No: 7/90	**Ref: EW/C1109**	**Category: 2a**

Aircraft Type and Registration:	Sikorsky S-61N, G-BFFJ	
No & Type of Engines:	Two General Electric CT58-140 turboshaft engines	
Year of Manufacture:	1977	
Date and Time (UTC):	11 May 1989 at 0745 hrs	
Location:	Sumburgh Airport, Shetland Islands	
Type of Flight:	Public Transport	
Persons on Board:	Crew - 2	Passengers - 16
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Severe damage to No. 1 drive train and main gearbox	
Commander's Licence:	Airline Transport Pilot's Licence (Helicopter)	
Commander's Age:	42 years	
Commander's Total Flying Experience:	10,800 hours (of which 7,500 hours were on type)	
Information Source:	AAIB Field Investigation	

History of Flight:

The accident occurred shortly before the aircraft was due to depart Sumburgh on its first flight of the day. The planned destination was the Brent D platform in the East Shetland Basin, refuelling at the North Cormorant Platform en-route after approximately 50 minutes flying. The crew accepted the aircraft at 0720 hrs after a Pre-Departure Check had been carried out, and 16 passengers were embarked.

The two-pilot crew carried out normal Pre-Engine Start Checks and after receiving start clearance from Air Traffic Control (ATC) successively started both engines, at about 0741 hrs. They encountered no abnormalities during Pre-Rotor Engagement Checks, and approximately 1 minute after starting engines the rotors were engaged and brought up to 100% rotor speed (Nr) in the usual way. All indications remained normal until, an estimated 3-4 minutes later, the crew members became aware of an abnormal whining noise. At the time they were carrying out a standard AFCS (Automatic Flight Control System) Check, scheduled prior to first flight of the day. The noise rapidly increased in pitch and volume over an estimated period of 2-4 seconds, culminating in a loud bang. During the noise, the commander noted indications on the triple tachometer of a momentary overspeed of Engine 1 power turbine in relation to Nr, and pulled both engine speed select levers back to their shut-off positions, virtually simultaneously with the bang. He then applied the rotor brake, at around 40% Nr, while requesting his co-pilot and the crew of an adjacent S-61N helicopter, WL, to check for signs of fire, and ordered the evacuation of the passengers.

The attention of WL's crew members had also been drawn by the whining noise, and they noticed a quantity of oil running down the left side of G-BFFJ's fuselage. All of G-BFFJ's occupants disembarked without difficulty or injury, and resumed their journey in another helicopter. Many of the passengers later reported having heard a whining noise for some while before the bang, in some cases from the time of engine start. Some of these passengers were considerably closer to the main gearbox (MGB) than the crew. None of the passengers or crew reported any abnormal vibration.

The crew members reported that all indications had been normal until the whining noise. In particular, there had been no warning of MGB low oil pressure. They considered that such a warning, provided by the central warning system, would have been unmistakable.

Description of Aircraft:

The S-61N is a twin-engined helicopter of conventional layout, with engines mounted on the cabin roof forward of the MGB bay. A free power turbine in each engine drives a MGB input section, comprising a combining geartrain in a magnesium alloy housing and cover, via an input drive shaft (IDS), (Fig 1). The drive is transmitted via a Thomas flexible coupling at the forward end of the IDS and a splined input coupling at its aft end, both catering for up to 0.5 degrees of continuous axial misalignment.

The IDS rotates within an engine mounting rear support assembly (EMRSA), a static 4.5 inch diameter steel tubular assembly attached to the MGB input section cover via a magnesium alloy gimbal ring, and providing support for the aft end of the engine. Four composite pads bonded to the gimbal ring aperture are intended to contain radial excursions of the splined coupling in the event of loss of normal radial location of the aft end of the drive train. A shaft forming part of the splined coupling passes through an oil seal located in the input section cover and is splined to an input spur pinion forming the first stage of the input section drive train. The seal consists of a steel carrier with radially spring-loaded carbon segments. The IDS, couplings and input pinion all rotate at power turbine speed, nominally 18,966 rpm at 100%. The drive from each input pinion is transmitted through a spur gear and a roller/ramp input freewheel unit (IFWU) to a combining gearshaft, which drives the MGB main speed reduction epicyclic gear. Associated with each IFWU is a hydraulic servo-type torquemeter.

Each input pinion (Part No. (PN) S6135-20607-2) has an integral shaft with a forward and an aft plain journal of around 2 inches diameter, and a plain annular thrust bearing surface formed on each side of the pinion barrel. The pinion is hollow throughout, machined from a 9310 Steel Alloy (Specification AMS 6260) forging, gas carburised to produce a 15 - 30 x10^{-3} inch (thousandth of an inch) thick case hardened layer of Rockwell C 60-64 hardness. Journals are of 0.437 inch wall thickness, and are flame-plated in accordance with AMS 2435 before finish grinding.

Input pinion journals run in a forward and an aft plain 'white metal' sleeve bearing (PN S-6135-20649 and -20650 respectively), located in a bore in the cover and housing, respectively, of the input section. The cover sleeve bearing consists of a low carbon steel cylinder, with an integral flange on the inner end forming a thrust bearing surface. The bore is lined internally with a 10 - 25 x10^{-3} inch thick layer of bronze, overplated with a 0.9 - 1.1 x10^{-3} inch thick layer of lead-tin-copper alloy, which in turn is flash-plated with a protective layer of lead-tin alloy of 0.05 x10^{-3} inch maximum thickness. The bore tapers inwards by 1.8 - 2.3 x10^{-3} inches diametrically, and specified dimensions provide a diametric clearance from the journal of 5.2 - 6.7 x10^{-3} inches. A 0.172 - 0.202 inch diameter oil port in the wall of the sleeve bearing feeds into a circumferential slot formed in the bore over an arc of 120 deg in the direction of pinion rotation. Bearing axial and rotational restraint in the cover bore is by two clips bolted to the cover and registering in rebates in the bearing flange. A location pin is also provided, located in a hole in the cover and registering in a slot in the edge of the bearing flange to ensure correct bearing orientation. The aft sleeve bearing is of slightly larger diameter than the forward bearing, but is otherwise similar.

MGB lubrication and cooling is by an internal wet-sump oil system, with nominal total contents of 14 United States gallons (USG), with a main and an emergency system. The main pump is driven by an accessory gearbox section, which is driven by an electric motor/generator prior to rotor start, and by the MGB thereafter. The main pump draws oil via a screen from a MGB main sump and passes it at a regulated 55 - 65 psi nominal pressure to a delivery pipe, via a non-return valve. Between the pump and the delivery pipe are a filter and a cooler, each of which is automatically bypassed in the event of blockage. A series of branches from the delivery pipe distribute oil to a number of jets within the gearbox and, via galleries in the input section housing and cover, to the oil ports in each input pinion sleeve bearing. A low pressure switch at a downstream point of the delivery system illuminates a cockpit central warning panel caption and activates an emergency pump if pressure falls below 6-8 psi. The crew is also provided with pressure indication and with an oil overtemperature central warning caption. The emergency pump is electric motor driven, and draws oil from an emergency sump below the main sump level and delivers it via a strainer and a non-return valve to the delivery pipe. A scavenge screen with magnetic elements is provided.

Cockpit Voice Recorder:

A Fairchild A100A four channel Cockpit Voice Recorder (CVR) was installed and a satisfactory replay was obtained, covering a 13 minute period from before engine start until after shutdown. It showed that rotors had been engaged approximately 1 minute after engine start, and that after a further 3 minutes a whine had become audible on the recording. This increased in volume over a period of 13 seconds, culminating in a bang. Engines were shutdown immediately and the evacuation order was given 40 seconds after the bang. A frequency spectrum analysis of the recording indicated that a signal at 322.5 Hz (cycles/sec) was present at an abnormally high amplitude, compared to recordings of other S-61N helicopters, throughout the period of engine running. Harmonics of this frequency also became detectable 2 minutes before the bang. The fundemental frequency corresponded to the rotational speed of the drive trains from the power turbines, including the input pinions.

Background:

Records indicated that the main gearbox had been overhauled by the transmission workshop of a major UK airline 121 hours before the accident. 1392 hours previously, at a Mid-Point Inspection by the same workshop, both input pinions had been replaced, because of corrosion. There were indications that the No. 1 pinion fitted had been new, but it did not prove possible to positively establish the details of the history of this component, in spite of exhaustive research, because of the method of record organisation employed by the overhauler.

Results of standard MGB checks after the overhaul were normal. However, after a short period of service, symptoms of defective performance of the No. 2 IFWU were noted, and it was replaced by the operator 74 hours after the Overhaul, 47 hours before the accident. This involved removal of the input section cover. During the standard MGB ground run check after reassembly, it was found that a considerable amount of oil was being released into the area forward of the MGB and running down the fuselage side. A series of ground runs was conducted, totalling an estimated 60-75 minutes, while attempting to identify the source of the leak. It was narrowed down to the area of the No.1 side of the input section cover, and eventually ceased after the No. 1 torquemeter pipe had been reseated onto its union in the cover. An estimated 0.5-0.75 USG of oil was released during the running. The available information did not eliminate the possibility that the oil release had originated from the carbon seal for the No. 1 pinion, although it was reportedly not normal for this type of seal to reseal after having once leaked.

MGB health had been monitored for some months prior to the accident by a Spectrometric Oil Analysis Programme (SOAP), a sampling check at regular intervals of the concentration levels of a number of different metals in the MGB oil. No abnormalities had been indicated by the results, including those from the last sample, taken 31 operating hours before the accident. The MGB was also fitted with a trial Health and Usage Monitoring System (HUMS), comprising a number of vibration transducers fitted to the casing and connectable to a recorder. The system was under development and regular recordings had not been made. However, comparison of recordings made approximately 50 hours and 30 hours before the accident, from a transducer positioned close to the No. 1 sleeve bearing, showed a substantial increase in the amplitude of a signal at a frequency corresponding to twice the rotational speed of the engine-MGB drive train. Some variation could be expected as a result of environmental changes, unconnected with the condition of the No. 1 sleeve bearing, but this could not be quantified because of lack of data.

On the day before the accident, the aircraft flew ten sectors between Sumburgh and North Sea rigs, a total of 5:06 operating hours. Passengers during the penultimate sector included four North Sea helicopter pilots, and two of these continued to Sumburgh in the aircraft on its last sector. None reported any abnormalities. The only reported defect during the day related to wheel brakes, and was rectified, and a Check A was carried out on the aircraft overnight at Sumburgh. This included removal and visual check of the MGB scavenge filter, which was found to be free of debris.

Examination of Aircraft:

Examination of the aircraft revealed that the No.1 input pinion and the No.1 IDS had fractured. The pinion had fractured transversely near the centre of its forward journal. Apart from a narrow band front and rear, the journal surface had been severely damaged, with the flame-plating extensively cracked and showing signs of considerable overtemperature and with much of it detached. The cover No.1 sleeve bearing remained in place in its bore, locked by both clips. The location pin had bent, but remained in register with the bearing. The white-metal had largely disappeared from the bearing, with signs that it had partly melted, and the remaining surface, generally bronze in appearance, was highly uneven and grossly smeared circumferentially. Adjacent to the bearing, the cover showed signs of severe overtemperature and was cracked. The carbon oil seal had been destroyed by heavy rubbing contact with the splined coupling shaft.

The input section was heavily contaminated with metallic debris but, apart from minor damage consistent with contact with this debris, no other MGB component damage, failures or defects were apparent. In particular, the pinion gearteeth and thrust bearing surfaces, and the aft journal and associated sleeve bearing, exhibited little damage and no abnormalities. Precision measurement, by the Quality Assurance Services Department of the Royal Aerospace Establishment Farnborough (RAEF), of the alignment of all bearing bores in the input section housing with those in the cover revealed no evidence of abnormality.

Each of the four lugs of the IDS aft flange had fractured near its root, with a resultant severance of the drive at this point also. The lugs and the splined coupling flange remained bolted together, and had rotated in contact with the gimbal ring, heavily machining and battering it and detaching the pads. The failed components were subject to detailed analysis and testing by the Materials Department of RAEF. This revealed evidence of high-strain fatigue at the IDS lug fractures, consistent with the effects of imbalance loads caused by the pinion failure. No plausible way in which the effects of the IDS fracture could have caused the input pinion failure was apparent.

The pinion fracture surfaces had been extensively smeared by relative rotational rubbing between them. However, it could be concluded that the failure had occurred predominantly from torsional loading, and that typical characteristics of extensive high cycle fatigue were absent. A microsection of the journal adjacent to the fracture revealed the presence of a widespread network of intergranular cracks, in some cases continuations of cracks in the journal plating, which had been extensively penetrated by a copper coloured material. This was found to be bearing lining material, indicative of severe overtemperature of the bearing. Its presence would have weakened the journal by a process of liquid metal embrittlement (LME), whereby the lead-tin-copper, overheated to a molten or plastic state, would have caused embrittlement of the journal steel and contributed to its rapid cracking. It was also apparent from axial and radial hardness profile measurements that the journal had been severely overheated, both as a result of rotational rubbing between the two fracture surfaces and as a result of having experienced a high friction running condition at an indeterminable point. It was assessed that the journal had fractured under normal loading as a result of gross strength reduction associated with a combination of elevated temperature and LME.

The evidence of bearing overheating as a result of high friction between the journal and the sleeve bearing was consistent with the effects of loss of normal lubrication. Detailed examination of the MGB oil system revealed no evidence of blockage, leakage or other malfunction that could have resulted in abnormality in the oil supply to the No.1 pinion cover bearing. It was not possible to ascertain that the No. 1 pinion carbon oil seal had been functioning correctly, but there was no evidence of abnormal oil depletion, or of major oil release, since the leak check 47 hours before the accident. On functional test the oil low pressure warning system operated normally. A complete absence of emergency pump screen contamination with the debris that was widely distributed through the MGB suggested that the pump had not operated.

The overall evidence was consistent with the drive train and MGB damage and failures having resulted from the effects of journal and bearing damage caused an indeterminable time before the accident by a temporary interuption to normal bearing lubrication. Tests have shown that this type of bearing suffers gross damage within a few minutes if its oil supply is lost. It was possible that damage had resulted from a temporary seating failure of the No. 1 input pinion oil seal some time before the accident, although there was no positive evidence that this had occurred. The possibility could not be dismissed that the journal plating had cracked as a result of a deficiency in the plating process, and that this had lead to blockage of the sleeve bearing port and consequent bearing overheat and subsequent journal failure.

Other Cases:

Information was found on three other cases where deterioration of the input pinion journal or sleeve bearing may have been a factor:

1. S-61N G-LINK, 17 Jan 1986:

A medium-high pitched whining noise developed shortly after rotor engagement. As speed select levers were retarded in order to shutdown engines there was a bang. The Thomas coupling had disintegrated, the IDS had separated from the splined coupling and the splined coupling had fractured, resulting in EMRSA tearing. The failures were attributed to incorrect use of an aluminium alloy pin, instead of steel, to locate a repair sleeve fitted in the input section cover bore for the pinion sleeve bearing. Failure of the pin had allowed the sleeve bearing to rotate, thereby reducing the oil port area and causing the bearing to overheat and seize. No evidence was available to indicate the cause of the pin failure or whether it may in fact have resulted from binding of the bearing caused by some other unidentified condition.

2. S-61N Far East Operator, 28 Feb 1989:

Fifteen minutes after take-off for an off-shore platform a high-pitched humming was heard, culminating after 5 seconds in a bang. The aircraft turned back. During the return flight the No. 1 Engine fire warning illuminated, but extinguished after the speed select lever was retarded. The

MGB oil low pressure warning caption illuminated shortly before landing, and indicated pressure was down to 10 psi after landing. Oil was dripping onto passengers and running down the outside of the cabin. Passengers reported an unusual noise before the bang, in some cases since before take-off. The Thomas coupling had fragmented, the IDS had separated from the splined coupling, the EMRSA had been damaged, the gimbal ring had fractured and the No. 1 input pinion forward journal had fractured. The failure was reportedly attributed to imbalance resulting from detachment of a nut from one of the four Tee bolts connecting the IDS to the splined coupling. The MGB had accumulated 278 hours since overhaul. It was noted that there had been reports of oil leaks from the No. 1 input area on two occasions, one 133 hours and one 105 hours before the accident. On the second occasion the input pinion oil seal had been replaced.

3. S-61N UK Registered, 1989:

During overhaul of the MGB (Serial No. 1085) the rear journal of the No. 1 input pinion and the associated sleeve bearing were found to be severely damaged. The journal exhibited extensive cracking and flaking of the plating over much of its surface and the sleeve was worn to the base metal and with signs of molten flow of some remnants of the white metal lining. Metallurgical examination showed that some cracks in the journal plating continued into the underlying steel as intergranular cracks which had been penetrated by bearing lining material. Some features of the damage were not identical to that found for G-BFFJ's failed journal, but it was concluded that the damage probably represented an embryonic state of the same type of failure.

Recommendations

It has been recommended that the CAA require that:

1. Inspection, repair and overhaul records for safety-critical components be maintained in such a way that full component histories are available for accident investigation purposes.

2. UK public transport S-61N helicopters to be fitted with a means of continuously monitoring the health of the main gearbox input pinion plain bearings.

DRIVE TRAIN LAYOUT

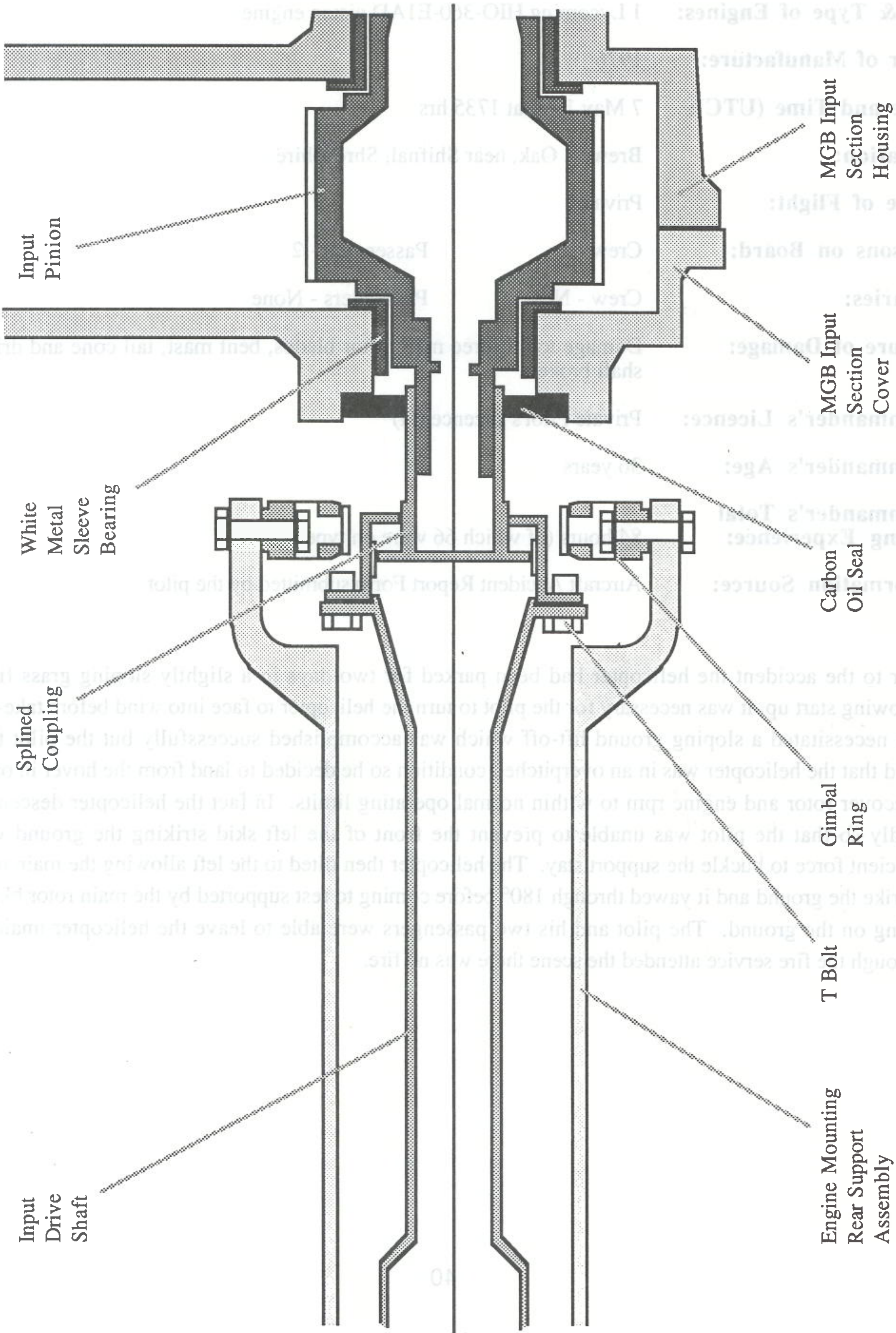

Fig 1