No: 12/91 **Ref: EW/A343** **Category: 2a**

Aircraft Type and Registration:	Sikorsky S-61N, G-BCLD
No & Type of Engines:	2 General Electric CT58-140-2 turboshaft engines
Year of Manufacture:	1974
Date & Time (UTC):	9 October 1990 at 1626 hrs
Location:	Near Mount Pleasant Airport, Falkland Islands
Type of Flight:	Public Transport
Persons on Board:	Crew - 3 Passengers - 14
Injuries:	Crew - None Passengers - None
Nature of Damage:	Drive train and structure connecting No. 1 engine to main gearbox severed, input section of main gearbox damaged
Commander's Licence:	Airline Transport Pilot's Licence (H) with Instrument rating
Commander's Age:	51 years
Commander's Flying Experience:	10,390 hours rotary wing (of which 2,888 were on type) and 339 hours fixed wing
Information Source:	Aircraft Accident Report Form submitted by the pilot and AAIB inquiries

History of Flight

The helicopter took-off after a 25 minute period of ground running with rotors turning. Around five minutes into the flight, as transmission torque was increased to 80% to initiate a cruise/climb from 500 feet QNH (250-300 feet agl), the crew heard a whine. This completely disappeared on lowering the collective to 60% torque, but when torque was again increased, to 75-80%, the whine reappeared and rapidly became worse. The crew identified the noise as coming from the left side of the transmission, and selected the main gearbox (MGB) emergency lubrication system on. Around one minute after the crew first heard the whine there was a loud bang, power was lost and the aircraft yawed. After the bang, the No. 1 Engine shutdown automatically. The crew established the aircraft in autorotation and achieved a gentle landing on sloping ground five nm east of the airfield, using No. 2 Engine power to cushion the touchdown. With the exception of holing of the tail rotor drive shaft fairing as a result of contact from a main rotor blade, no damage resulted from the landing. After landing, oil was seen pouring down the left side of the aircraft internally and externally.

Aircraft Description

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). The drive is transmitted via a Thomas flexible coupling at the forward end of the IDS and a splined coupling at its aft end (Fig 1), both intended to cater for up to 0.5° of continuous axial misalignment. The splined coupling is connected to the IDS by four T-bolts passing through flange ears integral with each component and retained by self locking nuts.

The IDS rotates within an engine mounting rear support assembly (EMRS), a static 4.5 inch diameter steel tubular structure that forms the engine aft mount. The EMRS is attached to the MGB input section cover via an aft isolator ring, a magnesium alloy gimbal arrangement fitted with Lord mounts, which incorporate vibration isolating elastomeric bushes. Four composite pads bonded to the ring are intended to contain radial excursions of the splined coupling in the event of loss of normal 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 MGB input section cover and is splined to a spur gear input pinion forming the first stage of the input section geartrain. 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 (316 Hz) 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 gearing.

Integral with each input pinion (Part No. (PN) S6135-20607-2) is a splined shaft, a forward and an aft plain journal of around two 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 case hardened layer 15-30 x 10^{-3} inch thick 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 forward and aft plain 'white metal' sleeve bearings (PN S-6135-20649 forward and -20650 aft), located respectively in a bore in the cover and housing of the input section. The forward sleeve bearing consists of a 1 inch long 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 x 10^{-3} inch thick layer of bronze, overplated with a 0.9-1.1 x 10^{-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 x 10^{-3} inch maximum thickness. The bore tapers from the outer end to the flange end by 1.8-2.3 x 10^{-3} inches diametrically, and specified dimensions provide a diametric clearance from the journal of 5.2-6.7 x 10^{-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° in the direction of pinion rotation. Bearing axial and rotational restraint in the cover bore is by two clips that are bolted to the cover and register in rebates in the bearing flange. A location pin, located in a hole in the cover and registering in a slot in the edge of the bearing flange, ensures correct bearing orientation. The aft sleeve bearing is of slightly larger diameter, but is otherwise similar. Adjacent to each sleeve bearing is an external blind threaded hole in the cover or housing which is used to hold a temperature transducer during MGB rig running for monitoring bearing condition.

MGB lubrication and cooling is by an internal wet-sump oil system, with nominal total contents of 14 gall US, with a main and an emergency system. The main pump is turned by an accessory gearbox section, which is driven by an electric motor/generator prior to rotor start, and by the MGB thereafter. The pump draws oil from a MGB main sump via a screen with magnetic elements and passes it at a regulated 55-65 psi nominal pressure to a delivery manifold, via a non-return valve. Between the pump and the manifold are a filter and a cooler, each of which is automatically bypassed in the event of blockage. A series of branches from the manifold distribute oil to a number of jets within the MGB and, via galleries in the input section housing and cover, to the oil port in each input pinion sleeve bearing. An electrically driven emergency pump can draw oil from an emergency sump below the main sump level and deliver it via a strainer and a non-return valve to the manifold.

Main Gearbox Health Monitoring

A low pressure switch at a downstream point of the MGB oil delivery system illuminates a caution caption on the cockpit central warning panel and activates the emergency pump if pressure falls below 6–8 psi. There is also an oil overtemperature central warning caption. The crew is provided with indication of MGB oil pressure and temperature but not with oil contents or magnetic chip detector indication. Ground monitoring is by daily inspection of the pump screen, and by a Spectrometric Oil Analysis Programme (SOAP).

Maintenance and Overhaul

The component parts of the engine-MGB drive train are dynamically mass balanced during manufacture and overhaul, both individually and as sub-assemblies, including the engine power turbine assembly, the complete engine, the IDS, the splined flange and the MGB input pinion. The IDS assembly, comprising the shaft with Thomas coupling and T-bolts and nuts attached, is dynamically mass balanced as a unit, after which T-bolt and nut positions must be maintained, using index marking. Procedures for reassembling the IDS/splined coupling joint specify that T-bolt nuts can be reused provided the run-on torque is at least 6.5 in-lb, signifying that the self locking capability remains adequate; that a replacement nut should weigh within 0.025 gm of its partners; that the T-bolt head is maintained tangential to the splined coupling; that each nut is torque tightened to 190-210 in-lb; and that T-bolts and nuts are visually duplicate inspected after tightening.

Following any drive train reassembly and installation in an aircraft, an Installed Engine Vibration Check (IEVC) specified in the Aircraft Maintenance Manual is conducted using a radial vibration transducer mounted on a bracket at the forward end of the EMRS. Portable test equipment is used to measure the transducer output from one engine while it is driving the rotors, with the other engine running at ground idle. The basic criterion is that the peak-peak amplitude of the once/rev frequency should not exceed 3 mils between 98-105% rotor speed. If this cannot be met, the test is repeated after altering the relative rotational orientation of the IDS assembly and the splined flange as this has been found to affect the measured vibration level. Following a Recommendation made in AAIB Report 3/90, an IEVC is now required for S-61N helicopters following any reassembly of the IDS/splined coupling joint. The aircraft is not equipped for continuous monitoring of engine, drive train, transmission or airframe vibration levels.

Background

Records indicated that G-BCLD had accumulated 22,349 operating hours time since new (TSN) when the accident happened. It had undergone a major maintenance check (P2 Check) 28 operating hours before, and at this time the No. 1 engine and the MGB had been replaced as they had almost reached the expiry of their overhaul periods. The replacement MGB (PN S6135-20600-046, Serial No. (SN) 74-976) had been newly overhauled by the aircraft manufacturer at 13,749 operating hours TSN. During the P2 Check both splined couplings were repacked with Type 204 grease and connected to the respective IDS in accordance with the required procedures. An IEVC conducted on each engine showed measured maximum vibration levels well below the limit. Flight Tests, comprising a 30 minute heavy hover operation and an Intercontingency and Power Assurance Flight Test on 3 October 1990, were satisfactory and the aircraft recommenced revenue operations. During the first three operating hours the crew noted a slight rise in the MGB oil temperature and a slight fall in the oil pressure indications but both parameters remained within limits and at levels comparable to those obtained during the heavy hover. On the same day, 23 operating hours before the accident, a passenger reported oil flowing down a cabin left side window as the aircraft transitioned into forward flight after a 20 minute period of ground running with rotors turning. Examination indicated the origin as leakage past a nicked O-ring sealing the shut-off sleeve carrying the oil pump screen. After O-ring replacement and a further hover check and inspection, the aircraft resumed service.

During subsequent operations the tendency continued for the MGB oil pressure to fall and temperature to rise somewhat when ground running, but both would re-stabilise at their previous in-flight values when airborne again. This was the case during the operations immediately prior to the accident, with indicated temperature and pressure of 95°C/37 psi during the 25 minutes ground running, compared to the normal in-flight values of 88°C/40 psi, again normalising after take-off. The MGB oil parameters at all times remained within the normal range of 40-120°C / 35-90 psi given in the operator's S-61N Operations Manual (Volume 9, Section 1), but the behaviour was reportedly uncharacteristic and may possibly have reflected a MGB anomaly. With this possible exception, there were no indications of abnormality prior to the whine.

Examination of Aircraft

In the No. 1 drive train the input pinion and the IDS/splined flange connection had fractured, the cover sleeve bearing had been severely distressed and the carbon oil seal in the MGB input section had been destroyed.

The IDS had bent and suffered fracture of three of its T-bolt lugs, and three of the splined flange T-bolt lugs had been torn off. The probable installed orientation of the IDS relative to the splined flange was established from frettage markings and this indicated that the intact lug on the IDS was No. 4, whereas the intact lug on the splined flange was No. 3. T-bolts Nos. 1 and 2 were recovered from the cabin roof with nuts in place; No. 4 and its nut were found separately in the cabin with threads stripped; and No. 3 and its nut were not recovered, and holes in the cowl were consistent with these having departed the aircraft. The aft isolator ring had been heavily machined on its internal bore and fractured into four pieces.

The No. 1 input pinion had fractured transversely through the integral shaft forward of the forward journal (Fig 2). The forward journal exhibited gross rotational wear, deformation and overheat over an approximately 170° arc, with a number of extensive circumferential cracks. Opposite this arc the forward thrust bearing face was overheated and plastically deformed. The aft journal and thrust bearing faces had lesser rotational damage at circumferential positions opposite to those of the forward journal and thrust bearing face damage. Damage characteristics were indicative of the effects of a severe imbalance force applied to the forward end of the input pinion, in a direction consistent with a reduction of mass at around the No. 2 T-bolt position. The forward sleeve bearing had severe rotational and overheat damage, had distorted and had jumped its restraining clips and turned in its bore in the MGB input section cover. This bore had signs of severe overheat and possibly wear or battering damage, giving approx 1 mm diametric clearance between it and the sleeve bearing. The carbon oil seal housing had rotated in its bore in the input section cover and the seal had been obliterated.

Engine No. 1 exhibited widespread damage, consistent with the effects of excessive vibration. The damage was generally minor, but included fracture of the inactive oil jet tube for the No. 5 bearing carbon seal, found in the No. 4 bearing housing, and 180° cracking of the active oil jet tube at its base.

No other abnormalities or signs of damage related to the accident were found, including no signs of abnormal gear meshing. However, several anomalous features in the input section or associated components were found. These included gross undertorque of the nut retaining the mounting flange for the rotor brake disc (approximately 30 lb-ft against a requirement of 300-350 lb-ft), with the locking wire for the nut intact and no evidence of distress to the flange or associated components; end float in Nos. 1 and 2 input freewheel units below the minimum requirement; and separation of the grease in the No. 2 splined coupling into a highly viscid and a highly liquid fraction. The evidence suggested that these deficiencies were unrelated to the cause or effects of the accident, and that the first two had been present since the MGB overhaul.

The evidence indicated that the No. 1 input pinion forward bearing had suffered gross deterioration resulting in severe overheating and that a major rotational imbalance had been present in the No. 1 drive train at some stage in the failure. The combined effects of overheating and imbalance had caused the pinion shaft to fracture which, by removing the radial restraint for the aft end of the IDS, led to rapid failure of the IDS/splined coupling joint. However, no evidence was found to positively indicate whether the primary failure had directly caused an imbalance that had then resulted in the bearing distress, or vice versa.

The evidence indicated that the most likely cause of a gross imbalance preceding bearing distress would have been loss of a T-bolt nut. Such an event was the cause attributed by the aircraft manufacturer to a previous accident with extremely similar resultant damage (see section on Other Cases). The manufacturer predicted that loss of a nut would result in bearing distress, but that both loss of self-locking capability and inadequate pre-load torque would be required to enable a T-bolt nut to back-off in service, although some cases of T-bolt cracking due to hydrogen embrittlement have been found. As one T-bolt and nut were lost and could not be examined, and as initial information cast some doubt on the nut self-locking characteristics, recommendations were made that the CAA should require, for UK registered S-61N helicopters, a number of checks regarding T-bolt nuts, including a tightening torque check at frequent regular intervals and consideration of a requirement for T-bolt nut renewal after each removal of a nut. CAA issued Emergency Airworthiness Directive 007-12-90 (11 December 1990) requiring these checks, together with a report on any nuts that failed. One set of four nuts was found with low tightening torque (50-60 in-lb), but run-on torque was above requirements. Detailed examination of G-BCLD's components suggested that Nos. 1, 2 and 4 T-bolts or nuts had not suffered pre-accident failure or separation, and the orientation of the eccentric damage to the drive train did not appear consistent with defects in the lost No. 3.

Checks on G-BCLD after the accident did not indicate the presence of a defect in the MGB oil system that could have led to inadequate oil supply to the No. 1 forward sleeve bearing. MGB oil pressure and temperature were possibly somewhat anomalous during prolonged ground running and an oil leak occurred 23 operating hours before the accident. Oil pressure and temperature reportedly remained within the manufacturer's limits at all times.

Input section problems have occurred apparently as a result of misalignment between cover and housing bearing bores, possibly due to permanent distortion to the cover and/or housing caused by their creeping in service (AAIB Accident Report 4/85). An alignment check has for many years been required at overhaul (Sikorsky Overhaul and Repair Instructions (ORI) 6135-342). Precision measurement (accuracy $\pm 0.5 \times 10^{-3}$ inch) by the Quality Assurance Services Department of the Royal Aerospace Establishment Farnborough of all five pairs of bores in G-BCLD's input section revealed that four bores were out of limits, by a maximum of $3.1 \pm 0.5 \times 10^{-3}$ inches, including the housing bore for the No. IFWU. The cover bore for the No. 1 input pinion bearing could not be measured because of damage. The excessive misalignment on a newly overhauled unit was of concern, but the lack of abnormal gear tooth marking indicated that misalignment had not contributed to the accident.

The possibility that the bearing distress had resulted from excessive vibratory loads was not supported by the satisfactory results of the IEVC carried out 28 hours before the accident. However, in the absence of any form of continuous or repetitive vibration monitoring, other than an IEVC after IDS/splined coupling disturbance, no means were available whereby in-service deterioration leading to excessive drive train imbalance would be reliably detected before major failure occurred. It has reportedly been widely considered that drive train distress would generate high frequency vibration that would be readily sensed by the crew, particularly via engine condition levers and yaw pedals. However, there were no such indications at any stage in a number of S-61N accidents where investigation showed that severe drive train distress had preceded the final failure.

Other Cases

Information was found on a number of other cases where distress 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, before lift-off. As speed select levers were retarded in order to shutdown engines there was a bang. The No. 1 drive train had failed, with the Thomas coupling disintegrated, the IDS separated from the splined coupling and the splined coupling fractured, resulting in EMRS 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 G-BCEA, 24 Feb 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 bearing was worn to the base metal, with signs of molten flow of remnants of the white metal lining. Metallurgical examination showed that some cracks in the journal plating continued into the underlying steel as intergranular cracks and that these had been penetrated by bearing lining material. It was concluded that the damage probably represented an embryonic stage of the more advanced failure that occurred in some of the other cases.

3. 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 five 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 subsequently reported having heard 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 EMRS had been damaged, the aft isolator ring had fractured and the No. 1 input pinion forward journal had fractured. The failure was attributed by the aircraft manufacturer to imbalance resulting from detachment of a T-bolt nut. The MGB had accumulated 278 hours since overhaul. It was noted that there had been reports of oil leaks from the No. 1 input section area on two occasions, one 133 hours and one 105 hours before the accident. On the second occasion the cover oil seal had been replaced.

4. S-61N G-BFFJ, 11 May 1989 (AAIB Bulletin 7/90)

Just before lift-off for departure, three minutes after rotors had been engaged and with all indications normal, the crew heard an abnormal whining noise. This culminated after 2-4 seconds in a bang, as engine shutdown was initiated. Oil was seen pouring down the left side of the fuselage. The cover bearing for the No. 1 input pinion had severely overheated. The pinion had fractured across its forward journal and as a result the IDS had fractured at its aft flange. Metallurgical examination showed a widespread network of intergranular cracks in the pinion, extensively penetrated by plain bearing lining material, and concluded that the journal had fractured under normal loading as a result of gross strength reduction associated with a combination of elevated temperature and liquid metal embrittlement by the lining material. The primary cause of the failure could not be positively established. Analysis of recordings from the cockpit voice recorder (CVR) and a trial Health and Usage Monitoring System (HUMS) showed that signs of drive train distress had been present throughout the 4 minutes of engine running, and had possibly initiated between 30-50 operating hours before the accident. No pre-accident abnormality had been indicated by any of the available means of health monitoring, including SOAP, visual checking of the MGB oil pump screen immediately before the accident, and cockpit instruments.

5. S-61N G-BEDI, May 1990

The MGB (SN A943) was bought by a UK operator as part of a used S-61N helicopter that was transferred from the USA back to the UK Register. On arrival in the UK abnormal debris was found in the MGB scavenge filter, including white metal. Strip examination reportedly showed that the aft bearing for the No. 1 input pinion was severely distressed. Part of the journal surface had flaked off; the sleeve bearing was loose in its sleeve (ORI 6135-342 repair scheme) and had turned; the sleeve was loose in the housing bore; and the sleeve location pin was loose. During test-running on a rig following repair the No. 1 input pinion failed.

6. S-61N G-BDDA, 1990:

The MGB (SN A14-1016) was bought by a UK operator as part of a used S-61N helicopter that was transferred from the USA back to the UK Register. ORI 6135-342 had reportedly been accomplished 130 hours previously. During subsequent North Sea operations low MGB oil pressure was reported, but never below the minimum specified by the manufacturer, and none of the other health monitoring means available to the operator indicated a problem. After 320 hours operation a routine MGB Mid-Point Inspection revealed distress of the housing bearing for the No. 1 input pinion, together with excessive local reshaping of the pinion gearteeth. The journal was superficially smooth, but was slightly discoloured and had many fine axial cracks in the surface; and the sleeve bearing was severely worn with the surface badly smeared and oil distribution passages largely blocked with debris. Fine tolerance measurements of the bearing bores showed no major alignment or positioning errors. It was found that the distressed sleeve bearing was undersized, providing a leakage path for the bearing lubrication supply and it was concluded that this had probably caused the bearing distress. The way in which an undersized sleeve bearing had come to be fitted could not be established.

7. S-61N G-AYOY, 5 November 1990:

The MGB had been installed in the aircraft after returning from overhaul by the aircraft manufacturer at 15,128 hours since new. During the post-installation IEVC excessive vibration and a loud rumbling noise from the MGB were apparent. Examination showed that the cover bearing for the No. 2 input pinion was distressed, with considerable roughness of the journal and sleeve bearing surfaces, consistent with the effects of foreign debris having been present. No abnormal debris was found in MGB filters.

8. Military Variant Experience

Obtainable information on similar cases of failure to military versions of the helicopter type, which reportedly use similar components, was scanty but included 16 cases between 1975-1985 of input pinion bearing distress. In some instances input pinion and/or IDS failure had occurred, and in five of the cases fire was reported. No common attributed cause was apparent.

9. Possible Associated Cases

A number of cases have also been reported of gross deterioration of the Lord mount elastomeric bushes leading to fretting damage to the EMRS, the isolator ring and the MGB input section yoke. In one of these cases IEVC vibration levels after replacement of the bushes was found to be excessive until the IDS had also been replaced.

Some evidence suggested that drive train and Lord mount problems could be associated with EMRS resonance. Some standards of the aircraft included a damper, comprising a mass attached to the EMRS, but this was not the case for the S-61N. A static test on a sample S-61N showed natural frequencies of 480 and 430 Hz for the left and right EMRS tubes respectively, compared to the drive train 100% frequency of 316 Hz. The experience of a major operator of military versions of the helicopter suggested that the natural frequency can reduce as low as 350 Hz if the Lord mount elastomers degrade, which can result from oil or grease contamination. Problems associated with high frequency vibration due to resonance were experienced by the operator, and the isolator elastomeric bushes were replaced with a hard-mount system which raised the natural frequency to over 550 Hz. It has been recommended that the CAA consider the need for measures aimed at providing significantly greater margin between the natural frequency of the S-61N engine mounting rear support assembly tube and the normal rotational frequency of the main gearbox input drive train. The operator has also observed that in a three year period a significant number of unscheduled removals and 34 mishaps, including five resulting in loss of the helicopter, had occurred which were associated with MGB input drive train problems, but that major improvement had occurred after the introduction of vibration analysis.

General

In the four cases known where drive failure has occurred to civil S-61Ns, the only warning of impending failure has generally been an abnormal noise heard by the crew in the few seconds immediately before the pinion fractured (around one minute in the case of G-BCLD). Passengers have often heard abnormal noises for considerably longer, being nearer the source and lacking noise-cancelling headsets, but naturally have assumed that the crew is aware of the situation. Usually abnormalities have not been indicated by MGB SOAP results or by the regular visual checks of the oil pump screen. Some evidence suggested that bearing deterioration may proceed relatively slowly in that two of the early stage cases were found during routine Mid-Point Inspection. The general lack of useful pre-warning is serious in view of the potentially very serious consequences of the failure. The immediate effect of complete loss of drive from one powerplant is accompanied by the destruction of the cover oil seal of the input section, which results in loss of MGB oil at a significant rate while rotors continue to turn, leading to depletion of the MGB oil supply. The available information on the failure that occurred to an S-61N in the Far East, 15 minutes after take-off, indicated that MGB oil pressure fell below the low pressure warning level towards the end of the return flight, which also apparently took in the order of 15 minutes.

It is also noted that the damage to the oil jet tubes supplying the carbon oil seal at the aft end of the engine, as occurred on the No. 1 engine of G-BCLD, is also potentially serious. This could lead to failure of the seal, and also failure of the power turbine speed sensing drive should a failed jet tube interfere with the right-angle gears. This has resulted in power turbine non-containment and engine casing severance (USAF HH-3E at Selfridge, Michigan, USA, in October 1985).

No positive explanation was found for the fact that the No. 1 side was affected in all the six known cases of bearing distress occurring to civil aircraft in-service. The only possibly relevant factor identifiable was the appreciable difference between the Nos. 1 and 2 IFWU, driven by the input pinions, both in design and in the history of modifications aimed at resolving extended IFWU slippage and wear problems, but these could not be definitely connected with input pinion bearing distress.

It is apparent that a plain bearing such as this, operating at almost 19,000 rpm, is likely to be intolerant of lubrication abnormalities. The results of a rig test in 1988 on the MGB of a military variant of the S-61N concluded that after total loss of MGB oil pressure followed by 90 seconds at hover power the aircraft could continue at cruise power for a maximum of around 100 seconds before deterioration of the input pinion bearings would force autorotation. On later versions of the variant the input pinion plain bearings were replaced with rolling element bearings, which have been demonstrated to possess a much improved run-dry capability. It has been recommended that the CAA consider requiring, for UK public transport S-61N helicopters, the replacement of input pinion plain bearings with rolling element bearings.

There is evidence that severe input pinion bearing deterioration has occurred a number of times; that in a number of cases this has resulted in MGB disablement; and that MGB monitoring techniques in use have generally failed to provide pre-warning. It is noted that the majority of operations for S-61Ns on the UK Register are in the particularly hostile environment of the North Sea. It has been recommended that the CAA require, for UK registered public transport and aerial work helicopters, a system to continuously monitor debris levels in gearboxes whose integrity is critical to flight safety and to provide immediate warning to the crew of abnormalities.

In view of the input pinion damage found on recently imported aircraft it has been recommended that the CAA review the requirements for acceptance of used foreign aircraft and components onto the UK Register. Input pinion damage has also been found on a newly overhauled MGB and it has been recommended that the CAA require improved quality control of overhauled S-61N main gearboxes.

The evidence suggests that a system capable of monitoring gearbox vibration or perhaps temperature in the locality of the bearings would provide an effective measure of their mechanical integrity, and probably be able to provide adequate pre-warning of excessive deterioration. It is probable that this requirement will be fulfilled by the comprehensive MGB monitoring to be provided by the HUMS scheduled to be fitted to UK S-61Ns and other helicopters, but there is likely to be an extended timescale of some years before full operational effectiveness throughout the UK S-61N fleet is achieved. Possible interim methods could include permanent installation of either temperature transducers or IEVC transducers and wiring whose outputs could be monitored continuously or at set flight conditions. The existing threaded hole in the input section cover or housing adjacent to each sleeve bearing would enable simple installation of a transducer able to monitor bearing condition in-service, rather than just during rig testing. It has therefore been recommended that the CAA require, for UK public transport and aerial work S-61N helicopters, the early provision of a means of continuously monitoring the health of main gearbox input pinion bearings. It has also been recommended that the CAA require, for UK registered public transport and aerial work helicopters, the early provision of a facility to continuously monitor the vibration of high-speed rotating equipment whose integrity is, or may foreseeably be, critical to flight safety.

It has been recommended that the CAA:

1. Require, for UK registered S-61N helicopters, a number of checks regarding T-bolt nuts, including a tightening torque check at frequent regular intervals and consideration of a requirement for T-bolt nut renewal after each removal of a nut. (Made 27 November 1990, reference CAA Airworthiness Directive 007-12-90, dated 11 December 1990).

2. Consider the need for measures aimed at providing significantly greater margin between the natural frequency of the S-61N engine mounting rear support assembly tube and the normal rotational frequency of the main gearbox input drive train.

3. Consider requiring, for UK public transport S-61N helicopters, the replacement of input pinion plain bearings with rolling element bearings.

4. Require, for UK registered public transport and aerial work helicopters, a system to continuously monitor debris levels in gearboxes whose integrity is critical to flight safety and to provide immediate warning to the crew of abnormalities.

5. Review the requirements for acceptance of used foreign aircraft and components onto the UK Register. (Made 27 November 1990).

6. Require improved quality control of overhauled S-61N main gearboxes.

7. Require, for UK public transport and aerial work S-61N helicopters, the early provision of a means of continuously monitoring the health of main gearbox input pinion bearings. (Made 27 November 1990. A similar recommendation was made on 14 June 1990 relating to the accident to S-61N G-BFFJ at Sumburgh on 11 May 1989, AAIB Bulletin 7/90).

8. Require, for UK registered public transport and aerial work helicopters, the early provision of a facility to continuously monitor the vibration of high-speed rotating equipment whose integrity is, or may foreseeably be, critical to flight safety. (Made 27 November 1990. A similar recommendation was made on 18 June 1991 in relation to the accident to AS355-2 Twin Squirrel G-WMPA near Birmingham on 30 December 1990 (AAIB Bulletin 12/91); on 21 November 1989 in relation to the accident to S-61N G-BEID in the North Sea on 13 July 1988 (AAIB Report 3/90); and on 25 November 1987 in relation to the accident to Bell 222 G-META at Lippitts Hill on 6 May 1987 (AAIB Report 3/88)).

DRIVE TRAIN SCHEMATIC

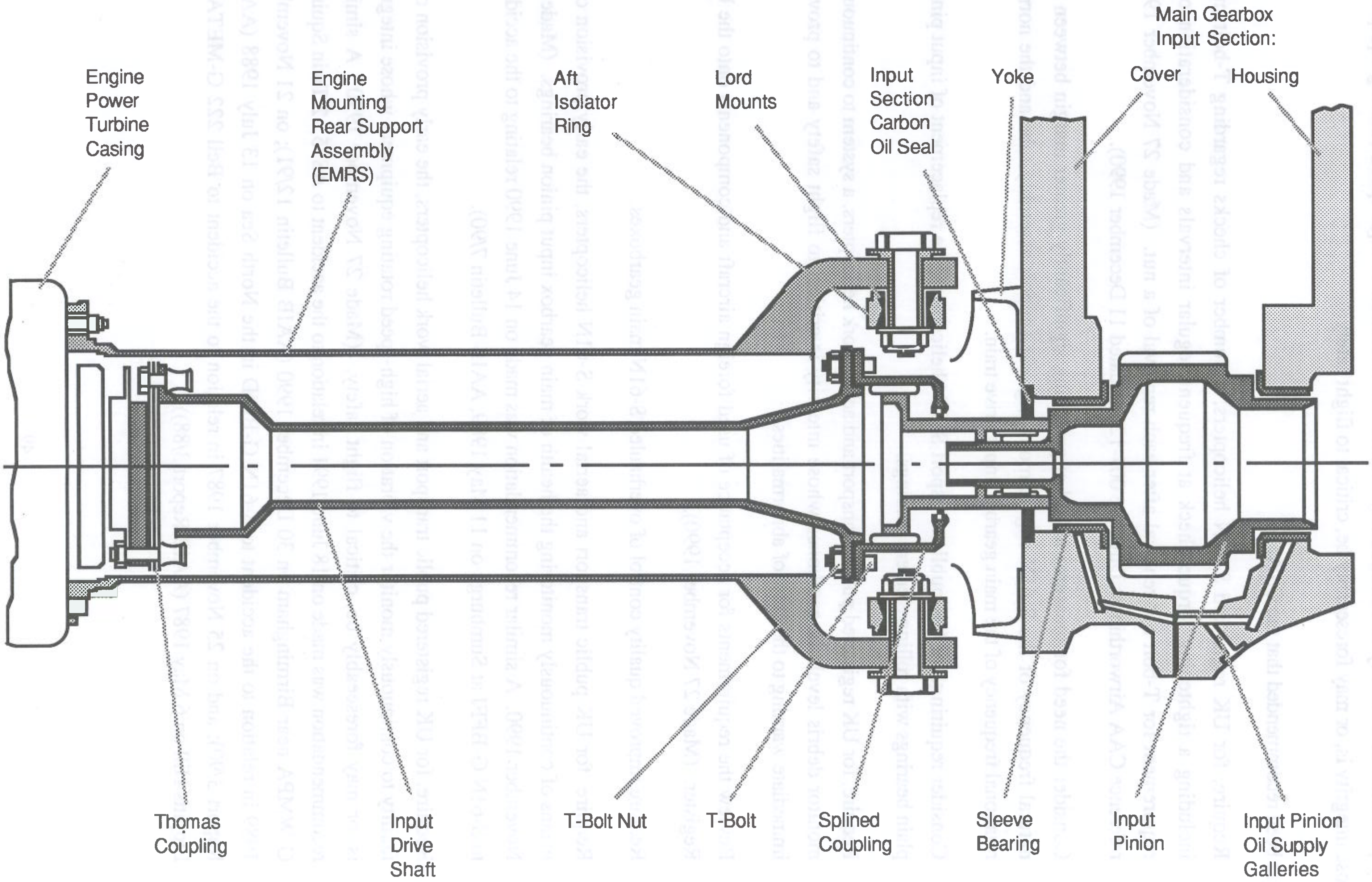
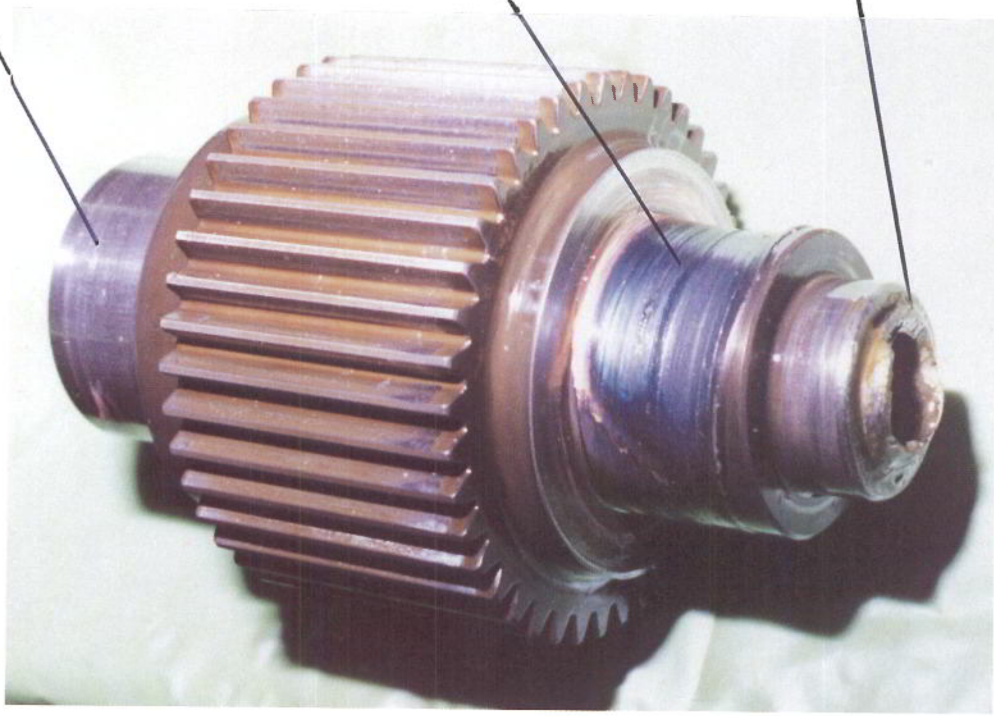
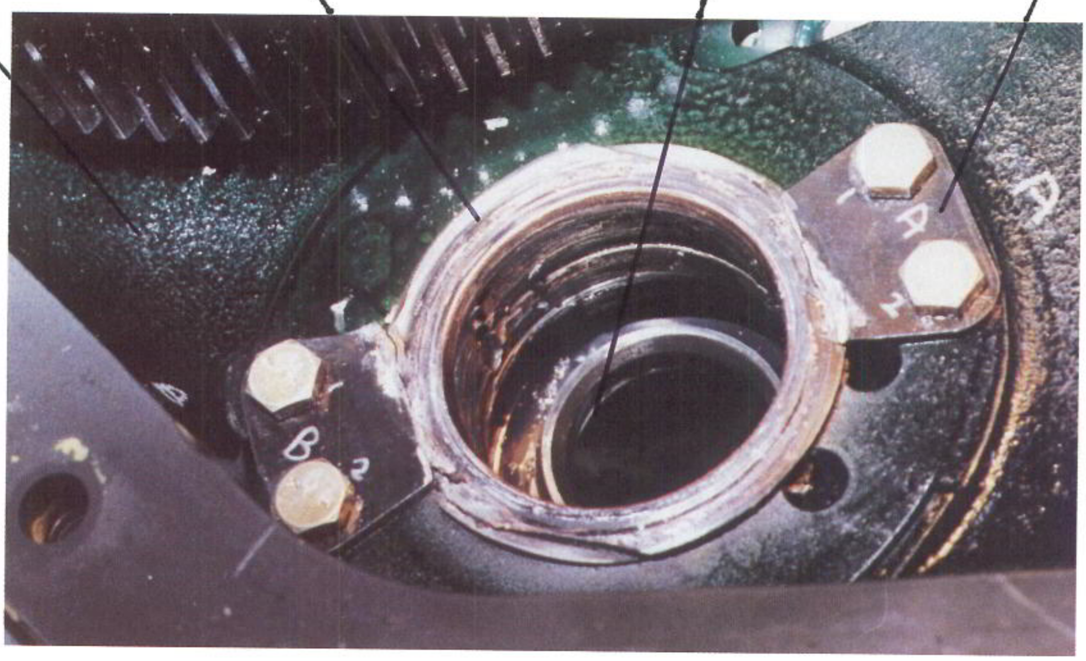


Fig 1

G-BCLD NO. 1 DRIVE TRAIN



INPUT PINION



FORWARD SLEEVE BEARING

Fig 2