bearing position data, whilst it indicated the extent to which dimensional accuracy of the bearing locations had been lost, did not by itself give any indication of the effects of these inaccuracies on the loading of the gear teeth, which is entirely dependent upon the relative alignment of the gear teeth at the point of meshing contact. In order to make such an assessment, it was necessary to develop a computer programme enabling the X and Y co-ordinate data to be resolved into angular misalignments of the gear shafts both in-plane and out-of-plane, and, ultimately, to a misalignment angle at the point of meshing contact on the gear tooth involute. From this angle, it was possible to calculate the expected increase in stress resulting from the misalignment. These latter calculations utilised standard data published by the American Gear Manufacturers Association and other recognised authorities on gear design.

A summary of results is tabulated in Appendix 6.

1.16.3 Sikorsky geartooth misalignment tests

In order to verify the applicability of the standardised design curves describing increase in tooth stress as a function of misalignment angle, the manufacturer carried out tests on an instrumented gear during which static loadings were applied to gears in mesh under a variety of alignment conditions, and the resulting tooth stresses recorded. It was found that the increase in tooth stress followed the predicted values within acceptable limits.

1.16.4 Chip migration tests

The possibility was considered that the failure of the spur gear was preceded by the loss of a tooth, or tooth fragment, as a result of fatigue or some other mechanism. A series of tests were carried out by the manufacturer to determine the time taken for a tooth fragment to migrate from the input casing to the scavenge filter or chip detector, where it could be expected to be found during an inspection. This work was carried out primarily as a precautionary measure by the manufacturer as a means of assessing the effectiveness of a frequent inspection, as an interim measure until the gear failure was more fully understood and long term remedial or inspection measures could be introduced.

1.17 Additional information

1.17.1 Ducane locator beacon

During the search phase of the investigation, when the Ducane beacon locator equipment was being operated from the search vessel, it was found that distinct pulses were being received which were typical of a Ducane beacon in all respects except that the frequency of the pulses was approximately 2 per second instead of the 1 per second specified. This is the second occasion when a doubling of pulsing frequency emitted by a Ducane locator beacon on a submerged helicopter has occurred during the search for wreckage. (The previous occasion was during the search for the Bell 212 registration G–BDIL in the North Sea on 14 September 1982).

Subsequent tests carried out on the beacons fitted to G–ASNL and to another S61 aircraft which had been recovered from the sea after a separate accident, showed that the pulse repetition time varied between 1.3 seconds and 0.5 seconds.

In the light of these experiences within a relatively short time interval, personnel carrying out a wreckage search in similar conditions should be alert to the possibility of pulsing frequencies which may be significantly different from the nominal one pulse per second.

1.17.2 Previous instances of spur gear failure

Failure of the spur gear rim is known to have occurred previously on four occasions, and tooth failures have been recorded in at least four further cases. In all cases the fractures had occurred within a relatively short time since installation of the main gearbox.

Detailed information was available in the case of one of the rim failures only, but poor tooth contact patterns, indicating poor gear alignment, were noted in three of the four rim failure cases and the fourth rim failure is believed to have been associated with corrosion pits on the teeth. Corrosion pitting was also observed in two of the tooth failure cases, and another was associated with failure of the input pinion sleeve bearing.

The single case of rim failure for which there is information available, occurred on a US naval aircraft at Pensacola, USA, approximately 16 hours after main gearbox overhaul. The failed gear was examined by both the US Navy and Sikorsky, and the conclusions were that the gear had fractured as a result of fatigue crack initiation and propagation from an origin at the surface in a tooth root. Several secondary fatigue cracks from similar surface origins were also noted around the wheel, at positions relating to the nodal distribution produced by a 7th order diametral mode resonance of the wheel. Unusual tooth wear patterns were noted indicating an unusually deep tooth engagement. The wheel had been constructed in accordance with drawing requirements.

1.17.3 *Bristow Helicopters/British North Sea Oil Corporation – Sikorsky S61N ditching trial*

In June 1982 Bristow Helicopters in conjunction with the British North Sea Oil Corporation conducted a "Helicopter Evacuation Trial" using a Sikorsky S61N helicopter in a controlled ditching on Meikle Loch near Aberdeen. The purpose of the trial was to produce a flight safety film on helicopter ditching procedures for off-shore oil workers.

During this trial the crew experienced serious difficulties during liferaft deployment in the prevailing 15/20 knot wind. An 18 man liferaft was deployed from the forward starboard door and, although it started to inflate normally, the wind picked up the windward side of the partly inflated liferaft and rolled it into a semi inverted position over the starboard sponson. The crew entered the water and, with considerable difficulty, were able to right the liferaft but the wind then caused it to drift aft where it came into contact with a VOR aerial mounted on the lower surface of the tail boom and both flotation chambers were ruptured and the liferaft was rendered unusable. Following the ditching of G–ASNL where a liferaft was ruptured in similar circumstances a copy of the Bristow/BNOC video was passed to the CAA and all VOR aerials were subsequently modified.

2. Analysis

2.1 The decision to ditch

Shortly after departing the rig the crew of G–ASNL were presented with an obvious mechanical failure, which manifest itself aurally and by the run-down of the No 1 engine. The subsequent vibration and associated noise, together with the illumination of the transmission oil caption, were indications of a continuing abnormality which the crew reasonably associated with the main transmission. The absence of low frequency vibration or control problems allowed the crew to assess the situation properly, carry out the number one engine shut down drills, transmit a distress message on 134.1.MHz advising the Piper 'A' of their situation, and to initiate a precautionary descent.

During the descent, the crew were able to further assess the situation. The vibration and noise were still present although of a slightly reduced magnitude due, presumably, to the reduced power and airspeed. The number two engine indications were observed to be normal but the transmission emergency lubrication system was 'on', the oil pressure had dropped to 30 psi (from the normal 50 psi) and the oil temperature was slowly rising. The aircraft continued to handle satisfactorily however, and the crew had the knowledge that a Bristow Helicopters AS332L was in attendance and could keep a watching brief, although it had no rescue capability as such. Having descended to about 500 feet, the crew found that the noise and vibration were still present, the oil temperature was still rising and the transmission oil pressure was below 30 psi and fluctuating occasionally. At this stage the crew faced a difficult decision. There was no possibility of returning to the Claymore Platform because a landing with one engine out, at the aircraft weight in question, would have required a run-on landing. Similar restrictions applied to all other platforms in the area and the available options were, therefore, to make a controlled ditching before the transmission malfunction became more serious, or to continue the flight in the hope that the transmission would not deteriorate further. In making their decision, the crew were undoubtedly influenced by the calm sea state, the fact that their position and situation was known, and that they were in company with another helicopter, which could carry out any co-ordination with rescue agencies which might prove necessary. There can be no doubt that the crew's decision to ditch the aircraft was a correct one in the circumstances and this has been borne out by subsequent examination of the gearbox.

2.2 Post ditching actions

It is clear that the crew made a skilful single engine ditching under power and that proper passenger briefings had been carried out. Once on the water the aircraft was found to be stable with the aircraft emergency flotation equipment deployed and main rotor still being driven. Evidently the failure of the sea anchor cover to deploy automatically did not prevent a satisfactory manual deployment, and in general terms the crew had the situation well in hand.

The illumination of the warning lamps associated with both number one and number two engine fire warning systems required that the engine shut-down and fire drills should be carried out, and this the crew did promptly. The absence of rotor braking effect clearly resulted from the fatigue fracture of the hydraulic brake supply pipe at the disc caliper unit, presumably as a result of the vibration associated with the primary mechanical failure. The reason for the double fire warning however is less clear.

The fire warning system was examined in some detail after the accident and, although corrosion and the ingress of sea water into certain components prevented a positive assessment of the system serviceability, no indications of abnormality were found. The possibility that hot oil being ejected from the main gearbox input casing had triggered the fire wire system was considered, but, given the layout of the fire wire system in the engine bays, which are forward of the fire walls separating the gearbox and engine bays, and the bias of the oil spray to starboard, this possibility is considered remote. It is worthy of note that this helicopter had a history of spurious fire warnings in the months preceding the accident. On 3 March 1983, a spurious double fire warning indication occurred after start-up. There were no indications in the technical log that the reason for the problem had been identified, but the aircraft was nevertheless returned to service. In the absence of any fire damage affecting either the engine or engine bay, it is considered quite feasible that the fire warnings following the ditching were another manifestation of this intermittent fault in the fire detection system.

2.3 Evacuation aspects

Once upon the water the subsequent attempts to deploy the liferafts met with a total lack of success. This was despite the almost ideal sea state, the undamaged aircraft structure and flotation systems, and the absence of injuries among passengers accustomed to working in a hazardous environment.

It has become increasingly clear as a result of actual ditching experience in the North Sea that the expectation of a successful evacuation into liferafts carried by the aircraft is low, even in good conditions. The trials carried out by Bristow Helicopters on their Sikorsky S61 aircraft in 1982 vividly illustrate the type of problem which may be expected, and which almost certainly was experienced by the crew of G–ASNL in the case of the aft liferaft. The punctures of both liferafts from G–ASNL occurred primarily because the liferafts became fouled against sharp obstructions on or close to the water line.

In this case the deflation of both liferafts did not affect the successful evacuation and rescue of the helicopter's occupants. However in other circumstances this could have been crucial to the survival of the passengers and crew. In the light of this experience, all helicopters currently in service should be critically examined and positive steps taken to remove, modify, or fair-in all obstructions which the liferafts may contact whilst in the water. It would also seem prudent that launch and restraint procedures be individually developed for each helicopter type so as to minimise the possibility of inverted inflation and reduce the risk of liferafts being blown into unavoidable obstructions, such as the tail rotor, or under the tail boom. The value of trials to actually launch liferafts from a specific helicopter type in the water was clearly demonstrated by the Bristow Helicopters trial, and it is suggested that such methods should be adopted wherever possible.

It is recognised that ditchings will often result in the helicopter rapidly turning over, in which circumstances liferaft deployment becomes an entirely different problem. A discussion of these aspects is not however, appropriate to this report beyond a recognition that the problems of evacuation generally are extremely complex and are likely to be satisfactory only when the helicopters are designed from the outset with these aspects in mind. The readers attention is drawn to the evacuation aspects covered in the AIB report Nos 11/71, 8/78 and 10/82 on earlier helicopter ditchings in the North Sea.

In the interim, until the mechanics of evacuation improve, the interests of flight safety would be well served by making available to helicopter crews realistic information about evacuation expectations in the variety of conditions found in the North Sea, so that a proper assessment can be made of the relative risks of continuing the flight versus ditching.

2.4 The spur gear failure

2.4.1 General characteristics

Although the greater part of the gear rim was ejected through the input casing wall and was not recovered, sufficient remained of the gear to enable the general characteristics of the break up to be determined.

The metallurgical examination of the fracture surfaces, together with a general examination of the patterns of distortion and fracture, leave no doubt that the break up started with a stable, high cycle fatigue crack growing radially inwards through the rim of the wheel. However, the precise origin of this crack could not be determined because of the extent of the damage suffered by this segment of the rim during the latter stages of the break up. As the crack reached the inner region of the web and started to traverse the bend radius between the web and the mounting flange, the crack bifurcated with one branch turning radially inwards and the other running circumferentially. In the initial regions of both branches the mechanism of crack growth was fatigue, although there were indications by this stage that the growth was associated with high magnitude cyclic strain. The residual strength of the inner part of the mounting flange was eventually reduced to the point where the remaining section of the flange failed. There are clear signs that the circumferential branch of the crack continued to grow with increasingly large strain reversals developing, eventually, into a rapid tear type rupture running around the gear leading to the total separation of the rim. There is little doubt that the separation of the two remaining rim segments occurred as a result of their being driven into the input pinion. Before an assessment can be made of the general break-up sequence, it is necessary to consider the behaviour of the wheel in carrying the loads imposed upon it.

The S61 spur gear is unusual in having a steeply cranked web. As a consequence, the gear depends to an unusual degree upon the integrity of the rim to react the inwards component of tooth loading and the centrifugal loading of the rim, which is largely reacted by circumferential, or 'hoop' stresses, and by shear stresses in the cylindrical rim.

If for any reason the crack grows through the rim parallel with a tooth, then the integrity of the rim is lost so far as hoop and local shear stresses are concerned, and the web will be subjected to in-plane bending about a radial axis.

As the wheel rotates and tooth loading is repeatedly superimposed upon the quasi-static centrifugal loading, the resulting cyclic load will tend to start a radial crack growing through the web. As the radial crack extends into the web, the increasing flexure of the rim will produce additional in-plane bending of the web about a circumferential axis, tending to turn the crack circumferentially. It can be seen that, following the initial rim fracture, the break-up of the gear followed broadly this pattern, and it would therefore appear that the overall fracture characteristics of the gear were a logical consequence of an initial fracture through the rim.

2.4.2 *The fatigue crack propagation*

Whilst the failure sequence following the rim fracture can be seen to follow a predictable path, the absence of undamaged fatigue surfaces from the origin region of the rim fracture make a discussion of this aspect of the failure much more speculative. Nevertheless, certain conclusions can reasonably be drawn, based upon a consideration of the available data.

The nature and direction of the undamaged fracture region in the outer web indicates a stable, high cycle fatigue crack growing inwards. It follows that for the crack to become established and progress inwards in this manner, it must have started further out in the rim. The crack growth direction is not compatible with initiation from the inner circumference of the rim, nor from the extreme outer edge of the web at its junction with the rim. It therefore appears that the crack must have started somewhere in the outer circumference of the rim, either in the root or flank of a tooth or, possibly, from one side of the rim.

Many cracks were found in the rim but these, upon further examination, proved to be a symptom of the break-up rather than a part of the causal mechanism. The only evidence of fatigue found in material from the outermost regions of a gear wheel was that found in the tooth fragment, which exhibited fatigue growth in a radial transverse plane. Whilst this fragment cannot positively be identified as having come from the spur gear, the characteristics of the other fracture sufaces and the general appearance of the fragment are more compatible with the spur gear than with the pinion. However, although the fragment probably originated in the spur gear there is no way of knowing its circumferential location relative to the primary rim fracture, nor is there any certainty that it formed part of the initial fatigue mechanism which led eventually to the rim fracture: it may have been caused by unusually high tooth loadings resulting from distortions of the gear wheel as the fracture developed. With so little positive evidence of the nature of the origin region it is necessary to consider all the modes of failure which might begin with fatigue fracture in the outer rim of the wheel, and compare features associated with those fracture modes with the known facts in the case of G–ASNL.

Historically, gear failures leading to complete break up of the gear are not as common as those which give rise to the loss of a tooth or tooth fragment. Fatigue cracks beginning near a tooth root often tend to grow under the tooth, leading eventually to separation of the tooth, or part of the tooth, from the rest of the wheel. In such circumstances, the tooth loss is unlikely to produce any immediate external symptoms. However, the loss of a tooth has the potential to set up a resonance in the wheel. In the case of the S61 spur gear wheel, the manufacturers estimate that such a condition could occur and that the most probable reasonance mode would be a seventh order harmonic, giving antenodes at intervals of 13.7 tooth pitches around the gear. On a previous failure of an S61 spur gear, which the manufacturers examined (Pensecola USA) there were indications that this had occurred, with teeth missing or separated at tooth pitch intervals of 13, 26, 28 and 29 around the gear. This did indeed closely match the 13.7 tooth pitch multiples of the antenodes, and it would appear that in that case the initial tooth loss set up a resonance which led to the loss of further teeth at the antenodes, and from these sites fatigue cracks grew into the rim.

In the case of G–ASNL, although the sizes of the two remaining sections of rim (24 teeth and 10 teeth) appear superficially to have some similarity to the 13.7 or 2 x 13.7 tooth spacing associated with a seventh order resonance, the segments displayed fatigue characteristics only in the primary fracture zone; all other fractures resulted from overload during the gear break-up. The rim remains from G–ASNL must, therefore, be regarded as part of a single segment of unknown size, but at least greater than 34 tooth pitches in length, on which all teeth were present. Had any teeth become separated from the segments of rim which were not recovered, as a result of fatigue prior to the main fracture propagating through the rim, one might reasonably expect these to have fallen to the bottom of the input casing in the same way that the large amount of pinion gear debris did during the subsequent gear break-up. No tooth fragments were recovered which exhibited fatigue except for the single fragment with the fatigue fracture lying in the radial plane, rather than the circumferential plane associated with the 'scallop' type failures which usually precede tooth loss. Given that the only opportunity for any fatigued fragments to have become lost was whilst the aircraft was inverted on the sea bed, and the fact that all the remaining debris appears to have remained inside the gearbox casing and was recovered successfully later, it would seem that the likelihood of a tooth fragment which detached as a result of fatigue becoming lost is remote.

Further, had the original fracture resulted in the loss of a tooth, which subsequently set up a resonance, then one might expect subsidiary tooth separations to have occurred, as demonstrated by the Pensecola spur gear failure, leaving a number of separated teeth to be recovered during the examination of the gearbox. The probability of all such teeth becoming selectively lost is so remote as to rule out multiple tooth loss as a feature of the failure mode on G–ASNL.

Whilst there is insufficient evidence to reach a positive conclusion as to the nature of the original fatigue crack propagation characteristics, there is complete lack of evidence from the wreckage in support of a mode of failure involving an initial tooth separation followed by resonance and rim fatigue. What little evidence there is: the size of the rim segment in relation to the model distribution, the lack of any evidence of fatigue cracks at other circumferential positions around the wheel, the lack of separated teeth bearing signs of scallop type fatigue failures and the orientation of the fracture in the only tooth fragment displaying signs of fatigue, all point towards an initial fatigue fracture at a tooth which grew radially inwards through the rim directly.

The reason for the crack initiating remains uncertain. One of the most puzzling features is the very long time, in terms of load cycles on the gear that the gearbox had been running since it was installed. Bearing in mind that ten hours of running time at 8.100 rpm produces 4.86×10^6 load cycles on the gear, the installed time of 379 hrs corresponds to about 1.8 x 10^8 load cycles, which would normally be considered, for all practical purposes, an infinite life. In this respect the failure of this gear was different from the other known instances of spur gear failure, all of which occurred within a relatively short time interval from gearbox installation. The possibility that mechanical damage during re-build or incorrect assembly led to fatigue initiation does not, therefore, seem to be a likely candidate as a fatigue initiating mechanism in the case of G–ASNL. In the light of this argument, the possibility that incorrect gear alignment led to abnormally high tooth operating stresses was considered in detail.

2.4.3 *Factors affecting spur gear loading*

It was noted that the tooth contact pattern on the failed gear was wedge-shaped, indicating clearly that the gear teeth were not meshing to produce a line contact along the tooth, but were loading one end of the tooth more than the other. However, the failed gear was not untypical and examination of a random selection of gears showed that most S61 spur gears displayed similar signs of uneven loading, and many were subjectively assessed as being more severely affected than the failed gear. The consequences of incorrect alignment of the gears, especially the 'out-of-plane' component of shaft alignment, are significant. The industry's standard design data show that, in broad terms, a mis-alignment of the gear teeth of 0.001 inches per inch of tooth length at the meshing line will produce a tooth stress increase in the order of 30%. It is clear therefore, that uneven tooth loading has the potential to dramatically increase stress levels, possibly leading to a fatigue failure of a tooth directly, or, under less severe misalignment conditions, to reduce the fatigue reserves.

The alignment of the teeth is controlled by a range of factors, most of which, for example casing, shaft and gear stiffnesses, could be expected to be of similar magnititude across the fleet. The absence of widespread fatigue failures suggest, therefore, that any stress increases resulting from mis-alignment caused by elastic strain of the gearbox components under load do not by themselves, raise the operating stress levels above the fatigue limit.

There are however, other conditions that could produce a sudden increase in tooth loading sufficient to initiate a fatigue crack.

The loss of gear shaft support caused by a bearing failure is one such mechanism. In this case however, the damage sustained by the number 1 camshaft and its bearing was shown to be of a secondary nature as a direct result of the gear failure and not the initiating factor. Free wheel unit slip and snatch is another mechanism whereby high stresses could be imparted to the gear teeth. This hypothesis was examined during the detailed examination of the gearbox. The number 1 freewheel unit showed no evidence of the kind which is sometimes seen after free-wheel unit slip has occurred in service, and although these comparative examinations cannot be regarded as conclusive, the freewheel unit components were found to be in better than average condition and there was no recorded history of any transient fall off in load transmission on G–ASNL.

Changes in the location of the gearshaft bearings, brought about by permanent distortion of the input casings and by the effects of repairs and re-furbishment of the bearing liners and bearing bores, are sources of tooth-alignment error which are likely to be more random in their effects upon the fleet as a whole, and must therefore be examined as possible factors contributing to the fatigue initiation process.

The results of the measurements carried out on the input casing of G–ASNL showed that the positions of the bearings which carry the input pinions and camshafts were, with the exception of the number one camshaft bearing in the housing, significantly outside the manufacturer's limits of ±0.001 inches in the X and Y axes. However, the magnitude of these position errors, which fell within the range of 0.0001 inches to 0.011 inches were not untypical of those found during corresponding measurements made on a sample of 12 gearboxes, drawn from overhaul facilities in the UK and the USA. Although the errors found in the locations of the bearings appears at first glance to be significant, the magnitude of the position errors alone does not indicate accurately the magnitude of the increases in tooth stress which result; the extent to which they produce misalignment depends upon whether they combine adversely or whether the errors tend to cancel each other.

In the case of the failed gear on G–ANSL, the post-accident measurements of bearing locations indicated a stress increase of 24% at the gear tooth. This compares favourably with the sample average of 28%, and was significantly better than the sample maximum of 64%. It is also considered significant that the No 2 spur gear on G–ANSL would have been operating with a calculated 36% increase in stress.

Whilst the data sample is too small to provide a definitive assessment of dimension error induced stresses for the S61 fleet as a whole, there are clear indications that the failed No 1 gear on G–ASNL was less severely affected than the intact No 2 gear, and was probably no worse than the fleet average. It is also considered to be significant that a stress increase of 31% can be generated by bearings located within the manufacturing tolerances, but with the tolerances stacked adversely. With bearing location errors falling into a random scatter within the 0.001 inches tolerance band, it would be reasonable to expect tooth stress increases of up to 30% above nominal in a significant number of gearboxes coming off the production line. If stress increases of this magnitude, which would be similar to that of the failed gear, are sufficient alone to produce a fatigue failure then one would expect a history of such failures. The absence of such a record of failure is a clear indication that the dimension induced stress suffered by the subject spur gear was not, by itself, sufficient to have triggered the fatigue failure.

Although the increase in stress caused by the dimension errors is unlikely to have been the sole cause of a fatigue failure in the rim, it nevertheless played a part in the failure sequence, by reducing the fatigue reserves, and thus making the gear more susceptible to the influences of other stress raising features which may have arisen in service. Such features include corrosion pits, and mechanical damage caused by foreign objects, or wear or by shock loading. Any one of these features could have occurred in this case. Corrosion pits were found, although none had cracks growing from them; it is possible that foreign objects were introduced at the time the main gearbox oil seal was replaced and, presumably, the gearbox topped up with oil; micro pitting was observed on the gear teeth which is known to initiate fatigue cracks in some circumstances; and lastly, the possibility of a freewheel snatch could not be positively ruled out. Because of the secondary damage in the origin region these possibilities cannot be pursued further without speculation to an unwarranted degree.

2.4.4 *The spur gear failure – summary*

To summarise the analysis of the gear failure it has been possible to conclude with reasonable confidence that the failure occurred as a result of a fatigue fracture, which initiated in the vicinity of a tooth, propagating inwards through the rim and web of the wheel. This fracture bifurcated into radial and circumferential branches, both of which developed into overload fractures leading to the break-up of the wheel. The wheel break-up led to substantial damage to the input casing and its internal components. A large segment containing some 60% of the total toothed rim of the gear was ejected through the input casing, damaging one of the main rotor blade pitch arms as it passed through the main rotor disc.

It has not been possible to positively identify the cause of the initial fatigue crack. However, several potential initiating factors have been demonstrated to be unlikely causes of the failure on G–ASNL. In particular, the possibilities of bearing failure, incorrect assembly, material deficiencies, and freewheel malfunctions have been ruled out. It is not thought likely that the initial fatigue fracture resulted in tooth separation, leading to resonance of the gear and consequent rim fracture in this case.

It is considered that the uneven loading of the gear teeth, caused by the combination of elastic strain under load and permanent deformation of the input casing, whilst not sufficient by themselves to initiate a fatigue crack, could appreciably reduce the fatigue margins. The addition of some other factor, for example foreign object damage or the in-service developments of corrosion pits, could however, in combination with the mis-alignment, raise the gear tooth stress level above the fatigue limit. Because of the extremely rapid accumulation of damage cycles, such a rise would not need to be into the high stress regions of the fatigue damage regime for a failure to occur.

The relatively small number of failures involving the spur gear up to the present time suggest that its basic fatigue reserves are good. However, the problems of mis-alignment inherent in the design of the input casing reduce the reserves unnecessarily. By introducing on military variants a gear with a small helix correction, sufficient to correct the alignment errors typically encountered on civilian S61 input gears, the manufacturer appears to have recognised that this problem existed long before the accident to G–ASNL. It is difficult to understand why similar steps were not taken in respect of the gears fitted to civil registered aircraft.

It would seem prudent therefore, in the light of this accident, that the manufacturer gives consideration to methods of improving the control of gear alignment so as to reduce the erosion of fatigue reserves that could otherwise occur. In particular, the currently accepted practice of remachining distorted input casing to bring the bearing positions back within limits is a simplistic attempt at solving a very complex problem. This procedure could, in cases of adverse tolerance stacking, exaggerate the problem it was intending to relieve and lead to an increase in gear tooth stress levels. The only valid solution is to accurately measure the bearing location errors for each input casing, calculate the resulting mis-alignment angle at the gear teeth interface, and then use a tolerance on this parameter to determine whether that individual casing is acceptable.

3. Conclusions

(a) *Findings*

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

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

(iii) The loud report and subsequent vibration experienced by the crew was caused by the disintegration of the first stage reduction, No 1 spur gear, in the main rotor gearbox.

(iv) A segment comprising approximately 60% of the outer web and rim of the spur gear was ejected through the main gearbox input casing, causing superficial damage to the gearbox fairing and to one of the main rotor blade pitch control arms.

(v) The failure of the spur gear led to a loss of drive through the No 1 transmission causing the No 1 engine to overspeed and automatically shut down.

(vi) The crew decision to alight on the water was justified in the light of the information that was available to them. The correctness of this decision has been confirmed by the technical examination.

(vii) The cause of the double fire warning indication which required the crew to shut down the No 2 engine could not be determined.

(viii) Both forward and rear liferafts were punctured and rendered unusable as a result of coming into contact with sharp projections on the hull of the aircraft.

(ix) The disintegration of the spur gear resulted from the growth of a radial fatigue crack through the rim and web of the gear which, in combination with circumferential cracking, led to rupture of the web and separation of the rim of the gear wheel.

(x) The features associated with the initiation of the fatigue crack in the root or flank of the gear tooth could not be determined due to secondary damage in the origin region.

(xi) The failed spur gear displayed signs of uneven tooth contact, indicating some degree of gear mis-alignment.

(xii) Elastic strain under load and static dimensional inaccuracies in the locations of the bearings supporting the gear shafts were identified as features which produced significant mis-alignment of the gears.

(xiii) Dimensional changes in the gear shaft bearing locations occurred in service because of permanent distortion of the input casing (creep) and as a result of re-machining the bearing locating sleeves during input casing refurbishment.

(xiv) The increase in tooth stress on the failed gear caused by static dimensional inaccuracies in the gear shaft bearing locations was approximately 25%. This figure is less than could occur as a result of an adverse combination of manufacturing tolerances on a unit within production limits.

(xv) No single loading mechanism was identified which, by itself, led to the gear failure.

(xvi) The increases in tooth operating stresses, which occurred as a result of gear tooth mis-alignment, significantly reduced the fatigue strength reserves and made the spur gear unacceptably sensitive to other stress raising features such as corrosion pitting, foreign object entrapment, and snatch loading.

(xvii) The current procedures for reclaiming distorted main rotor gearbox input casings could, in circumstances of adverse tolerance stacking, increase gear tooth stress levels.

(xviii) The maintenance records for the main gearbox did not carry separate information recording the service history of individual internal components, and the operating hours accumulated by the failed spur gear could not be determined accurately.

(xix) The main gearbox records did not provide a clear record of the unit's history, and did not contain information necessary for the determination for the repair history of the input casing.

(b) Cause

The accident was caused by the fatigue failure of a spur gear in the main rotor transmission gearbox, which resulted in a rupture of the gearbox casing and a loss of transmission lubricating oil.

Distortion of the main rotor gearbox input casing, which led to gear mis-alignment and increased spur gear stress levels was a contributory factor.

4. Safety Recommendations

It is recommended that:

4.1 The manufacturer and the certificating authority should review the procedures for reclamation of distorted main transmission input casings to ensure that gear alignment, and hence gear stress levels, are maintained within design limits.

4.2 The helix correction introduced on spur gears in military S61 helicopters to correct typical alignment errors should be introduced on the civil registered aircraft.

4.3 The UK Civil Aviation Authority should review the maintenance record keeping procedures relating to the servicing and repair of transmission components with a view to ensuring an accurate and comprehensive record of component history.

4.4 The helicopter manufacturer and the certificating authority should take steps to remove, modify, or fair-in, all sharp obstructions which deployed liferafts may contact whilst in the water.

4.5 The United Kingdom Civil Aviation Authority should consider a requirement for operators to demonstrate ditching, liferaft deployment, and evacuation on each helicopter type.

K P R Smart
Inspector of Accidents

Accidents Investigation Branch
Department of Transport

February 1986.