AIRCRAFT ACCIDENT REPORT 2/2011

Air Accidents Investigation Branch

Department for Transport

Report on the accident to Aerospatiale (Eurocopter) AS332 L2 Super Puma, registration G-REDL 11 nm NE of Peterhead, Scotland on 1 April 2009

This investigation has been carried out in accordance with
The Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996, Annex 13 to the ICAO Convention on International Civil Aviation and EU Regulation No 996/2010

The sole objective of the investigation of an accident or incident under these Regulations shall be the prevention of accidents and incidents. It shall not be the purpose of such an investigation to apportion blame or liability.

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This report contains facts which have been determined up to the time of publication. This information is published to inform the aviation industry and the public of the general circumstances of accidents and serious incidents.

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Air Accidents Investigation Branch
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October 2011

The Right Honourable Justine Greening
Secretary of State for Transport

Dear Secretary of State

I have the honour to submit the report by Mr M P Jarvis and Mr P Sleight, Inspectors of Air Accidents, on the circumstances of the accident to Aerospatiale (Eurocopter) AS332 L2 Super Puma, registration G-REDL, 11 nm NE of Peterhead, Scotland on 1 April 2009.

Yours sincerely

Keith Conradi
Chief Inspector of Air Accidents

Contents

Appendices

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

°C	Degrees Centigrade
°F	Degrees Fahrenheit
°M	Degrees Magnetic
AAD	Advanced Anomaly Detection
AAIB	Air Accidents Investigation Branch
aal	above airfield level
AD	Airworthiness Directive
ADN	VOR near Aberdeen
agl	above ground level
AIU	Airborne Interface Unit
AMM	Aircraft Maintenance Manual
amsl	above mean sea level
AOC	Air Operator’s Certificate
ARCC	Aeronautical Rescue Co-ordination Centre
AS	Aerospatiale
ATC	Air Traffic Control
BCAR	British Civil Airworthiness Requirement
BEA	Bureau d’Enquetes et d’Analyses Pour la Securité de l’Aviation Civile
BST	British Summer Time (UTC+1)
CAA	Civil Aviation Authority
CAM	Cockpit Area Microphone
CAP	Civil Aviation Publication
CI	Condition Indicator
cm	centimetre
CQAR	Card Quick Access Recorder
CS	Certification Specification
CSI	Controlled Service Introduction
CVFDR	Combined Voice and Flight Data Recorder
CVR	Cockpit Voice Recorder
DGAC	Direction générale de l’Aviation civile
DECU	Digital Engine Control Unit
DFDAU	Digital Flight Data Acquisition Unit
DOA	Design Organisation Approval

EASA	European Aviation Safety Agency
EASB	Emergency Alert Service Bulletin
EDR	EuroHUMS Diagnostic Report
ELT	Emergency Locator Transmitter
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FDM	Flight Data Monitoring
FDRS	Flight Data Recording System
FE	Finite Element
FOD	Foreign Object Debris
fpm	feet per minute
ft	feet
g	gravity
HFDM	Helicopter Flight Data Monitoring
HOMP	Helicopter Operations Monitoring Programme
HSU	Heading Sensor Units
HTG	Helicopter Task Group
HUMS	Health and Usage Monitoring System
Hz	Hertz
IAW	In Accordance With
ICAO	International Civil Aviation Organization
IFDS	Integrated Flight Display System
IGB	Intermediate Gear Box
IiC	Investigator in Charge
JAA	Joint Aviation Authorities
JAR	Joint Airworthiness Requirement
kg	Kilogram
km	Kilometre
kt	knot
lb	pound
LPC	Licence proficiency check
LS	Service Letter
m	metre
mb	millibar
MCD	Magnetic Chip Detector
MGB	Main Rotor Gearbox

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

mm	millimetre
MOPS	Minimum Operational Performance Specifications
MTC	Maintenance Task Card
NE	north-east
nm	nautical mile
NMD	Navigation and Mission Display
OEI	One Engine Inoperative
OPC	Operator proficiency check
PCMCIA	Personal Computer Memory Card International Association
PFD	Primary Flight Display
PIC	Pilot in command
psi	pounds per square inch
PSU	Pressure Sensor Unit
QNH	altimeter pressure setting to indicate elevation amsl
rpm	Revolutions per minute
RT	Radio Transmission
RTCA	Radio Technical Commission for Aeronautics
SAR	Search and Rescue
SB	Service Bulletin
SEM	Scanning Electron Microscope
SMD	Smart Multimode Display
SOA/SOAP	Spectrographic Oil Analysis Programme
TDS	Tail Drive Shaft
TEM	Transmission Electron Microscope
TGB	Tail Gear Box
TOGAA	Technical Oversight Group for Ageing Aircraft
TRTO	Type Rating Training Organisation
UTC	Co-ordinated Universal Time
VHF	Very High Frequency
VHM	Vibration Health Monitoring
VNE	never exceed airspeed
VOR	VHF omni-range
WG	Working Group

Air Accidents Investigation Branch

Aircraft Accident Report No: 2/2011 (EW/C2009/04/01)

Registered Owner and Operator	Bond Offshore Helicopters Ltd
Aircraft Type	AS332 L2
Nationality	British
Registration	G-REDL
Place of Accident	11 nm NE of Peterhead, Scotland
Date and Time	1 April 2009 at 1255 hrs

Synopsis

The Air Accidents Investigation Branch (AAIB) was notified of the accident by Aeronautical Rescue Co-ordination Centre (ARCC) Kinloss at 1326 hrs on 1 April 2009 and the investigation began the same day. In accordance with established international arrangements the Bureau d'Enquetes et d'Analyses Pour la Securité de l'Aviation Civile (BEA), representing the State of Manufacture of the helicopter, and the European Aviation Safety Agency (EASA), the Regulator responsible for the certification and continued airworthiness of the helicopter, were informed of the accident. The BEA appointed an Accredited Representative to lead a team of investigators from the BEA, Eurocopter (the helicopter manufacturer) and Turbomeca (the engine manufacturer). The EASA, the helicopter operator and the UK Civil Aviation Authority (CAA) also provided assistance to the AAIB team.

The accident occurred whilst the helicopter was operating a scheduled passenger flight from the Miller Platform in the North Sea, to Aberdeen. Whilst cruising at 2,000 ft amsl, and some 50 minutes into the flight, there was a catastrophic failure of the helicopter's Main Rotor Gearbox (MGB). The helicopter departed from cruise flight and shortly after this the main rotor and part of the epicyclic module separated from the fuselage. The helicopter then struck the surface of the sea with a high vertical speed.

An extensive and complex investigation revealed that the failure of the MGB initiated in one of the eight second stage planet gears in the epicyclic module. The planet gear had fractured as a result of a fatigue crack, the precise origin of which could not be determined. However, analysis indicated that this is likely to have occurred in the loaded area of the planet gear bearing outer race.

A metallic particle had been discovered on the epicyclic chip detector during maintenance on 25 March 2009, some 36 flying hours prior to the accident. This was the only indication of the impending failure of the second stage planet gear. The lack of damage on the recovered areas of the bearing outer race indicated that the initiation was not entirely consistent with the understood characteristics of spalling (see 1.6.5.7). The possibility of a material defect in the planet gear or damage due to the presence of foreign object debris could not be discounted.

The investigation identified the following causal factor:

1. The catastrophic failure of the Main Rotor Gearbox was a result of a fatigue fracture of a second stage planet gear in the epicyclic module.

In addition the investigation identified the following contributory factors:

1. The actions taken following the discovery of a magnetic particle on the epicyclic module chip detector on 25 March 2009, 36 flying hours prior to the accident, resulted in the particle not being recognised as an indication of degradation of the second stage planet gear, which subsequently failed.

2. After 25 March 2009, the existing detection methods did not provide any further indication of the degradation of the second stage planet gear.

3. The ring of magnets installed on the AS332 L2 and EC225 main rotor gearboxes reduced the probability of detecting released debris from the epicyclic module.

Seventeen Safety Recommendations are made.

1. Factual Information

1.1 History of the flight

1.1.1 Previous flights

The helicopter was scheduled to operate a series of flights from Aberdeen to oil platforms in the North Sea on the day of the accident. It was serviceable with one deferred defect affecting the ice detection system. This, however, did not affect its ability to operate in the prevailing weather conditions.

Prior to the accident flight the helicopter had flown an uneventful return passenger flight between Aberdeen and the Bruce Platform. The crew on that flight reported that there were no abnormalities observed during the external inspection or throughout the flight. The next flight, flown by a different crew, was scheduled to fly oil workers from Aberdeen to the Miller Platform (see Figure 1).

The flight crew operating the accident flight, reported for duty and carried out their pre-flight preparations. The helicopter arrived from its previous flight,

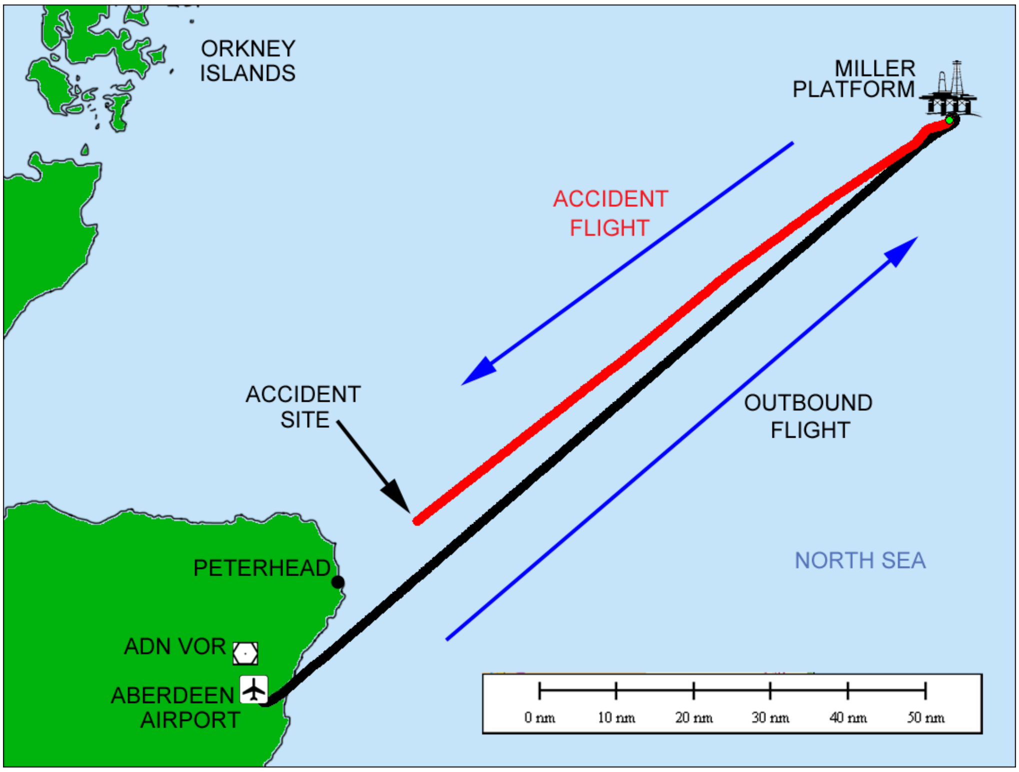


Figure 1

Location of the Miller platform

and a rotors-running crew change was carried out. The co-pilot boarded the helicopter first. The commander then entered the helicopter through the cabin, checked the aircraft technical log and received a brief from the off-going commander who described the deferred defect and stated that the helicopter was otherwise serviceable. He also informed the commander that the daily in-flight checks for the helicopter had been completed satisfactorily.

The helicopter was refuelled, the passengers boarded, and it lifted off at 1042 hrs. Most passengers destined for the Miller Platform described the outbound flight as normal, though a few thought they heard a noise, about 5-10 minutes before the landing, which they described as being similar to a heater or air conditioning unit being turned off. They did not, however, consider it sufficiently abnormal to report it to the crew. The helicopter landed on the Miller platform at 1149 hrs.

1.1.2 Accident flight

A rotors-running turnaround was carried out on the Miller Platform. The outbound passengers disembarked, the helicopter was refuelled and 14 passengers boarded for the inbound flight to Aberdeen.

The helicopter lifted off at 1203 hrs and climbed to 2,000 ft amsl, tracking inbound towards the ADN[1] VOR. Approximately 20 minutes before the expected arrival time at Aberdeen, the co-pilot made a routine call to the operating company, stating that the helicopter was inbound with 14 passengers, it was serviceable and was expected to arrive at 1314 hrs. Twelve seconds later, at 1254 hrs, the commander made a MAYDAY call on the Air Traffic Control (ATC) frequency; the co-pilot then made a similar transmission.

An eyewitness working on the vessel Normand Aurora, approximately two nm from the accident site, reported that the visibility was good. He recalled hearing and then seeing a helicopter descending rapidly before it hit the surface of the sea. He stated that the helicopter was not trailing any smoke. He then saw the main rotor blades, which had separated from the helicopter but still connected at the hub, fall into the water. Around this time, he also heard two "bangs" close together. After the helicopter struck the water a cloud of grey smoke appeared, which soon turned black. A few seconds later, he heard what he thought was an "explosion".

He raised the alarm immediately and the vessel turned towards the impact position.

1 The ADN VOR is located near to the airport at Aberdeen.

1.1.3 Search and rescue

A fast rescue boat was launched from the Normand Aurora as it made its way towards the accident site. The radar controller at Aberdeen acknowledged the MAYDAY call and tried unsuccessfully to contact the crew of G-REDL. He asked another helicopter (call sign 45B), outbound on a similar route, to examine the sea in the area where the helicopter was last seen on radar.

The flight crew of '45B', and the crew of the fast rescue boat, described arriving very promptly at an area of disturbed water, roughly 150 m in diameter. Debris from a helicopter, two life rafts and eight people wearing survival equipment were observed within the area. The fast rescue boat crew, however, found no signs of life.

Numerous other Search and Rescue (SAR) assets were on scene within 40 minutes of the accident.

1.1.4 Wreckage recovery

Radar data, and the information given by the eyewitness on the Normand Aurora, identified the probable location of the wreckage. On the afternoon of 1 April 2009, floating debris was recovered by several vessels which had positioned to the area. During the evening of 2 April a survey vessel, which had been operating in the area on behalf of the Maritime and Coastguard Agency, was tasked to survey the seabed using its high definition sonar system. By the morning of 3 April 2009, the ship had identified the location of three main items of wreckage, (see Figure 2).

The depth of the water precluded salvage divers operating from the surface, therefore a 'saturation diving recovery vessel' was chartered by the AAIB, and this was on station late on the afternoon of 4 April 2009. That evening, the Combined Voice and Flight Data Recorder (CVFDR) was located and recovered. By late afternoon on 5 April 2009 the remaining bodies and all the wreckage that could be identified on the seabed had been recovered on-board. The wreckage was transported to the AAIB facility at Farnborough on 6 April, where the detailed examination began.

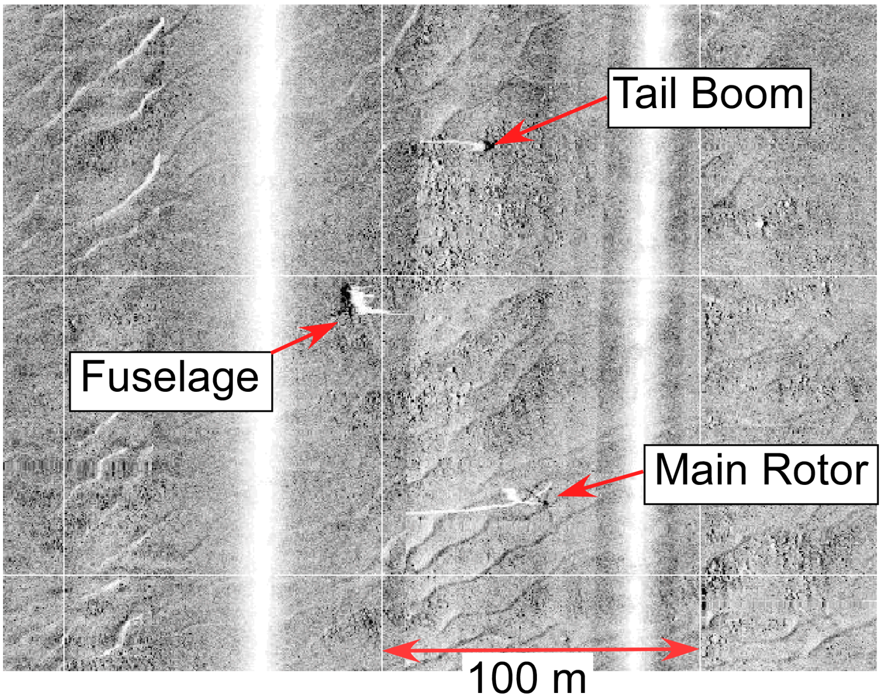


Figure 2
Sidescan sonar picture of main wreckage items

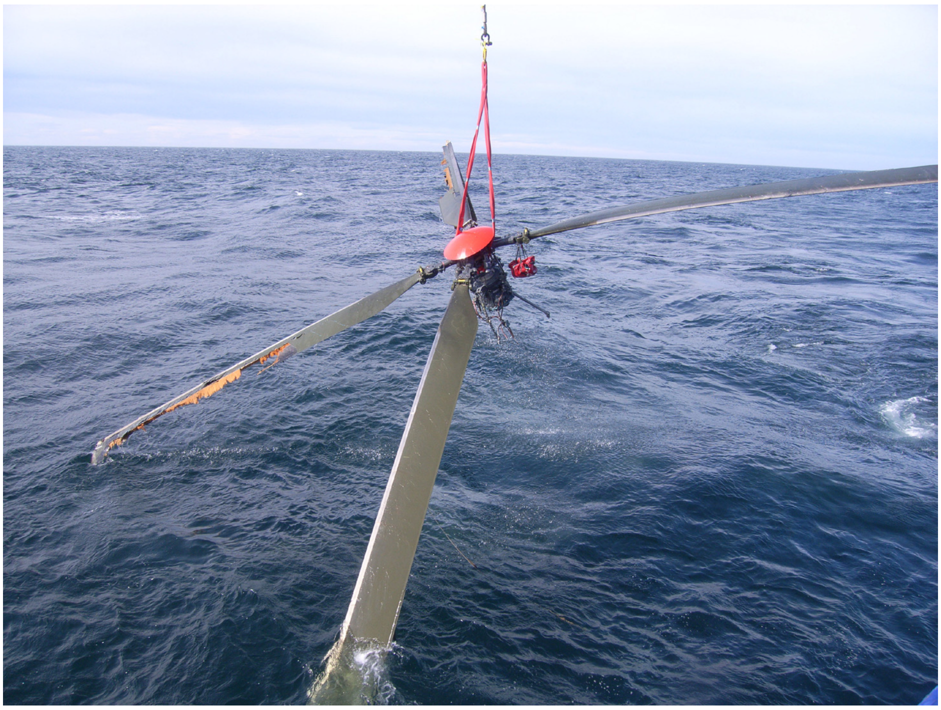


Figure 3
Main rotor head recovery

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	2	14	None
Serious	-	-	None
Minor/none	-	-	None

1.3 Damage to aircraft

The helicopter was destroyed.

1.4 Other damage

None.

1.5 Personnel information

1.5.1 Commander

Licence:	Air Transport Pilot's Licence (H)
LPC/OPC renewed:	16 February 2009
Line check renewed:	28 November 2008
Medical certificate:	2 September 2008
Total hours:	2,575 hours (1,870 on type)
Total PIC:	1,357 hours
Last 90 days:	96 hours
Last 28 days:	37 hours
Last 24 hours:	3 hours
Previous rest period:	24 hours

1.5.2 Co-pilot

Licence:	Commercial Pilot's Licence (H)
LPC/OPC renewed	5 January 2009
Line check renewed:	2 March 2009
Medical certificate:	18 March 2009
Total hours:	395 hours (140 on type)
Total PIC:	100 hours
Last 90 days:	140 hours
Last 28 days:	49 hours
Last 24 hours:	8 hours
Previous rest period:	16 hours

1.6 Aircraft information

1.6.1 General description and background

The Eurocopter AS332 L2 Super Puma is a four-bladed, twin-engine, medium-size utility helicopter marketed for both civil and military use. The AS332 L2 is a development of the AS332 L1 which is a lengthened version of the original AS332 helicopter. The AS332 L2 differs from the L1 in that it is fitted with an electronic flight instrumentation system, a redesigned rotor head and up-rated engines and transmission. Further development of the AS332 L2 led to the EC225 which incorporates a five-bladed rotor head and a further increase in engine power. The MGB of the EC225 makes use of the same main module and epicyclic module reduction gears as the AS332 L2.

The AS332 fleet (including military variants) includes 688 helicopters of various versions, which by the end of 2010 had accumulated approximately 4.2 million flight hours. By the same date, the AS332 L2 fleet (including military variants) had accumulated some 567,000 hours and the EC225 fleet (including military variants) 135,000 hours.

1.6.2 Leading particulars

Manufacturer:	Aerospatiale (Eurocopter)
Type:	AS332 L2
Manufacturer's serial number:	2612
Year of manufacture;	2004
Powerplants:	Two Turbomeca Makila 1A2 turboshaft engines
Total airframe hours:	7,728 hrs at 1 April 2009
Certificate of Airworthiness No:	055686/003
Category of C of A:	Transport Category (Passenger)
Valid until:	5 July 2009
Issuing Authority:	UK CAA
Certificate of Registration No:	G-REDL/R1
Registered Owner:	Bond Offshore Helicopters Ltd.
Issued:	10 May 1993
Issuing Authority:	UK CAA

1.6.3 Main (standard) characteristics

Standard aircraft empty weight including unusable fuel, oils and fluids :	4,660 kg
Maximum gross-weight at takeoff: (standard conditions)	9,300 kg
Helicopter performance (at 8,000 kg gross weight)	
Maximum speed, V_{NE}:	170 kt
Maximum cruise speed:	153 kt
Recommended cruise speed:	141 kt
Maximum rate of climb (at 70 kt):	1,732 fpm

G-REDL was configured for two crew and 18 passengers. However, since the early 2000s, most oil companies and operators have prohibited the use of the middle-rear seat, reducing effective capacity to 17 passengers.

Calculations have confirmed that the helicopter had been operating within its weight and centre of gravity limitations at the time of the accident.

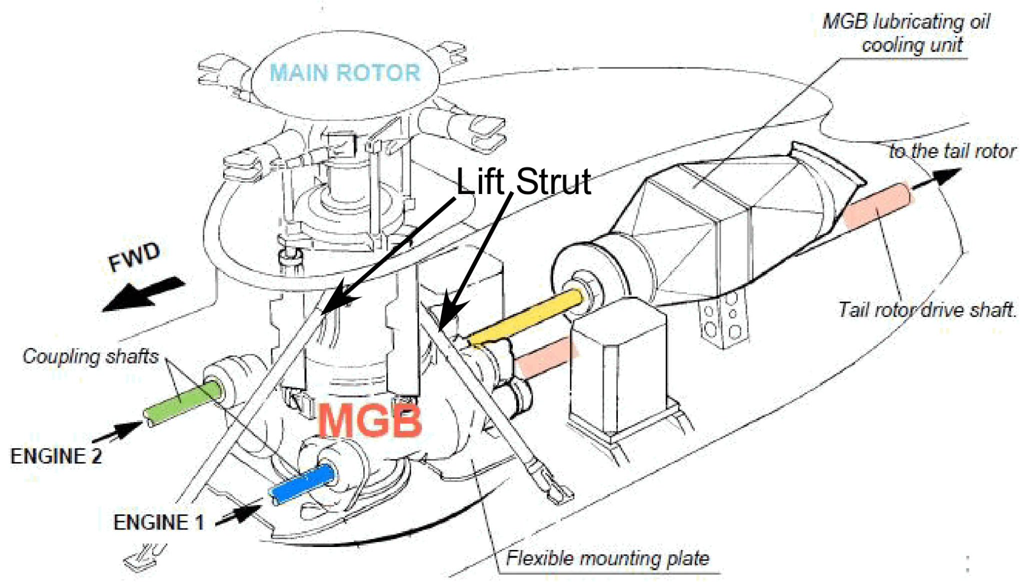
1.6.4 Flying controls

Control inputs from the cyclic control and main rotor blade pitch inputs from the collective control are transmitted from the cockpit to three hydraulic actuators mounted on the lower section of the MGB. These transmit control inputs to a non-rotating swash plate located immediately below the rotor head. Movement of the non-rotating swash plate results in a corresponding movement of the rotating swash plate and a change in main rotor blade pitch. Hydraulic power for the actuators is provided by two independent hydraulic circuits.

1.6.5 Transmission

1.6.5.1 General

Two shafts, one from each of the two free turbine Turbomeca Makila 1A2 engines, drive the main and tail rotors through the MGB, where the high speed of these shafts (23,000 rpm) is reduced to the nominal main rotor speed of 265 rpm, (see Figure 4).



(Courtesy of Eurocopter)

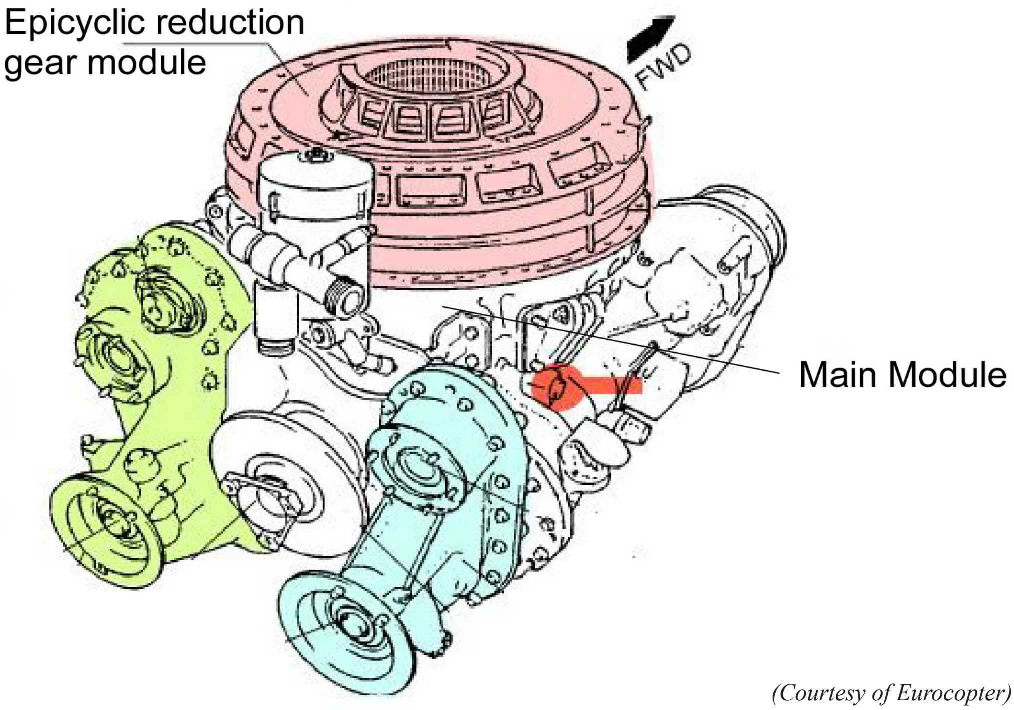
Figure 4

Transmission layout diagram

1.6.5.2 Main rotor gearbox (MGB)

The main rotor gearbox is spilt into two sections. The lower section, referred to as the 'main module', reduces the input shaft speed to around 2,400 rpm. The epicyclic reduction gearbox module is located on top of the main module, Figure 5. This reduces the rotational speed of the output from the main module to around 265 rpm (see Figure 6). A conical housing, which contains the main rotor head and drive shaft, is fitted on top of the epicyclic gearbox.

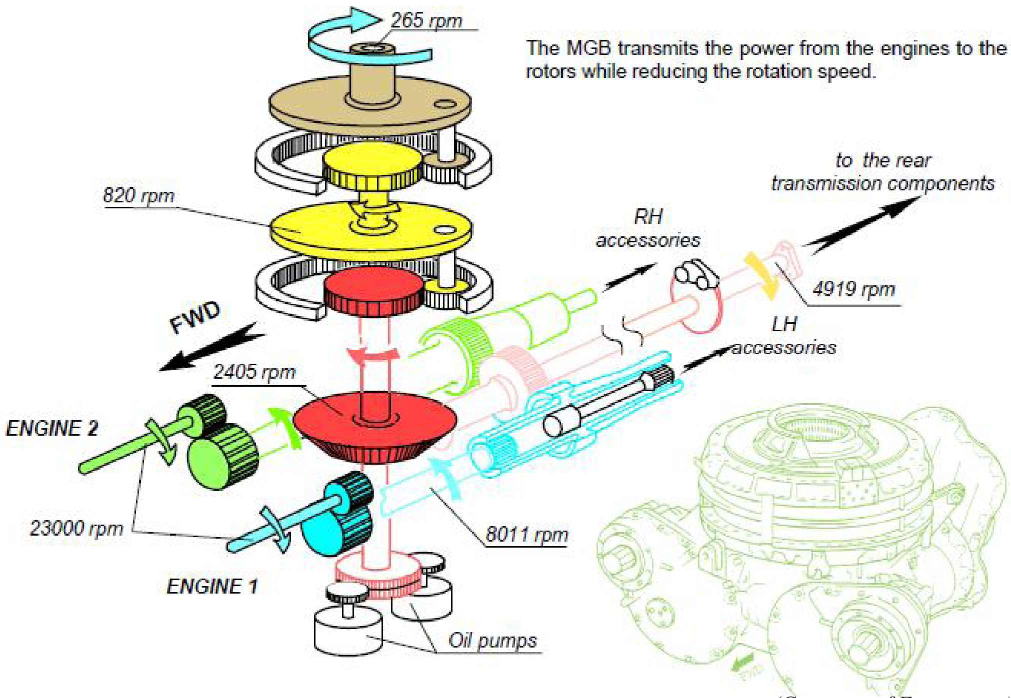
The MGB assembly is secured to a flexible mounting plate on the engine deck. This reacts the torque loads produced in the main rotor gearbox. The lift loads generated by the rotor system are transmitted to the fuselage by three 'lift struts' which are secured to the conical housing (see Figure 4).



(Courtesy of Eurocopter)

Figure 5

Location of the epicyclic gearbox (conical housing not shown)



(Courtesy of Eurocopter)

Figure 6

Main rotor gearbox internal configuration

Power output from both engines is transmitted to the main module of the MGB through the left and right reduction gearboxes, mounted on the front of the main module. These reduce the rotational speed of the input drive from 23,000 rpm to 8,011 rpm. The output from the left and right reduction gearboxes provides power to the left and right accessory modules respectively and is combined by the combiner gear within the main module (see Figure 6). This combined drive provides power to the tail rotor drive shaft and the bevel gear. The bevel gear reduces the rotational speed of the input drive to 2,405 rpm and changes the combined input into the vertical plane to drive the epicyclic reduction gearbox module.

Drive from the main module is transmitted via the first stage sun gear (see Figure 7). This drives eight first stage planet gears, contained by the first stage ring gear and mounted on the first stage planet carrier. The upper section of the first stage planet carrier consists of the second stage sun gear. This drives eight second stage planet gears, contained by the second stage ring gear and mounted on the second stage planet carrier, which then turns the main rotor drive shaft through a splined union.

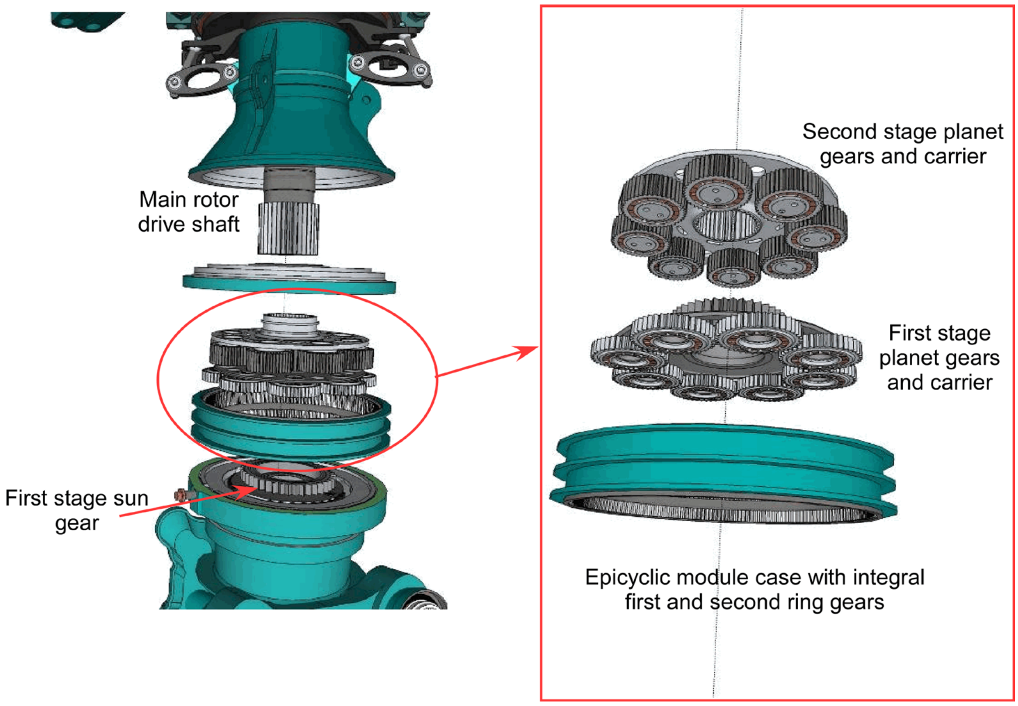


Figure 7
Layout of the epicyclic reduction gearbox

1.6.5.3 Second stage planet gear

The epicyclic module planet gears are designed as a complete gear and bearing assembly. The outer race of the bearing and the gear wheel are a single component, with the bearing rollers running directly on the inner circumference of the gear. The gear wheel of the planet gear has a total of 51 gear teeth. The remainder of the assembly consists of an inner race, two sets of 14 roller bearings, and two bearing cages. Each planet gear is 'self aligning' by the use of spherical inner and outer races and barrel shaped bearing rollers (see Figure 8). The geometry of the bearing rollers is such that, when rolling, the linear velocity of the surface of the bearing varies along its rotational axis. This means that some sliding of the bearing rollers on raceways may occur. The planet gears/outer race are manufactured from 16NCD13 steel, the bearing rollers and inner races from M50 steel.

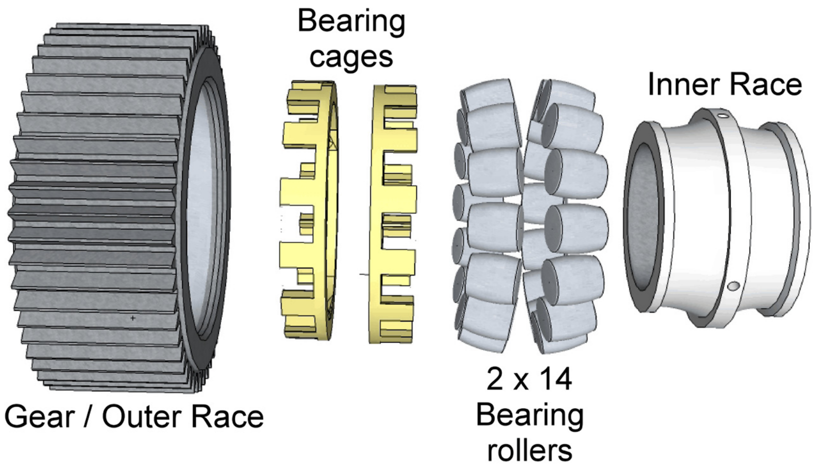


Figure 8

Planet gear configuration

The use of M50 steel in bearings is common within the aviation industry and its properties and performance are understood. However, its hardness makes it unsuitable for use as a gear, where it would be exposed to repetitive bending loads. The properties of 16NCD13 steel make it more suitable for use in the manufacture of gears; however, it is less suitable as a bearing surface.

In order to improve the cyclic load bearing characteristics of 16NCD13 steel, after initial manufacturing and finishing, the gear wheel undergoes a carburisation process. This involves immersing the component in a carbon-rich atmosphere (usually methane) which results in carbon molecules diffusing into the surface. The depth of the carburisation, which is dependant on the temperature and duration of the process, typically extends between 0.85 mm and 1.70 mm into the body of the material.

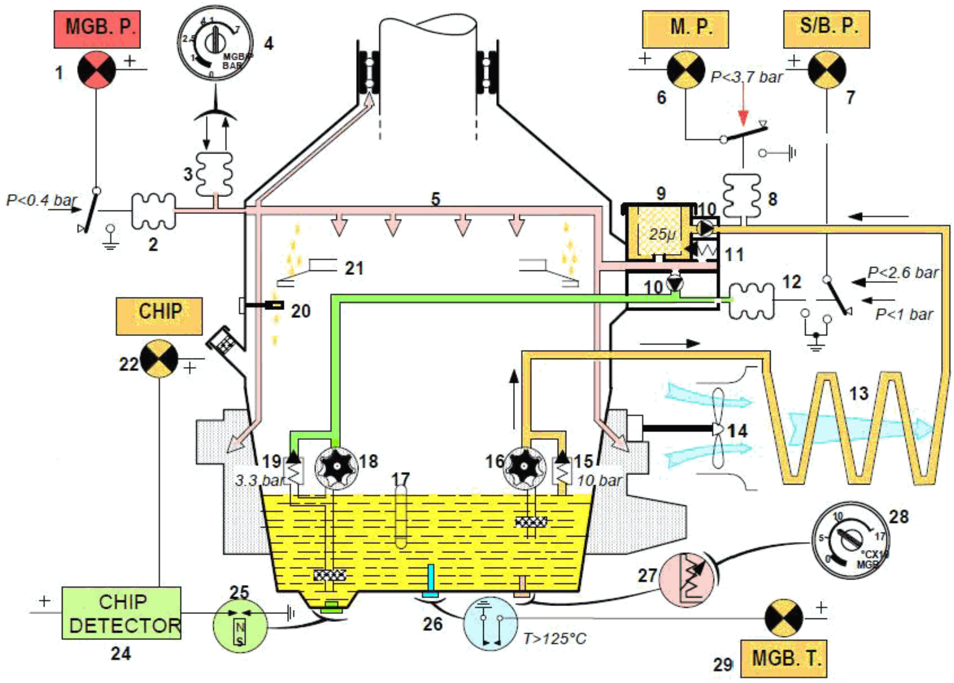
The process has two significant effects; firstly it hardens the exposed material, making it more suitable for use in bearing applications and secondly, it introduces a layer of residual compressive stresses close to the surface of the gear wheel. This second effect is particularly desirable for the bearing outer race area as it means that if any damage occurs within the carburised layer, the compressive stress should prevent the damage progressing into the body of the gear.

The gear wheel is carburised and finished, with the exception of the outer race surface, which is only partially finished. This is then matched with an inner race and set of bearings. As part of this matching process, the surface of the outer race undergoes two low speed honing processes, followed by low speed polishing. Prior to polishing, the surface of the outer race is chemically etched to ensure that the surface has not become overheated or the carburised layer breached during the honing process.

The design of the second stage planet gear used in the AS332 L2 took advantage of a significant amount of in-service and design experience from earlier AS332 and SA330 Puma helicopter gearboxes. The gear was designed to be capable of withstanding the operational loads of the EC225 helicopter which are higher than those of the AS332 L2. The helicopter manufacturer stated that the design took advantage of the technology available at the time and, recognising the potential limitations of the design process, took a conservative approach when determining the safety factors for the gear. The original design case of the planet gear determined that it had a safety factor of 4.15. The ultimate life of the gear, which was not required to account for operational wear, was based on a fatigue failure of a gear tooth. Calculations showed that, in this case, the gear would have an unlimited life. As a result of the helicopter manufacturer's experience of in-service mechanical wear with earlier AS332 and SA330 variants the planet gear was given an operational life of 6,600 flying hours in the AS332 L2 and 4,400 flying hours in the EC225.

1.6.5.4 Main rotor gearbox oil system

Lubrication for the MGB is provided by a primary and a standby oil pump (see Figure 9). Oil from the primary pump travels through the gearbox oil cooler before passing through a 25 micron filter. The filtered oil is provided to all the internal components within the gearbox through internal galleries.



1 - Oil pressure drop red warning light on 10WW panel (the MGB is no longer lubricated)
2 - Pressure switch (P<0.4 bar)
3 - Oil pressure transmitter
4 - Oil pressure indicator (0 to 7 bar)
5 - Lubrication ramp
6 - Amber warning light "main low pressure" on lubrication panel (P<3.7 bar)
7 - Amber warning light "Stand-by low pressure" on lubrication panel (2 thresholds : P< 2.6 bar or P< 1 bar)
8 - Pressure switch (P<3.7 bar)
9 - Oil filter (filtration 25 µ)
10 - Check valve (set to 0.1 bar)
11 - Filter bypass, Δ P 8 bar (opens in the event of clogging)
12 - Dual thresholds pressure switch (P< 2.2 bar or P< 1 bar)
13 - "Oil-to-air" heat exchanger
14 - MGB driven Fan
15 - Pressure relief valve set to 10 bar
16 - Main oil pump
17 - Oil level sight
18 - Stand-by oil pump
19 - Pressure relief valve set to 3.3 bar
20 - Intermodule magnetic plug
21 - Oil deflector (prevents pollution due to particles)
22 - Amber warning light (on lubrication panel): metallic chips
24 - Detection
25 - Magnetic chip detector
26 - Excessive oil temperature detection probe
27 - Oil temperature probe
28 - Oil temperature indicator
29 - Amber warning light excessive oil temperature (on XMSN monitoring panel)

(Courtesy of Eurocopter)

Figure 9

MGB oil system

1.6.5.5 Gearbox condition monitoring

The MGB is fitted with two magnetic chip detectors. One is located in the sump area below the main module and one adjacent to the epicyclic gearbox module. A third magnetic chip detector is located in the conical housing. These are designed to detect and retain any chips of magnetic material shed, for example, from the gears or their bearings. The main module magnetic chip detector provides a warning to the flight crew when a chip of sufficient size, or an accumulation of small chips, is detected (see Figure 10). The plug adjacent to the epicyclic stages provides evidence of chip detection to the HUMS when the helicopter is equipped with such a system, which was the case with G-REDL. The magnetic chip detector in the conical housing is not connected to any warning system and is visually inspected at periodic intervals.

The epicyclic module magnetic chip detector fitted to the EC225 provides flight crew with a visual warning of the detection of a magnetic chip in addition to recording the information on the HUMS, when fitted.

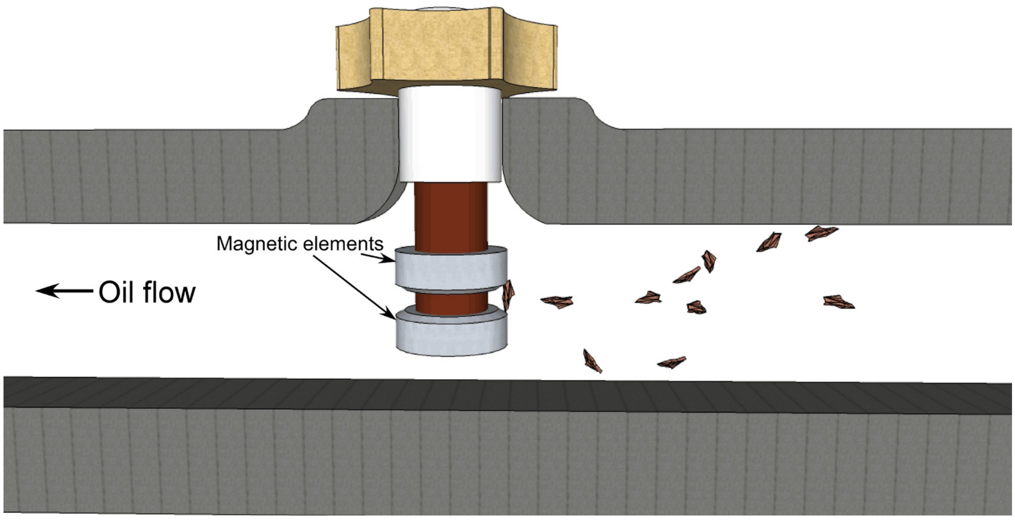


Figure 10

Generic diagram of a magnetic chip detector

1.6.5.6. Relevant design differences between the MGB of the AS332 L1, L2 and EC225 helicopters

AS332 L1

In-service experience of the epicyclic gearbox section of the MGB fitted to the AS332 L1 helicopter showed that 'spalling' (see 1.6.5.7) of the first and second stage planet gear spherical roller bearings could occur. This takes the form of 'flaking' from the raceways and rollers. Many small particles may be released as a result of the high stresses generated at the roller/raceway interface. This deterioration mode of the bearing is progressive and experience has shown that it does not compromise the operation of the MGB in the short term.

Lubrication oil is sprayed onto the various components and, under the influence of gravity, it descends to the bottom of the MGB, carrying any released particles (or chips). Relatively heavy particles within the oil are directed towards a low point in the sump where they can be collected by the chip detector. The location of the detector is such that it should collect a significant number of these particles, thereby providing a warning to the flight crew.

When particles pass through the main (lower) part of the MGB, they have the potential to cause minor damage (surface marking/indentations) to the bearings and gear teeth in this section of the MGB. This can lead to the need to replace these components.

AS332 L2

The design of the AS332 L2 MGB was based on the design of the L1 model, and used essentially the same main module as the L1. In order to maximise the benefits of the increased engine power between the L1 and L2, changes were made to the epicyclic gearbox module. These included increasing the size of the second stage epicyclic planet gears and reducing their number from nine, in the L1, to eight. These changes not only took account of the increased power to be transmitted, but were also aimed at reducing the probability of spalling.

In-service experience to date has shown an improvement over the L1 gearbox with respect to spalling. In order to further minimise the possibility of particles from the epicyclic gearbox contaminating the main module of the MGB, the gearbox was modified to a modular design. This modularity was achieved by adding two concentric oil deflector plates immediately below the epicyclic reduction gearbox, with a gap between them to allow for the passage of oil. A ring of magnets was attached around the inner circumference of the outer plate, with the intent that these would collect most of the particles generated by the epicyclic gearbox, preventing them from contaminating the main module (see Figure 11). However, these collected any magnetic particles produced by the epicyclic gearbox before they could be detected by the main module chip detector. This resulted in an additional magnetic chip detector being installed just below the epicyclic module. This was mounted on the main module casing, with the sensing element protruding into a recess in the edge of the outer plate. In this position, only a proportion of the oil draining down from the epicyclic module flows past the detector.

Certification testing demonstrated that when the slow degradation process of a bearing began to release particles, the epicyclic chip detector collected sufficient particles to give adequate warning of a problem using the prescribed inspection interval for the detector.

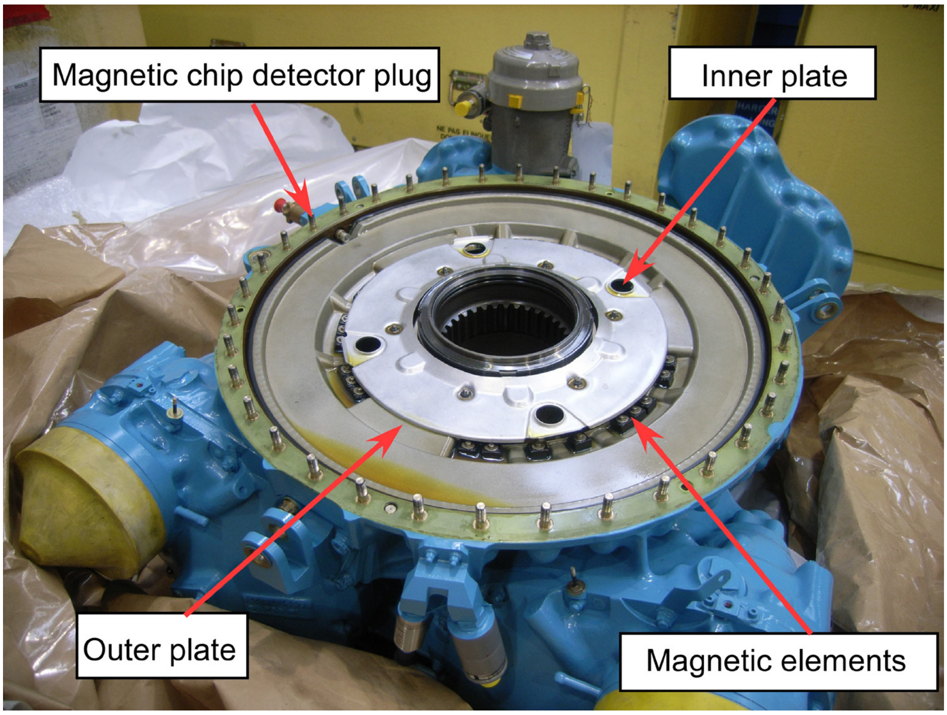


Figure 11

Main module with epicyclic module removed, showing concentric plates, ring of magnets and the epicyclic gearbox magnetic chip detector location

1.6.5.7 Spalling (rolling contact fatigue)

Spalling is a phenomenon which can be found in rolling element bearings and is one of the most common reasons for bearing failure.

Even when operating within the design criteria, the rolling elements and raceways of a bearing can eventually fail as a result of rolling-contact fatigue. This is characterised by spalling, which initiates when the cyclic loading of the surface results in the formation of small subsurface fatigue cracks. These eventually result in the release of microscopic particles from highly loaded areas of the surface of the race or rolling elements. The release of these particles leaves craters in the surface which act to further concentrate local stresses. Subsequent contacts at those sites cause the progression of further spalling which results in an increase in both the number and size of the particles released.

Spalling can be classified into two basic forms; subsurface initiated and surface initiated. Generally, subsurface initiated spalling originates at material defects such as large precipitates and inclusions within the shear stress zone below the contact surface. Historically, this was the most common form of spalling; however, due to significant improvements in steel production methods in the 1970's, such as that used on the AS332 L2, subsurface initiated spalling is rare.

Surface initiated spalling is not fully understood, but it is known to initiate from surface-breaking inclusions, micropitting/spalling, dents, grooves, etc. The dents may be generated by lubricant borne debris/ or Foreign Object Debris (FOD) being rolled into the surface.

1.6.6 EuroHUMS

EuroHUMS fulfils two functions; the Flight Data Recording System (FDRS) and the Health and Usage Monitoring System (HUMS). These two functions are combined into one system as there is some duplication of the flight data parameters used by each. The system comprises a number of avionics components, sensors and control panels.

Central to the EuroHUMS is the Digital Flight Data Acquisition Unit (DFDAU) which performs two roles. The first is to acquire flight data parameters from helicopter sensors, which are then recorded by the CVFDR and usage monitoring system. The second is to perform mathematical operations and data processing for the Vibration Health Monitoring (VHM) part of the HUMS. HUMS data is transmitted to an Airborne Interface Unit (AIU) which records the data to a data card.

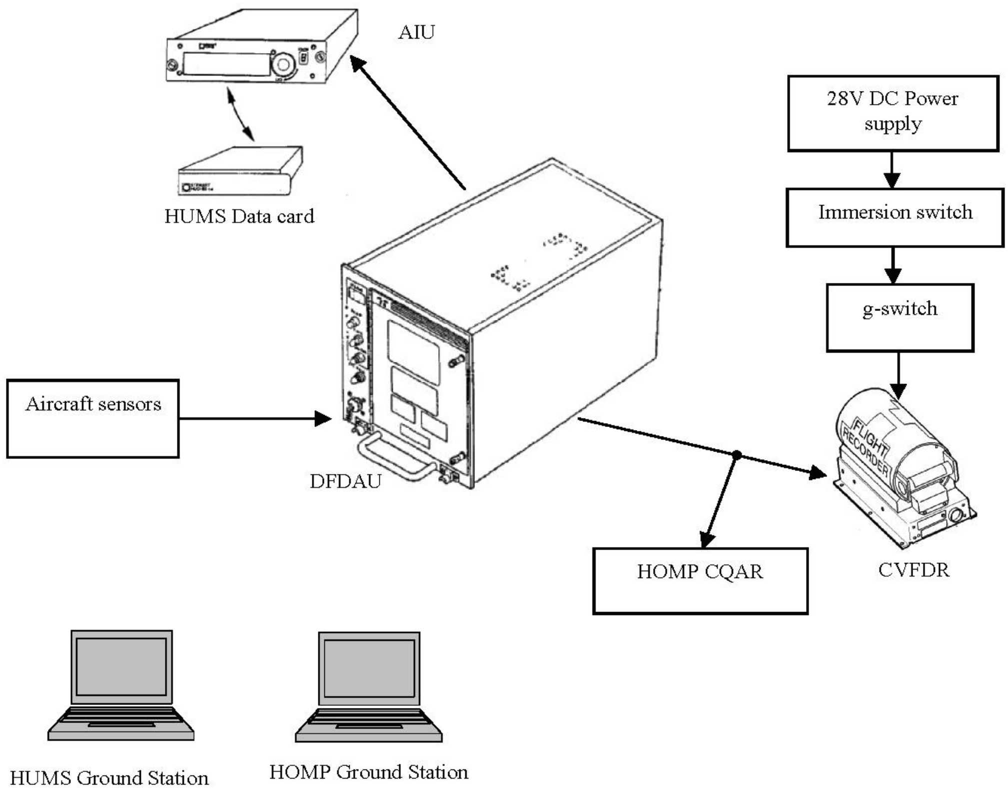


Figure 12
EuroHUMS

The HUMS is divided into two specific functions; health monitoring which monitors the health of the rotors, transmission assemblies and engines, and usage monitoring which monitors the usage of the airframe and dynamic components.

The safety potential of VHM was recognised by the CAA and, in June 1999, the system was mandated on UK registered helicopters with a Certificate of Airworthiness in the Transport Category (Passenger) and maximum approved passenger seating configuration of more than nine[2]. Civil Aviation Publication (CAP) 753 provides the latest guidance material for operators of VHM systems. VHM is defined in CAP 753 as:

> *'Use of data generated by processing vibration signals to detect incipient failure or degradation of mechanical integrity.'*

Systems operate by measuring the vibration response of a component over time in an attempt to identify any changes in vibration behaviour which might be identifiable as the early stages of degradation.

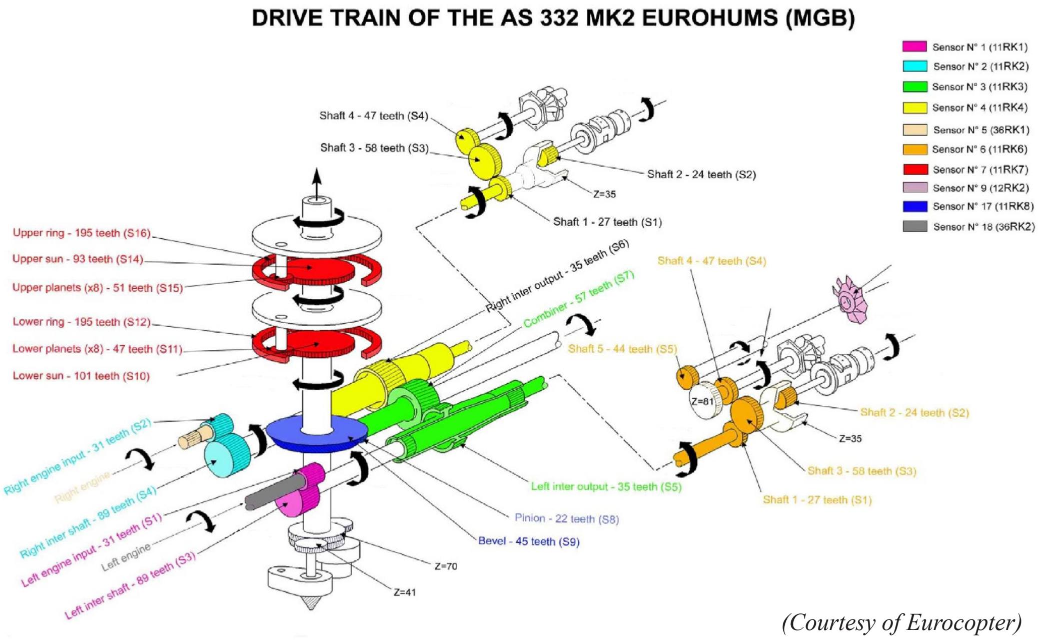
Despite being a mandatory fit for G-REDL, HUMS is regarded as a maintenance advisory tool by industry, and is not considered by the manufacturer as the primary method of detecting gearbox degradation. As such, HUMS is provided by the helicopter manufacturer as an option and, at 1 April 2009, 44 of the global fleet of 82 AS332 L2 helicopters were fitted with HUMS.

1.6.6.1 HUMS functionality

The G-REDL HUMS used a number of sensors installed around the engines, transmission and airframe. These sensors included accelerometers to measure vibrations levels, magnetic chip detectors to detect metallic particles within the gearboxes and engines, and tachometers to measure component rotational speeds. A number of other functions included rotor track and balance monitoring, airframe usage and recording of system status and warning alerts.

A total of 18 accelerometers were installed on G-REDL and each of the coloured items in Figures 13 and 14 represents the components monitored by each accelerometer. The first and second stages of the epicyclic module are monitored by one accelerometer, sensor 7 (11RK7).

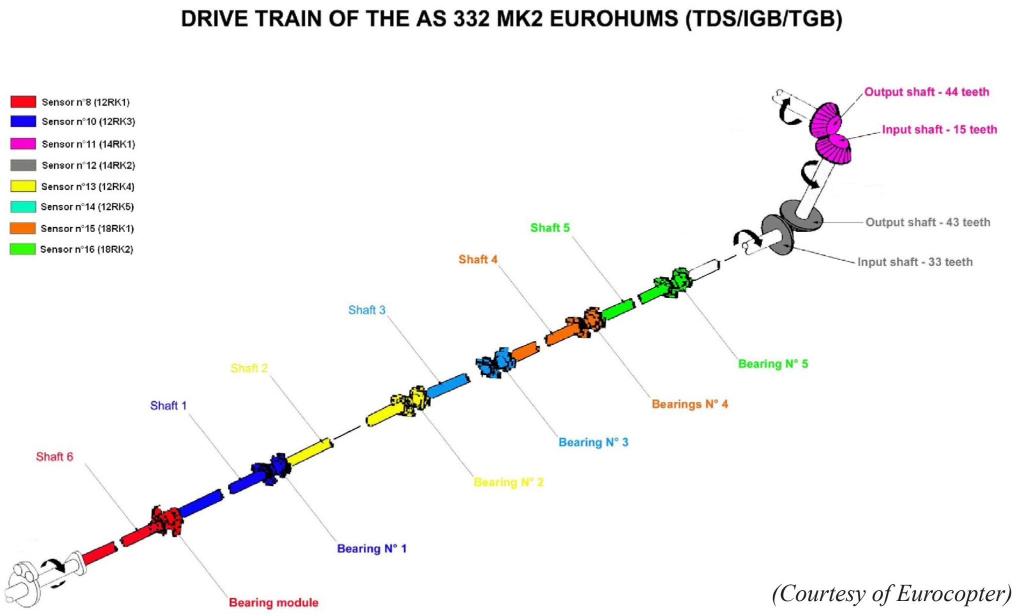
2 Additional Airworthiness Directive 001-05-99 issued in June 1999.



(Courtesy of Eurocopter)

Figure 13

EuroHUMS MGB monitoring



(Courtesy of Eurocopter)

Figure 14

EuroHUMS Tail Drive Shaft (TDS), Intermediate Gear Box (IGB) and Tail Gear Box (TGB) monitoring

1.6.6.2 Condition Indicators

The vibration effects associated with gearbox shafts and gears are generally synchronous with, or a harmonic of, the rotational speed of the shaft. The speed of each individual shaft is calculated using either an engine output shaft or the main rotor tachometer with an appropriate ratio. Signal averaging is then performed to improve the signal to noise ratio.

Typical bearing vibrations are not synchronous with the associated shaft speed, so signal averaging is not used in the EuroHUMS bearing signal acquisition. Some noise reducing measures are implemented, which are specific to the component being monitored.

After acquisition, the HUMS performs mathematical processes on each signal to generate diagnostic indicators known as Condition Indicators (CIs). These CIs are designed to reduce the complexity of the vibration signatures into a set of indicators that can show the level of energy in the vibration signal or a fault pattern.

The process of acquiring vibration data and the calculation of the CIs is specific for each component being monitored. Some CIs are defined as primary indicators and are used to flag alerts when the vibration levels exceed a threshold. Other CIs, known as secondary indicators, are used to provide further information on components under investigation.

In EuroHUMS, epicyclic planet gears and bearings are monitored as a first or second stage rather than as individual planet gears. If a trend is identified in planet gear CIs, it would not be possible to ascertain which planet gear had caused the change in vibration level. For bearing analysis, CIs are generated for the bearing outer races, inner races and rolling elements.

1.6.6.2.1 CI threshold setting

Thresholds are set on some HUMS CIs to alert operators to a change in the vibration data. An alert is triggered if a CI meets the criteria for exceeding the threshold. A red (level one) threshold is one which requires immediate investigation of the affected component. An amber (level two) threshold is set lower than red and requires observation of other indicators associated with the component. Trends above an amber threshold must be monitored and, if in doubt, contact made with the manufacturer.

Setting thresholds requires an important balance between being low enough to ensure that alerts are generated, but high enough to ensure spurious alerts are minimised. Thresholds, set by statistical review of fleet data and data from individual helicopters, are reviewed periodically.

Approximately 19% of the CIs have thresholds which are capable of generating either an amber or red alert on the ground station. These thresholds are all limited to gear indicators; there are no thresholds for bearing indicators. Of the 98 CIs for the epicyclic module gears and bearings, 18 have thresholds. The thresholds are set in the ground station so if an exceedance occurred in-flight, it would be only highlighted once the HUMS data was downloaded to the ground station.

1.6.6.2.2 Data collection

The HUMS classifies an ‘operation’ as the time between Nr[3] rising above 85 rpm nominal rotational speed and reducing to below 80 rpm, typically the time between engine start and shutdown. Information recorded on the data card includes the CIs, the processed vibration signals used to generate the CIs and any warnings or status information.

CIs for each component are not processed continuously throughout the flight but during specific flight regimes and at specific intervals depending on the gearbox component. This allows the vibration data to be compared to operations in a similar flight regime to establish whether there has been any change over time.

The majority of data collection is during the ‘normal’ flight regime which requires the helicopter to be operating in stable cruise conditions. Data is collected on a more frequent basis for faster rotating components such as the input shafts from the engines as, in general, components subject to higher rotational speed are likely to degrade more rapidly.

A complete ‘sweep’ of data collection for all gearbox components would take approximately 30 minutes and requires the helicopter to remain stable within the ‘normal’ flight regime. The system will alert the ground station operator if CIs for a component had not been captured in the last 10 flight hours. The epicyclic module CI collection intervals are all performed in the ‘normal’ flight regime (see Table 1).

3 Nr is defined as the rotational speed of the main rotor.

Component	Data collection interval (minutes)	Priority (low number is higher priority)
Second stage ring gear (S16)	45	13
Second stage planet gears (S15)	30	8
Second stage planet bearings	45	2
Second stage sun gear (S14)	45	12
Second stage sun bearings	45	2

Table 1

Second stage epicyclic module component HUMS data collection

Throughout the flight, as soon as the CIs have been calculated for a component, the data is transferred to the HUMS data card.

1.6.6.3 HUMS chip detection warning

G-REDL was fitted with seven magnetic chip detectors, six of which were electrically connected to the HUMS. These included one on each engine and one on the MGB sump, epicyclic module, intermediate gearbox (IGB) and tail-rotor gearbox (TGB). The engines and the MGB sump chip detectors were the only ones connected to indicators displayed in the cockpit. The status of the electronically monitored chip detectors was recorded on the HUMS data card throughout the flight.

The HUMS detection of a metallic chip works on the principle of a chip, or accumulation of small particles of conductive metal which bridge two elements to complete an electrical circuit. A minimum particle size of 2.28 (±0.12) mm is required to bridge the gap between the chip detector elements and provide an indication of the presence of a particle (see 1.6.5.5 Figure 10). If a particle continually bridges the chip detector element gap, additional particles collected by the chip detector will not be recorded on the EuroHUMS as additional chip detector warnings.

In order to minimise spurious warnings detected by a ‘loose’ particle on the detector, the EuroHUMS requires the chip detector elements to be bridged, completing the circuit, for a minimum of 15 seconds before a chip detection warning is triggered. For the system to record an additional chip detector warning, the circuit has to be opened for a minimum of 0.5 seconds before the circuit is re-made and confirmed for a further 15 seconds. The EuroHUMS records both the time of a chip detection warning and the cumulative chip detection warnings for each operation. This cumulative count is normally reset to zero at the start of each operation.

1.6.6.4 HUMS ground station

Data accumulated during helicopter operations is transferred, usually on a daily basis, to the operator's ground station. Once downloaded, data for each operation is summarised for the ground station operator in a series of summary screens. The operator is then expected to 'acknowledge' each operation via a menu selection to confirm that they have verified the data presented and have been made aware of any alerts, including chip detection warnings and threshold exceedances. Alongside the summary screens are a number of other menus allowing the operator to view further detailed data such as each CI, chip detections and supplementary recorded data. This data is typically accessed after an alert has been generated to facilitate troubleshooting.

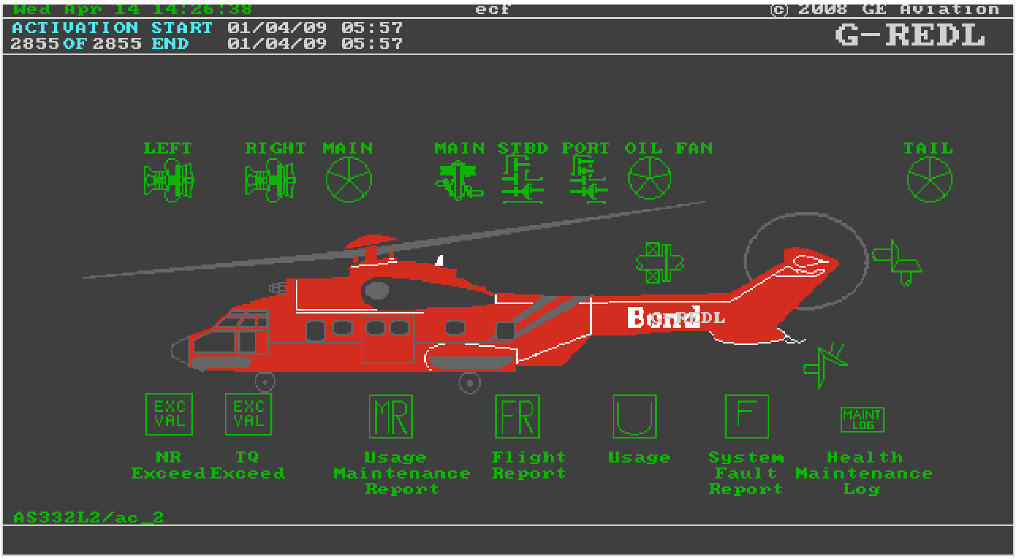


Figure 15

EuroHUMS ground station screenshot

The ground station will also automatically print three reports for each operation; the Flight, Usage and Health Reports which are essentially duplications of the information provided on-screen. The Flight Report details items such as aircraft identification, operation duration, engine timings and the number of warnings generated for the flight. The Usage Report details the usage and exceedances, and the Health Report summarises the maintenance actions for the operation. If a chip is detected or a CI threshold is exceeded, this is normally indicated in the Health Report.

If an alert has been generated, the ground station operator can be alerted in a number of ways. On the screen pictured in Figure 15, there will be a colour change of the icon in the area of the helicopter where the alert was generated. If a level one threshold exceedance has occurred, an icon should flash red, if a level two threshold or a chip detection, the icon should flash purple. If no alerts are generated, all icons will be green. Alerts are also summarised on-screen in the respective Flight, Usage and Health reports.

1.6.6.4.1 HUMS reporting procedure

In the event of an alert generation there is an established procedure to allow the operator to contact the helicopter manufacturer HUMS specialists for support. This procedure (AMM 45.11.02 Appendix A) involves the operator completing a EuroHUMS Diagnostic Report (EDR) which is transmitted to the helicopter manufacturer's HUMS specialists. This report should specify the apparent problem, the helicopter concerned, the generated warnings and ground station messages and details of the helicopter's operation when the warnings were generated. When the EDR is received it is processed within the helicopter manufacturer and the 'Eurocopter only' answer section of the EDR is completed and returned to the operator. The procedure also states that:

> *'In the event of a mechanical failure on the aircraft, detected or not by the HUMS system, it is advisable to send an EDR to the EC support in order provide feedback.'*

There was no direct data link between the helicopter manufacturer and the operator's ground station. HUMS support by the manufacturer relied on emailed screenshots and periodic copies of the ground station database to facilitate technical support.

1.6.6.5 HUMS issues

A detailed review of the HUMS data during the investigation revealed a number of issues with the EuroHUMS.

1.6.6.5.1 HUMS data card

After the helicopter is shut down and prior to removal of the data card from the AIU, the last remaining HUMS data is transferred to the card. The HUMS relies on information from the helicopter sensors to activate this transfer, which can also only be completed if there is sufficient space on the card. A card can hold approximately 10 hours of data.

The effect of not closing down the HUMS data card correctly is that the HUMS will not know that the operation has ended. When the data card is then downloaded to the ground station, the operation end time will display the operation start time and the printed Flight Report an operation activation time of zero hours. Other more significant effects are that the ground station will not display any alerts on any of the summary screens if any chips are detected or CI thresholds exceeded, and no Health Report will be printed.

Despite not displaying any alerts, all the recorded data on the data card will be successfully downloaded to the ground station and the Flight and Usage Reports will be printed. To establish whether a chip was detected, the operator can navigate the ground station menus to establish the status of each chip detector for each operation.

This problem, also known as 'card lockup', had been experienced by the operator and other HUMS users prior to the accident and measures had been implemented by the manufacturer to try to prevent it occurring. These included instructions to flight crew not to remove the HUMS card until its shutdown operations were indicated as being completed. However, the operator reported that the full consequences of the 'card lockup' problem were not known until this investigation. In addition, no troubleshooting measures were available in the Aircraft Maintenance Manual (AMM) to specifically identify it and the actions that should be taken.

On 3 July 2010 the operator of G-REDL was carrying out routine maintenance on G-REDN, another AS332 L2, when it discovered metallic particles on both MGB and the main rotor head magnetic chip detectors. During an AAIB investigation, the 'card lockup' problem was once again encountered and as a consequence, on 23 September 2010, the operator issued an internal Technical Information Letter (Appendix B) on the subject. In September 2011 the helicopter manufacturer released Information Notice 2368-I-45 which informed operators of this issue. They have also indicated that in a new version of the EuroHUMS ground station software, this issue is monitored with a maintenance task card in place to allow action to be taken. This software is available for upgrade through Eurocopter Service Bulletin AS332-45.00.46 dated 6 April 2011.

1.6.6.5.2 First stage epicyclic module accelerometer

When EuroHUMS was first introduced on this helicopter type, the first and second stage epicyclic module vibration was monitored by two different accelerometers. In 2007, as a product improvement, the helicopter manufacturer issued Service Bulletin (SB) 45.00.21 to move the accelerometer monitoring the first stage of the epicyclic module to the left accessory gearbox. The accelerometer designated to monitor the second stage of the epicyclic module was then to be reassigned to monitor both epicyclic stages, and was to be accomplished by a software change in the airborne HUMS. The SB ensured that this was accomplished for the analysis of the first stage of epicyclic gears but not for the analysis of bearings.

As a consequence, at the time of the accident, the first stage epicyclic bearing analysis used data from an accelerometer mounted on the left accessory gearbox. According to the manufacturer, this rendered all HUMS data for the first stage epicyclic module planet and sun gear bearing analysis invalid. This has since been corrected by Eurocopter SB 45.00.21 revision 1, dated 23 July 2009.

1.6.6.5.3 Epicyclic module bearings pattern analysis

To calculate the rotational speed of the epicyclic components, the HUMS used a tachometer attached to the engine drive shaft, along with a ratio to ascertain the expected rotational speed of each component. For the epicyclic module, these ratios were discovered to be incorrect for all the bearing *pattern* analyses CIs which rendered them as invalid. According to the manufacturer, the bearing *level* analysis was not affected.

Since the accident, the helicopter manufacturer has implemented corrective action as part of new EuroHUMS ground station software which is available for upgrade through Eurocopter Service Bulletin AS332-45.00.46 dated 6 April 2011.

1.6.7 Maintenance information

1.6.7.1 Maintenance requirements

The MGB of the AS332 L2 has an overhaul life of 3,000 flying hours. Due to higher loading, the MGB of the EC225 has an overhaul life of 2,000 flying hours.

In addition to the HUMS monitoring of the MGB chip detectors and the warning light linked to the main module chip detector, the approved maintenance programme for the AS332 L2 included a requirement to carry out a periodic visual inspection of each magnetic plug for contamination in accordance with AMM 60.00.00.212 (Appendix C). The required period of inspection was 25 flying hours for the epicyclic module chip detector and rotor mast chip detector, and 100 flying hours for the main module chip detector.

At the time of the accident, if HUMS recorded chip detection warnings the HUMS ground station directed the operator to carry out maintenance task card reference 45.11.02.07; '*Metal particle detection fault*' (see Appendix A). Since March 2010, operators have been directed to use maintenance task card 45.11.02.08 which requires inspection of the magnetic chip detectors in accordance with AMM procedure 60.00.00.212.

The procedure to inspect a magnetic chip detector is contained in AMM procedure 60.00.00.212 (see Appendix C). This procedure includes details of the inspection procedure for electrically monitored chip detectors, and the additional steps to take on discovery of a particle. If a particle is found on the epicyclic chip detector, engineers are directed to complete subtask 3.1, which includes the following instructions:

'- *if particles are found, open the epicyclic module*
- *Remove the epicyclic module as per 63-22-00-021*
- *Use a magnet to recover all particles which you find on the magnets of the collector.*
- *Refer to MTC for the analysis of the recovered particles:*
    - *If the results of the particle analysis fall within the limits of the acceptable criteria, install the epicyclic module as per 63-22-00-421*
    - *If the analysis results are out of the limits of the acceptable criteria:*
        - *Send the epicyclic module to an approved repairer's shop for survey:*
        - *Refer to subtask 05-53-00-218-001 and 05-53-00-218 to check the contamination of the flared housing and of the MGB'*

If particles are found on the main module chip detector, subtask 3.4 of procedure 60.00.00.212 directs engineers to task 60.00.00.641, which details the requirements for draining and inspecting the MGB oil for contamination and to task 05.53.00.218, (see Appendix D). This gives all the steps necessary to recover any metallic particles from the MGB oil system and the MGB sump plate. A review of the EC225 AMM, at the time of the accident, identified that this manual did not include the need to remove the epicyclic module and examine the magnets on the separator plates, even though both helicopters share a common design of epicyclic and main modules. This disparity has since been corrected.

The Maintenance Task Card (MTC) referred to in task 60.00.00.212 is MTC 20.08.01.601 entitled '*Periodical Monitoring of Lubricating Oil Checking Elements*' (see Appendix E). This is a generic procedure used for a number of different helicopter types. The procedure contains a number of paragraphs describing the various types of particle which may be found within the MGB and a number of basic chemical tests which could be performed to verify the type and material of a particle. The use of these tests are caveated by cautions that the size of the particle may prevent more than one test being carried out, and that if the MGB is to be sent for repair, the particles should be sent to the overhaul agency with the MGB without chemical testing by the operator. No illustrations or photographs of representative particles, to aid the process of identification, are included in the procedure.

If, after completion of MTC 20.08.01.601, particles of nickel or carbon steel are identified and the volume of particles collected is within limits, the MGB can be returned to service but is required to undergo 'close monitoring' for the next 25 flying hours. This procedure is described in AMM task 05.53.00.218 subtask 003, (see Appendix D).

If the particles recovered are classified as silver or cadmium, the MTC 20.08.01.601 states that *'these particles form part of the plating of certain elements and are unimportant'*. It goes on to state *'normal inspection of the power transmission assembly',* meaning that the MGB can be returned to service without the need to undergo any additional monitoring.

1.6.7.2 G-REDL Maintenance history

1.6.7.2.1 General

A team of AAIB inspectors were at the operator's facilities on an unconnected matter at the time of the accident. Immediately, on being notified of the accident, they quarantined all the documentation and records relating to the operation and maintenance of G-REDL.

Examination of the maintenance records confirmed that G-REDL was compliant with all the mandatory Service Bulletins and Airworthiness Directives in force at the time of the accident. There were no in-service defects relating to the MGB prior to 25 March 2009. Due to operational life limitations, on 1 March 2009 (150 flying hours prior to the accident) the main rotor gearbox conical housing/rotor head was removed and replaced with an overhauled unit. This replacement was completed by the operator in accordance with the manufacturer's approved procedures. Discussions with the engineers involved confirmed that no abnormalities had been encountered during the task and that adequate controls had been in place to prevent foreign objects from entering the MGB whilst the conical housing was being removed. During these discussions it also became apparent that after previous conical housing/rotor head replacements, magnetic particles had been discovered on the MGB chip detectors of other helicopters. On investigation these were found to have been generated during the conical housing/rotor head replacement. Other operators of the type and the manufacturer confirmed that this was not an unusual occurrence.

1.6.7.2.2 Maintenance performed on 25 March 2009

The following account has been compiled from information obtained from the helicopter records, statements from the operator's engineering staff and information provided by the helicopter manufacturer.

On 25 March, G-REDL was scheduled to operate a number of flights from Aberdeen to various oil production platforms. G-REDL returned from the first of these flights at approximately 0820 hrs and the normal turnaround maintenance was carried out. This included removal of the HUMS card for replay on the HUMS ground station. After completion of the turnaround maintenance, G-REDL departed for its second series of flights. During the subsequent download of the HUMS card, an alert was observed, indicating that an epicyclic module chip detection warning had been recorded. Discussions with the pilots who had flown the helicopter into Aberdeen confirmed that there had been no abnormalities on the inbound flight and the helicopter was allowed to continue to operate its planned flight. In order to investigate the reported warning, the decision was made to remove the helicopter from the remainder of the day's flying programme on its return to Aberdeen.

On the helicopter's return to Aberdeen, at approximately 1140 hrs, a physical inspection of all of the MGB magnetic chip detectors was carried out. No particles were found on any of the detectors; however, the body of the main module chip detector appeared to be loose in its housing, so it was replaced. There were no reported defects apparent with the epicyclic module chip detector. The HUMS card was removed from the helicopter for downloading. The helicopter was then moved into a hangar to allow further investigation of the chip detection warning and a scheduled 25 hour inspection.

After the HUMS data from the second series of flights was downloaded, the engineer analysing the data noted that there was another alert relating to the epicyclic magnetic chip detector. The ground station logged the following message "*94 CHIP(S) DETECTED – WORK CARD 45.11.02.07: CHIP 2*". The work card, (see Appendix B), gave details of troubleshooting a defect within the chip detection system. The same engineer went to G-REDL in the hangar, removed the epicyclic magnetic chip detector and observed a small metallic particle adhering to it. He stated that, from his previous experience, he did not think that this discovery was unusual due to the conical housing/rotor head replacement, which had been completed on 1 March 2009. He informed the engineering supervisor of the presence of the magnetic particle. As he had already removed and inspected the epicyclic chip detector, he informed another engineer who had been tasked with inspecting the magnetic chip detectors as part of the 25 hour check, that he would inspect the remaining magnetic chip detectors. He then checked the other two magnetic chip detectors. The work card for the completion of this task was subsequently signed off later that evening.

The particle was removed from the chip detector and mounted on a 'debris slide'. This slide was found within the helicopter records after the accident, labelled as having been removed from the epicyclic magnetic chip detector. No reference was made to AMM 60.00.00.212 and the epicyclic module was not removed to recover any particles which may have collected on the magnets fitted to the gearbox separator plate. However, as a result of the discovery of the magnetic particle, the operator had initiated a plan to remove G-REDL's MGB and replace it with a unit from another helicopter undergoing heavy maintenance.

During the analysis of the recent HUMS data, the engineers had observed an abnormal vibration trend on the main module bevel gear and had decided to contact the helicopter manufacturer's HUMS specialists for advice by telephone. All the subsequent communication between the operator and manufacturer took place using a combination of telephone conversations and email exchanges. The operator's engineer stated that whilst the first telephone conversation regarding the HUMS trend was ongoing, the manufacturer's HUMS specialist was made aware of the presence of a particle on the epicyclic module magnetic chip detector. The EDR procedure was not used.

The manufacturer stated that their HUMS specialist was contacted by the operator's engineering department and reported that: "There was a chip warning on the EuroHUMS software on the epicyclic module", although the number of warnings was not specified. The statement continued; "Trends were also observed on the Bevel Gear S9" and "that maintenance staff had found a few particles detected in the bottom of the main gear box."

Information provided by the manufacturer stated that their HUMS specialist believed that metallic particles had been found in the main module of the gearbox, not the epicyclic module. It was also stated that he had commented to the operator's engineer that it was unusual to find particles in the main module of the gearbox when the chip detector alert had been generated by the epicyclic gearbox chip detector.

The operator's engineers had no recollection of this being discussed.

In order to provide the operator's engineers with the assistance that had been requested, the manufacturer's HUMS specialist verbally relayed the information that several small particles had been found on the main module chip detector to a specialist in the mechanical aspects of the AS332 L2 MGB. In response to inquiries made by the BEA during the course of the investigation, the manufacturer stated that they believed that all the maintenance actions detailed in AMM tasks 60.00.00.212, 60.00.00.641 and 05.53.00.218, relating to the discovery of particles on the main module chip detector, had been completed.

The operator called the manufacturer at 1656 hrs and were given advice regarding troubleshooting the defect which included completion of Maintenance Task Card 20.08.01.601, (see Appendix E), and a torque check of the rotor brake 'shur-lock' nut. This was confirmed at 1723 hrs BST by an email from the manufacturer which stated:

> *'Dear all*
>
> *I send you this e-mail concerning G-REDL.*
>
> *Further to our phone conversation, we have contacted our mechanical experts.*
>
> *We would recommend you to apply and follow work card 20.08.01.601 dealing with the check of the power transmission assembly on the magnetic plug.*

> *If you find less particle than the criteria value (maximum 50mm^2) then check in detail the shur-lock rotor brake (nut torque…).*
>
> *If nothing abnormal is found there is no need to ground the aircraft and you can go flying tomorrow morning.*
>
> *After this flight, please send us updated graphs and inspect both magnetic plugs on the MGB.*
>
> *We remain at you dispose in case of other requests*
>
> *Best regards……'*

In addition to completing the maintenance task card actions, the gearbox oil filter was removed and examined and the gearbox drained of oil which was then filtered. No additional metallic particles were found.

Using MTC 20.08.01.601 the engineers began to examine the particle. The particle dimensions were 2.88 x 0.8 mm. After comparing the descriptions of various types of particle they came to the conclusion that the particle was a piece of 'scale'. Further visual examination of the appearance of the particle led them to believe that it was silver or cadmium plating which, in accordance with MTC 20.08.01.601, was '*..unimportant..'* and did not require the gearbox to be removed from service or to be put on 'close monitoring'.

The gearbox was declared serviceable by the operator and its planned replacement cancelled. The 25 hour inspection was completed with no further defects identified which were related to the accident. The documentation for the check, including the inspection of the magnetic chip detectors, was completed during the evening of 25 March 2009. The write up of the inspection of the magnetic chip detector, discovery of the magnetic particle and the subsequent work carried out to confirm the gearbox's serviceability made no reference to AMM task 60.00.00.212.

In order to determine if the gearbox would produce more metallic particles when returned to operation, the operator raised a task card which stated "*inspect the epicyclic and main module chip detectors every shut down for the next 25 flying hours*". A physical inspection of all the magnetic chip detectors was completed during every turnaround in Aberdeen, together with a download of the HUMS card. The helicopter remained on this additional monitoring up until the day of the accident, some 31 flying hours after the discovery of the metallic particle. No additional particles had been detected during this period.

It was later determined by the helicopter manufacturer that the abnormal trend was an anomaly within the HUMS ground station and did not represent a deterioration of the gearbox components.

1.6.8 Epicyclic reduction gearbox history

In June 2004 the epicyclic module (manufacturer's serial number M2088) was removed for overhaul due to the presence of metallic particles being found on the magnetic chip detectors. The module had accumulated 844 flying hours since new. During this overhaul all the first and second stage planet gears were replaced with new units. The manufacturing records for these gears were examined, and it was confirmed that there were no abnormalities recorded in any of the production process and that all the gears passed the required quality tests and inspections.

After overhaul, the epicyclic module, together with other modules, was built into a complete MGB. This assembly was fitted to G-REDK in April 2006. On 6 February 2007, G-REDK sustained a lightning strike. After successfully completing the required inspections, the MGB was assessed as serviceable and it remained in operation. The MGB operated for 2,113 hours until it was removed for a scheduled overhaul.

Following its overhaul, the MGB was then installed in G-REDL in April 2008. At the time of the accident the epicyclic module had accumulated approximately 4,467 hours since new and the planet gears within the module 3,623 hours since new.

A review of the overhaul records for the epicyclic module confirmed that no anomalies were found during overhaul.

1.7 Meteorological information

At the time of the accident, the UK was within a broad, warm sector. High pressure, centred in the central North Sea, resulted in a light south-east to southerly surface flow. The proximity of the high pressure cell resulted in a subsidence inversion that generated cloud-free regions, and otherwise limited cloud tops to approximately 5,000 ft or 6,000 ft amsl.

The reported conditions at Aberdeen at 1250 hrs were surface wind 170/7 kt, visibility 10 km or more, broken cloud with a base of 4,200 ft, and a QNH 1024 mb. The temperature was 13°C and the dewpoint 4°C.

Pilots of other helicopters flying in the same area at the time described that there was no cloud below 3,000 ft, visibility was "excellent", and flying conditions were "smooth". They described the sea state as "flat calm".

1.8 Aids to navigation

Not applicable to this investigation.

1.9 Communications

The helicopter was operating under the call sign 'Bond 85N'. The helicopter was in contact with Aberdeen ATC prior to the accident.

1.10 Aerodrome information

Not applicable to this investigation.

1.11 Flight Recorders

The FDRS records data acquired by the DFDAU and the audio from the commander and co-pilot's headset and Cockpit Area Microphone (CAM) to the CVFDR.

The CVFDR is powered from the battery bus and will start recording as soon as the bus is energised. The CVFDR power supply can be interrupted by loss of the battery bus or by means of two switches which are designed to operate in the event of an accident. These are an immersion switch which operates on contact with water, and a 'g-switch' which senses acceleration. The g-switch is in place to satisfy an airworthiness requirement requiring the cockpit voice recording to stop within 10 minutes of a crash. It operates by mechanically sensing the level of acceleration in all three axes, cutting electrical supply once 6g has been exceeded.

The operator also operated a Helicopter Operations Monitoring Programme (HOMP) which is a helicopter version of the fixed wing Flight Data Monitoring (FDM) programmes. G-REDL was fitted with a Card Quick Access Recorder (CQAR) which recorded a direct copy of the data stream sent to the CVFDR onto a PCMCIA card. The CQAR was powered by a different electrical supply from the CVFDR. The PCMCIA card was removed periodically from the helicopter and downloaded to a ground station for analysis. The operator kept a database of HOMP data for each helicopter to facilitate analysis of helicopter operations over time.

1.11.1 HUMS data prior to 1 April 2009

A review of the operator's HUMS database between the date of the installation of the MGB and 23 March 2009 revealed no recorded chip detection warnings on any of the HUMS magnetic chip detectors. A review of the ground station summary screens for 24 March 2009 revealed no alerts, nor were any highlighted in the helicopter technical log. Upon detailed review of the HUMS data, an epicyclic module chip detector warning was recorded at 1443:33 hrs with HOMP data confirming that, at the time, the helicopter was in the cruise.

The cumulative chip detection warning count then increased for the remainder of the operations of 24 March 2009, reaching a total of 667 at the end of operations. A review of the detection timings, which were recorded once per second, revealed that 579 detections were recorded at between 15 and 16 seconds apart. The helicopter manufacturer considered such a high chip warning count as unusual and after reviewing the EuroHUMS operation confirmed that they had not encountered it before. They considered the most likely explanation was a chip of a size which only just bridged the chip detector elements, making or breaking the electrical contact depending on the oil flow in the gearbox.

The operation start and end time for 24 March 2009 were both noted to be 0719 hrs and no Health Report could be found in the operator's archive. The symptoms suggested that the HUMS card did not close down normally on 24 March 2009, meaning that any alerts would not have been displayed on the ground station. A review of the HOMP data confirmed that the rotors running time was in excess of 10 hours duration, indicating that the card may have been full.

On 25 March 2009, the HUMS recorded two operations, the first starting at 0618 hrs. Epicyclic chip detection warnings were recorded; the first at 0621:20 hrs, just after engine start with the helicopter on the ground in Aberdeen. Once the first operation ended at 0822 hrs, the cumulative chip detection warning count had reached 76, 42 of which were 15 or 16 seconds apart. The HUMS data card was successfully closed down, removed from the AIU and downloaded to the ground station. The cumulative chip detection warning count was reset and during the next operation, between 0908 hrs and 1144 hrs, HUMS recorded further chip detection warnings on the epicyclic chip detector, with the cumulative count reaching 94; 49 of which were 15 or 16 seconds apart. The first recorded chip detection warning in this operation was detected at 0912:13 hrs, just after engine start on the ground in Aberdeen.

During the 'additional monitoring' period of 26 March 2009, until the end of operations on 31 March 2009, the HUMS recorded no further chip detections or relevant threshold exceedances on the MGB CIs.

1.11.2 1 April 2009 operations

1.11.2.1 Prior to the end of the CVFDR recording

The CVFDR recorded 24 hours of flight data and a 3-channel, one hour audio recording from each of the commander and co-pilot's headsets, and the CAM. The CVFDR installation was in accordance with regulatory requirements.

The CVFDR was successfully recovered from the seabed and downloaded at the AAIB. Data from the HUMS data card containing information from the operations conducted on 1 April was also recovered. This information was then merged with the rest of the operator's ground station database to form a complete record. Data was also recovered from the Digital Engine Control Units (DECU), Smart Multimode Displays (SMD)[4], DFDAU and HOMP card. NATS also provided radar and RT recordings.

Just prior to the accident, the CVFDR data showed that the helicopter was in the cruise on a heading of 234°M, at an indicated airspeed speed of 142 kt, radio altitude of 1,983 ft and pressure altitude of 1,718 ft.[5] Recorded engine and flight control parameters were as expected for an AS332 L2 helicopter operating in the cruise.

1.11.2.1.1 HUMS CIs

As a result of the accident, the HUMS card from 1 April was not closed down properly and, as expected, when viewing this operation on the ground station, the operation start and end times were both 0557 hrs. A review of the recorded HUMS data confirmed that the airborne system had successfully acquired all the epicyclic stage CIs within the required time interval. The final second stage planet gear bearing CI acquisition was at 1215:50 hrs and final component CI acquisition (combiner gear) at 1247:13 hrs.

4 The SMDs are the four cockpit displays which consists of two Primary Flight Displays (PFDs) and two Navigation and Mission Displays (NMDs).

5 Recorded pressure altitudes use a pressure datum of 1013 mb which requires a correction of +297 ft for a QNH of 1024 mb.

1.11.2.1.2 Other flight data

Spectral analysis of the CAM recording revealed an amplitude step change, in a frequency consistent with damage to the second stage epicyclic ring gear, occurring at 1250:58 hrs, (see Figure 16). This change in acoustic signature was inaudible on all the recorded channels. At approximately 1251:19 hrs an epicyclic chip detection warning was recorded on HUMS. Over the next minute and 43 seconds, three further chip detector warnings were recorded.

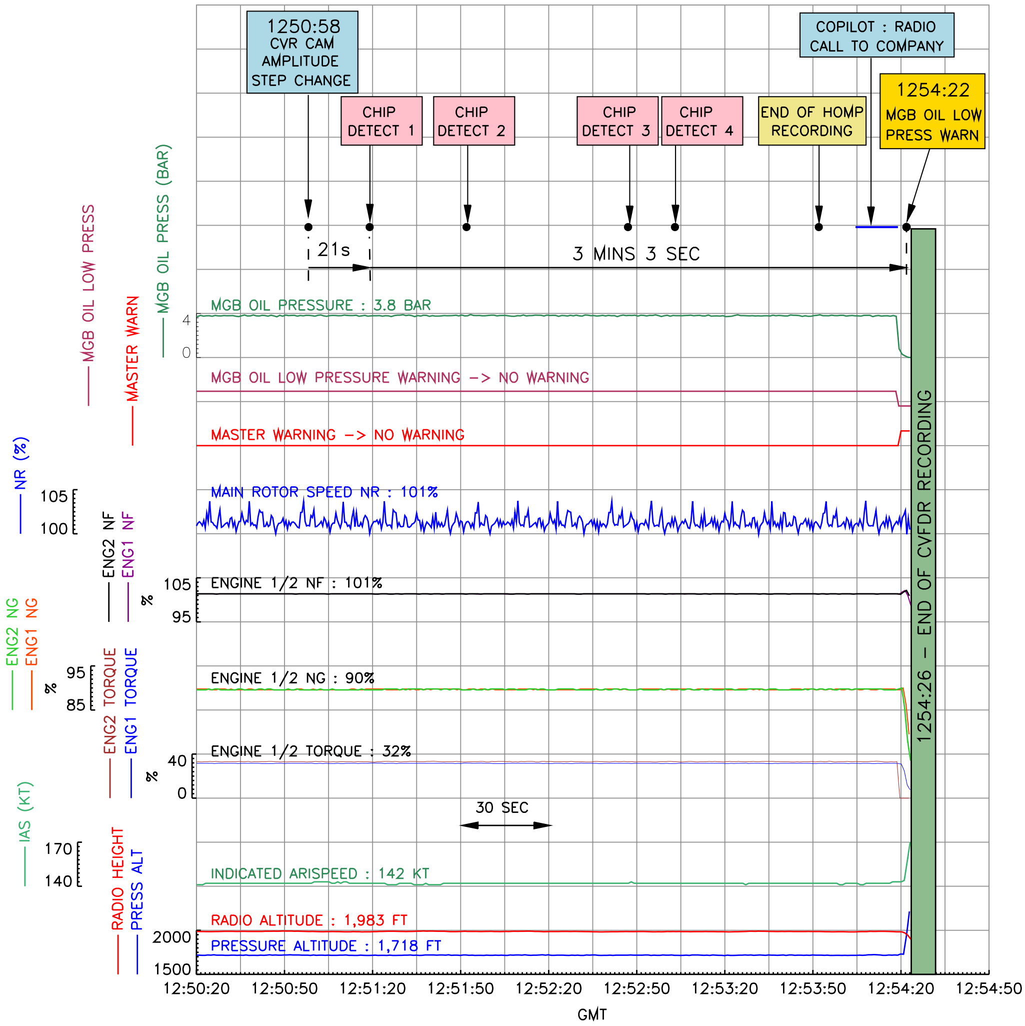


Figure 16

G-REDL recorded flight data

At 1253:52 hrs, the HOMP recording ceased. Thirteen seconds later, the co-pilot made a radio call to company operations indicating "WE'VE GOT ER FOURTEEN IN THE BACK, WE ARE SERVICABLE EXPECTED TO BE WITH YOU AT ONE....ONE THREE ONE FOUR". Two and a half seconds after the end of this transmission, the first warning, which was a MGB oil low pressure warning, together with a master warning, were recorded. The time between the first epicyclic chip detection and this warning was three minutes and three seconds.

The recorded MGB oil pressure reduced from 3.8 bar to 0.8 bar within one second and the data confirmed that the helicopter immediately deviated from cruise flight conditions. Half a second later, the recorded right engine torque reduced from 33% to zero, (see Figure 17). Apart from this recorded loss of torque, engine operation during the final part of the recording was normal, and the recorded main rotor rpm remained at between 100% and 103%.

At the same time as the MGB oil low pressure warning, the CAM recording changed to what can be described as a 'grinding' noise, which continued for four seconds until the end of the recording. Two seconds after the warning, the CVFDR recorded the commander expressing alarm which was also recorded on the radio transmission recording.

Twenty seconds prior to the last fault recorded by the SMDs, each SMD recorded faults associated with the Integrated Flight Display System (IFDS), including the disengagement of the autopilot and multiple system warnings. These would have been presented to the flight crew as either red or amber warnings on the Primary Flight Display (PFD) and NMD. In addition, each SMD simultaneously recorded a Pressure Sensor Unit (PSU) discrepancy[6], the exact reason for which could not be determined. UTC was not recorded by the SMDs, only operational running time. The exact time of this discrepancy could not be established, but was probably after the MGB oil low pressure warning as, prior to this, neither flight crew verbally acknowledged any discrepancy indication.

The final two seconds of the CVFDR recording suggested an indicated airspeed increase to 170 kt, radio altitude decrease to 1,898 ft but the pressure altitude increased to 2,215 ft. This represented a pressure altitude rise of 14,500 fpm which is beyond the capabilities of this helicopter.

6 A PSU discrepancy is triggered when the Flight Data Computer (FDC) detects a difference between either the acquired airspeed, pressure altitude rate or pressure altitude from by PSU1 and PSU2.

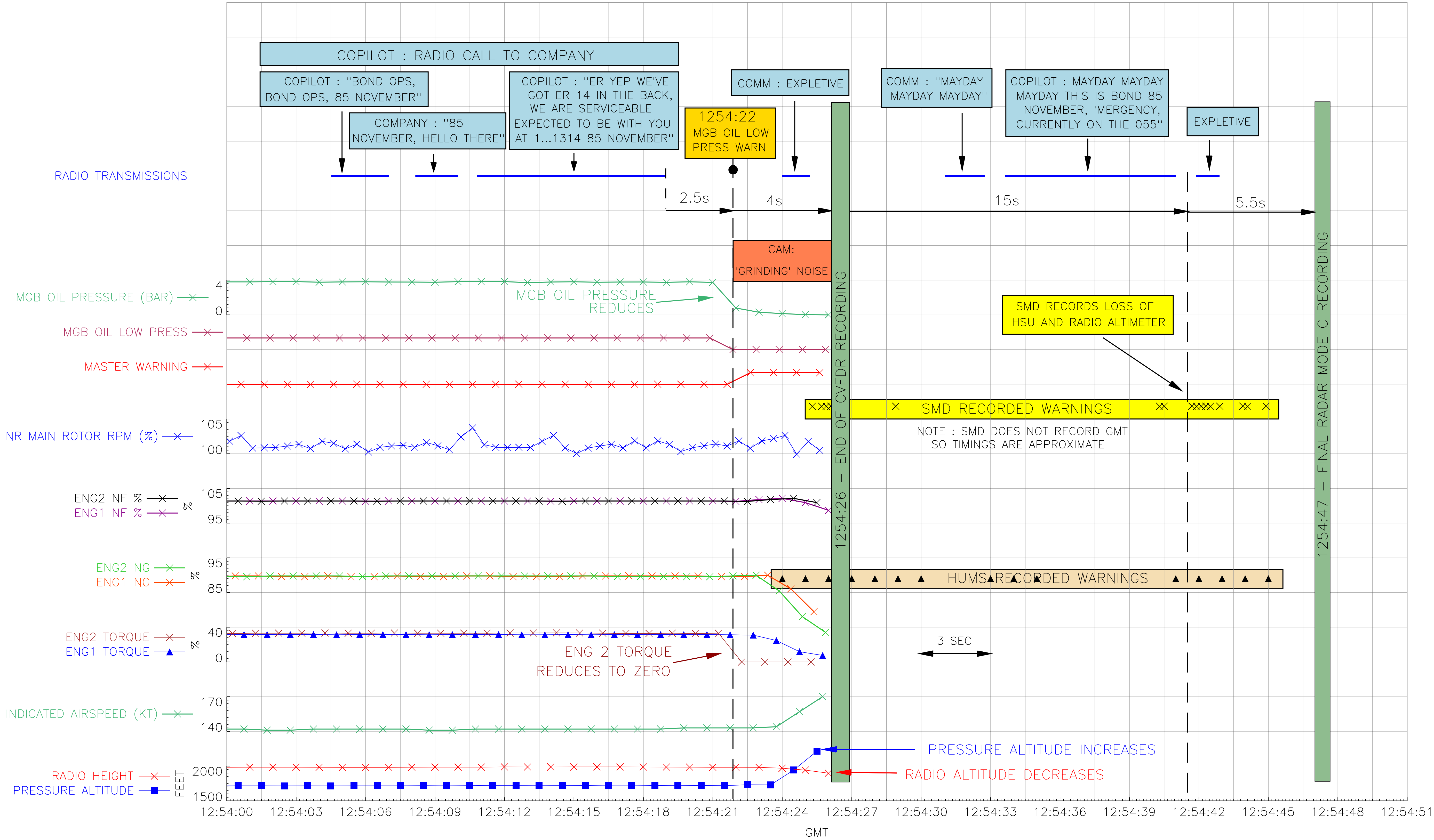


Figure 17

G-REDL recorded flight data

In normal operation, air data is measured from the pitot static probes which are positioned on the nose of the helicopter, exposed to the surrounding airstream. The PSUs acquire the pressure data which is converted and transmitted to the SMDs for display to the flight crew. Pressure parameters from one of the PSUs are also recorded by the CVFDR and altitude data is transmitted by the helicopter's transponder.

The transmitted altitude was recorded on the radar recordings. Air data collected from the pitot static probes was reliant on their position in the airflow and pressure measurement may have been affected by the helicopter's attitude. If the nominal cruising attitude was not maintained, the misalignment of the probes in the relative airstream may have created erroneous pressure readings.

The CVFDR data showed that when the radio altitude decreased, the collective pitch reduced to zero and the normal acceleration also decreased, indicating that the helicopter had entered an immediate descent. This, along with the detection of a PSU discrepancy and rate of change of pressure altitude, suggested that the CVFDR and radar pressure altitude data recorded after the PSU discrepancy was not representative.

The CVFDR recorded only four seconds of the accident sequence and ceased at 1254:26 hrs. Accelerations in the lateral and longitudinal directions were recorded at four times per second and the normal direction at eight times per second. The level of g experienced during the last four seconds of recording did not exceed 1g in any direction; however, due to the sampling rate, an acceleration spike may not have been recorded.

1.11.2.2 Accident sequence after the end of the CVFDR recording

The CVFDR recording ended prematurely and curtailed the only data and audio recording source designed to survive an accident. The outcome of this was a limited amount of data for the remainder of the accident sequence, which relied on information recovered from non crash-protected components.

Radar altitude continued to be recorded every six seconds and showed an increase to 1,900 ft before then indicating a descent. Recorded radar data showed a turn to the right together with a reduction in groundspeed. The HUMS also continued recording a number of status and warning indications including MGB chip detections, engine Ng[7] difference warnings, engine 2 oil chip detections and engine bleed air selections.

7 Ng is defined as the engine gas generator shaft rotational speed.

The remaining audio recordings were all sourced from the recorded VHF radio transmissions. At 1254:31 hrs, six seconds after the commander expressed alarm, he transmitted "MAYDAY MAYDAY MAYDAY", followed one second later by the co-pilot transmitting "MAYDAY MAYDAY MAYDAY, THIS IS BOND 85 NOVEMBER, 'MERGENCY, CURRENTLY ON THE 055". One second later, at 1254:42 hrs, one of the flight crew uttered an expletive; this was the final radio transmission. This occurred 20 seconds after the MGB oil low pressure warning.

Recorded fault messages downloaded from the SMDs revealed that, at approximately the same time as the final radio transmission, data from both the Heading Sensor Units (HSU) and the radio altimeter was lost to all four SMDs concurrently. The radio altimeter is located in the tail section of the helicopter on the shelf above the CVFDR, and the HSUs further aft.

HUMS continued to record status and warning discretes until 1254:45 hrs, with the final radar altitude recorded at 1254:47 hrs. This was the last recorded evidence that confirmed electrical power was still available to the helicopter. The final recorded radar altitude was 1,000 ft, 20.5 seconds after the end of the CVFDR recording and five and a half seconds after the end of the final radio transmission.

1.11.3 Helicopter performance

Directly after the loss of MGB oil pressure, the helicopter deviated from its cruise conditions. With only four seconds of flight data, analysis of the helicopter response was limited. During these four seconds, the helicopter initially rolled left to -11.3° before rolling right to 9.1° within two seconds. Magnetic heading increased by 30 degrees with pitch attitude reducing to -1.4° pitch down before increasing to no more than 2.1° pitch up. Recordings of flight control inputs show a reduction in collective pitch to zero, and commands to pitch up, yaw to the right and roll right then left, (see Figure 18).

1.11.3.1 Manufacturer's flight data analysis

The recorded flight data was provided to the manufacturer who ran a simulation to analyse the consistency between flight control inputs and the helicopter response during the final seconds of operation, see Appendix F. The analysis was performed in two stages. The first was to input the recorded flight control commands and analyse the simulated helicopter response. The second was to use the recorded helicopter attitudes and determine the required flight control inputs to achieve them. The results indicated that, two seconds after the MGB oil low pressure warning, the helicopter was no longer responding normally to flight control inputs.

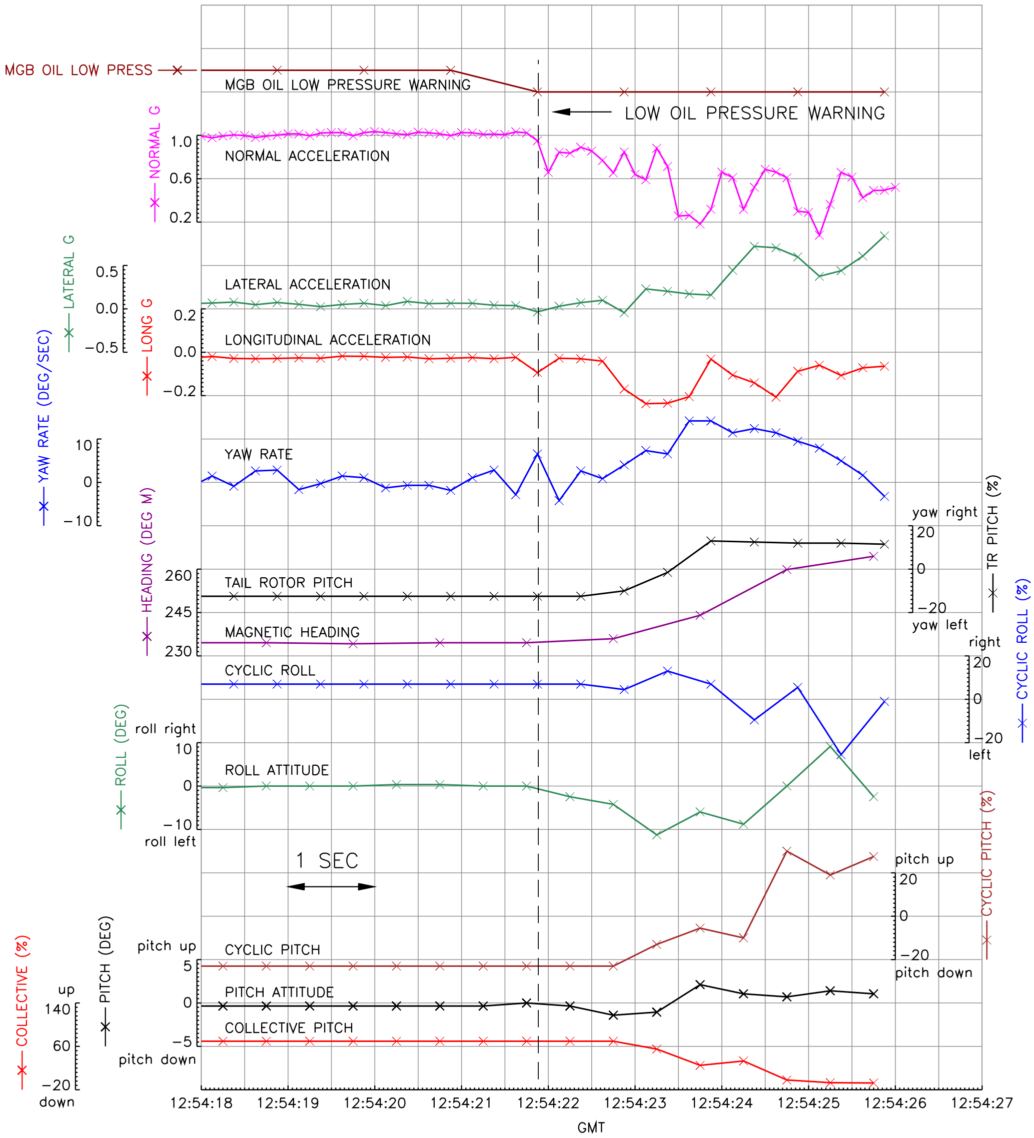


Figure 18

Flight control inputs and helicopter response

1.11.4 HOMP data

Once it was established that the CVFDR had not recorded the entire accident sequence, the focus turned to the HOMP which recorded a copy of the flight data. Upon investigation, the HOMP recording ceased 34 seconds prior to the CVFDR. The HOMP installed on G-REDL contained a memory buffer which stored flight data for up to two minutes before being written to the removable card. If power to the memory is lost, then its contents will be lost, including up to two minutes of flight data.

1.11.5 HUMS

1.11.5.1 Review of G-REDL HUMS CIs

The database for the G-REDL MGB was reviewed and no unusual CIs relevant to this accident were found, nor were any thresholds exceeded during 1 April 2009 operations. This review had to bear in mind the issues identified with all first stage epicyclic module bearing CIs and the pattern indicators for the second stage epicyclic module. Rising trends were identified on two CIs for the first stage planet gear bearings, (see Appendix G). The rising trend commenced in early October 2008 which is coincident with the date of a left accessory gearbox change. This trend change resulted in additional analysis work into this CI and was how the anomaly associated with the location of the first stage epicyclic module accelerometer was identified. The trends were therefore anomalous.

1.11.5.2 Manufacturer's analysis of G-REDL HUMS

The helicopter manufacturer was provided with a copy of the G-REDL HUMS database and the downloaded HUMS data card from 1 April 2009 operations. Their analysis was performed by two teams; the first being by their customer technical support team which reviewed all CIs. They concluded that there was *'nothing abnormal to report'*.

The second was performed by their HUMS design office team, who analysed the raw vibration data to generate additional CIs for both gears and bearings. These CIs were not included as part of EuroHUMS. Their analysis of all gearbox components revealed a rising trend in two CIs during the final weeks of G-REDL's operation, (see graph extracts in Appendix H). The rising trends were considered representative of an increase in the meshing energy of the first and second epicyclic stages, which were indicative of an increase in general ring gear wear. The CI generated for the first stage ring gear is based on a calculation that the manufacturer uses in their M'Arms system[8]. On this system there is an amber threshold set at ± 5 standard deviations which would not have been exceeded with this calculated data from G-REDL.

The manufacturer's HUMS experts reviewed the upward trends and scatter in the data. It was determined that no maintenance action would have been proposed if these CIs were available prior to the accident. They confirmed that, in their opinion, there was no evidence in the G-REDL HUMS data that suggested a component failure was imminent.

8 M'Arms is Eurocopter's latest generation HUMS.

1.11.6 CVFDR audio analysis

The one-hour audio recording commenced during the rotors-running turnaround on the Miller Platform. The recording captured the takeoff from the platform and the remaining 51 minutes of the flight. Spectral analysis of the CAM recording was performed by the AAIB and also by the manufacturer, under the supervision of the AAIB. The analysis showed clear harmonics of blade passing frequencies associated with rotation of the main rotor which were consistent with the N_r speeds recorded by the CVFDR. Gearbox and engine component frequencies, along with their harmonics, were also identified for as many of the components as were within the frequency range of the audio recording[9]. The analysis focused on frequencies which did not correspond to expected gearbox frequencies and also those which showed a significant change in amplitude over the recording duration.

Three minutes and 24 seconds prior to the MGB oil low pressure warning, an amplitude step change was identified at harmonic frequencies matching those which may be observed in the case of second stage ring gear damage. For a main rotor speed of 268 rpm, the fundamental frequency of such damage is 35.7 Hz, based on the assumption that if the damage was present on the second stage ring gear, each of the eight planets would pass over it every time the main rotor made one revolution. Amplitude step increases in 107 Hz, 143 Hz and 178 Hz frequencies, representing the third, fourth and fifth harmonics were identified.

A progressive amplitude rise was also seen in a 286 Hz frequency, starting two and a half seconds after the amplitude step changes, and continuing to rise until the end of the recording. While 286 Hz corresponds to the eighth harmonic of the second-stage ring-gear damage frequency, it also matches the second harmonic of the left accessory gearbox oil-cooler shaft rotational speed. Increasing amplitude in the second harmonic of a rotating shaft is typically attributed to shaft misalignment. As the amplitude of other harmonic frequencies of the ring-gear damage did not vary significantly, it suggested that the 286 Hz frequency was associated with shaft misalignment.

The CAM recording changed significantly during the final four seconds, to what can be described as a ‘grinding’ noise. The previously identified frequencies were masked by a significant increase in amplitude of broadband noise. This noise had no identifiable discrete frequencies to help determine its origin.

9 CVFDR CAM specified bandwidth was between 150 Hz and 6 KHz although frequencies could be identified in the range 55 Hz to 6.4 KHz.

No other defect frequencies were identified but there were a number of frequencies identified by the audio analysis which could not be attributed to gearbox meshing or shaft rotational frequencies. During the cruise, the most notable was 1,022 Hz, which was identified as being transmission-related as it followed the profile of other transmission components during rotational speed changes at takeoff. This 1,022 Hz frequency represented the highest amplitude single frequency recorded throughout and did not vary significantly in amplitude. The G-REDL audio recording was compared to other AS332 L2 recordings and this unknown frequency could not be identified on any of them. A recording from the G-REDL annual CVFDR check of August 2008 was made available which, after analysis, also showed no evidence of the 1,022 Hz frequency.

1.12 Aircraft and site examination

1.12.1 Accident site

The accident site was located approximately 11 nautical miles north-east of the port of Peterhead. A side scan sonar search of the sea bed confirmed that the helicopter had broken into three sections, the fuselage, tail boom and main rotor assembly. The water depth was approximately 95 m and the sea bed was sandy with good visibility. A survey of the site by a remote operated submersible vessel confirmed that the helicopter fuselage had suffered from significant disruption on impact with the sea and identified a small debris field lying between the remains of the fuselage and the tail boom.

1.12.2 Initial aircraft examination

Numerous items of light composite structure had been recovered from the surface of the sea immediately after the accident; these included sections of composite fuselage panels, both main landing gear sponsons and several sections of the MGB and engine cowlings. Evidence of a significant fluid leak was found on the remains of the left main landing gear sponson and a section of the rear left side of the fuselage. The remains of the rear gearbox cowling showed evidence of both a fluid leak and a fire. Evidence of fire was also identified on the remains of the forward left MGB cowling.

Damage to the tail boom of the helicopter confirmed that it had separated from the fuselage prior to the impact with the sea. It had suffered from multiple main rotor blade strikes on the boom and at the base of the fin, (see Figure 19). Damage to the tail rotor drive shaft was consistent with the shaft rotating when it was struck by the main rotor blades.

Figure 19
Helicopter tail boom after recovery

All four main rotor blades remained attached to the rotor head. Evidence of paint from the tail boom was found on all the blades which confirmed that they had struck the tail during the failure sequence. There were varying degrees of damage to the rotor blades which was consistent with the rotor system losing energy whilst striking the tail boom. The upper section of the gearbox assembly, which included the remains of the second stage of the epicyclic reduction gearbox, the conical housing and all three lift struts, had detached from the MGB and were recovered with the rotor head.

The fuselage of the helicopter had suffered from significant disruption due to the impact with the sea. The lower section of the MGB and both engines remained attached to the upper section of the helicopter's fuselage.

Initial examination of the engines revealed significant damage to their external casings. The free turbine case of the right engine was found to have been breached and the turbine blades were found severely damaged. The epicyclic reduction gearbox had suffered significant damage. The epicyclic module case and ring gear had split vertically and had separated from the main module, (see Figure 20). The first stage planet carrier was found lying on the remains of the main module and the remains of all eight first stage planet gears, together with pieces of a second stage planet gear, were recovered from within the MGB main module and its surrounding area.

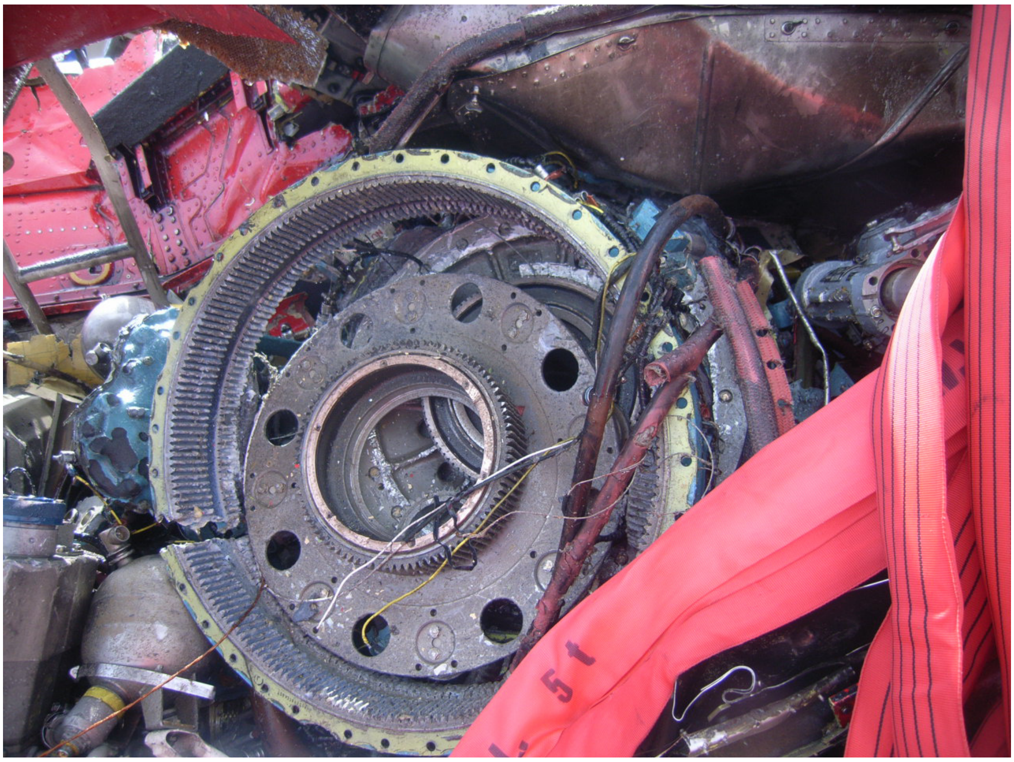


Figure 20

The epicyclic module ring gear shortly after recovery from the sea

1.12.3 Detailed aircraft examination

1.12.3.1 Flying controls

There was no evidence of a pre-existing failure or restriction within the flying control system. All the damage observed was consistent with the helicopter's impact with the sea.

1.12.3.2 Engines

The engines were taken to the manufacturer's overhaul facilities for detailed examination under the supervision of the investigation team. Both engines had suffered external damage consistent with the impact, which included deformed casings, damaged engine mounts and accessory mounting flanges.

Internal damage to both engines indicated that they were rotating at the time of the casing deformations. Foreign object impact damage to the first stage compressor blades and airframe debris in the internal air paths of the engines confirmed rotation at the time of the impact with the sea.

Both engine's DECUs were downloaded. Analysis showed that there were no recorded parameter exceedances. The One Engine Inoperative (OEI) mode had not been activated and the position of the engine over-speed relays confirmed that there had been no engine over-speed.

Both engines were assessed to have been in good condition prior to the accident and no signs of pre-existing anomalies or over-temperature were evident.

1.12.3.3 Rotor head, mast and conical housing

The rotor head, mast and conical housing (complete with the lift struts) were stripped and inspected at the manufacturer's facility under the supervision of the investigation team. The three lift struts attached to the conical housing had separated from the engine deck due to torsional overload. There was no evidence of a primary failure within any of the components examined.

1.12.3.4 Main Rotor Gearbox main module

The gearbox, (serial number M2092) had remained attached to the airframe by the flexible mounting plate, which is designed to react the gearbox torque. The mounting plate had sustained little damage in the accident. This observation was pertinent in that it helped to exclude the possibility of a lift strut failure as being a primary cause of the accident, since such an event would transfer lift loads, via the gearbox, into the mounting plate causing obvious distortion.

The first stage sun gear had remained engaged, via its splined connection, with the bevel gear in the main module and it was established that there was little measurable run-out. This suggested that little if any disruption had occurred upstream of the sun gear. However, the teeth had sustained heavy damage, which was more severe than that seen on the first stage planet gears. It was separately established that the sun gear had most probably contacted the first stage planet gear inner races following the break-up/release of the planet gears, whilst turning at speed. The sun gear was extracted, at which point comparatively minor damage was observed on the splines.

A breach in the circumference of the bevel gear support plate at the approximate 5 o'clock position[10], matched the location of the vertical split in the epicyclic ring gear. Gear teeth marks were visible in the surface of the plate adjacent to

10 The twelve o'clock position equates to the longitudinal axis of the helicopter looking forward.

the breach, together with significant abrasion around the entire circumference; this had resulted in smearing of several of the bevel gear support plate attachment bolt heads. In addition, most of the oil separator plate containing the magnets had been abraded away.

The main module was severely contaminated by the products of corrosion arising from seawater immersion. However, the bevel gear, its drive pinion and components such as the main and emergency oil pumps, showed no evidence of operational distress. The reduction gears at the engine input side of the gearbox, together with the accessory gearbox components, similarly showed no evidence of operational distress. The only noteworthy feature was that the right engine torque-meter shaft showed evidence of a permanent set in the over-torque direction. This may have resulted from the right engine continuing to apply torque during a series of temporary seizures that probably occurred during the break-up of the epicyclic gear stages.

During the examination, metallic particles and a number of planet gear bearing rollers were recovered from within the main module sump.

1.12.3.5 Epicyclic module

The investigation concentrated on the examination of the gearbox epicyclic module failure. The ring gears, both sun gears and all planet gears, together with the planet gear carriers, were recovered with the exception of approximately one third of one planet gear from the second stage.

There was evidence of damage throughout the epicyclic module, consistent with it operating for a period of time whilst contaminated with debris. Several imprints of rollers from the failed second stage gear and those released from the first stage planet gears were evident on second stage gears and the ring gears.

Two gears in the first stage had failed; one had suffered a single fracture, the other had broken into four sections. All first stage planet gears had separated from the carrier, releasing their rollers, only a proportion of which were recovered. The inner raceways from all the planet gear bearings were recovered, with none exhibiting evidence of pre-accident failure or degradation. One first stage planet-gear inner raceway exhibited damage over a limited area of its circumference which was consistent with it continuing to operate during the failure sequence.

Seven of the second stage planet gears remained attached to the second stage planet carrier, (see Figure 21). The inner race of the eighth planet gear remained attached to the planet carrier but the gear / outer raceway and its associated bearings and bearing cages had separated from the inner race. Three sections of this gear were recovered, identified as the 9-tooth, the 10-tooth and the 16-tooth section, (see Figure 23). In addition, 12 of the gear's 28 bearings were recovered.

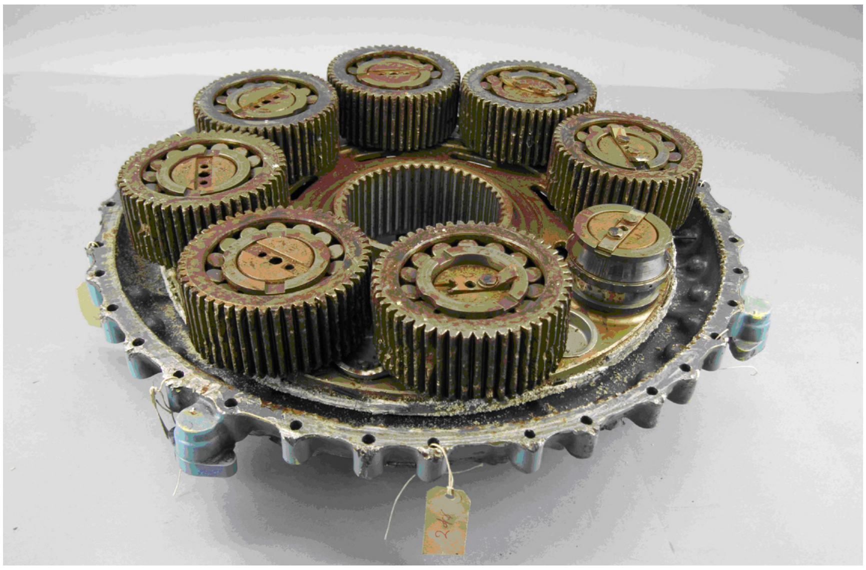


Figure 21
Second epicyclic stage, as found (shown inverted)

Figure 22
Complete undamaged gear, for reference

There was evidence on both the first stage and second stage planet gear teeth of damage caused by debris, consistent with the gearbox running in an abnormal condition prior to the separation of the main rotor head. Detailed metallurgical examination was carried out on all of the recovered components from the epicyclic gearbox module and compared with analysis of equivalent components from another epicyclic module.

1.12.3.5.1 Failed second stage planet gear

Initial inspection of the three recovered sections of the gear showed that the 9-tooth section did not fracture match with the other two sections. The 10-tooth and 16-tooth sections shared a common fracture face. In addition, the 9-tooth section exhibited a distinct 'flattening' of its curvature when compared with the other sections.

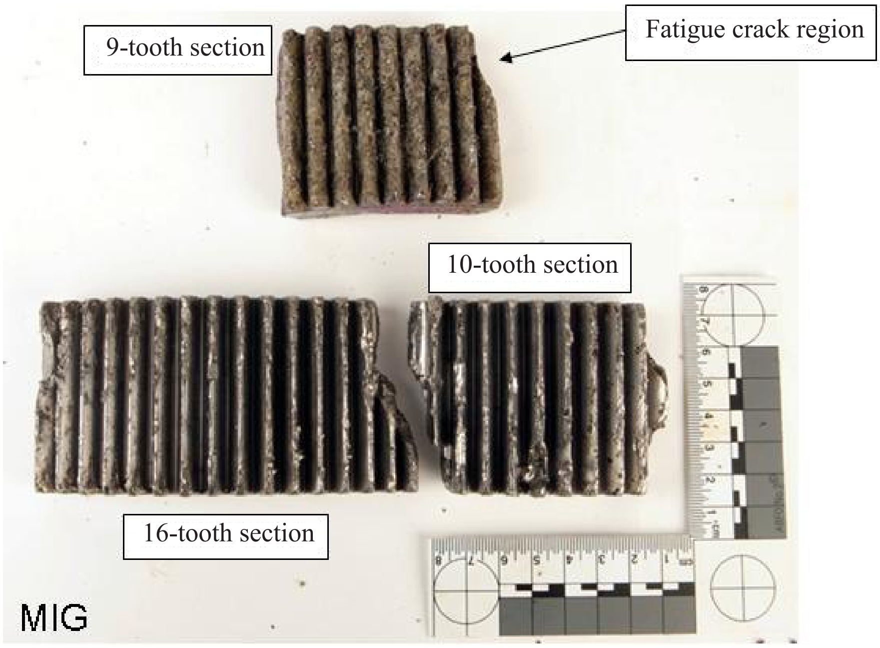
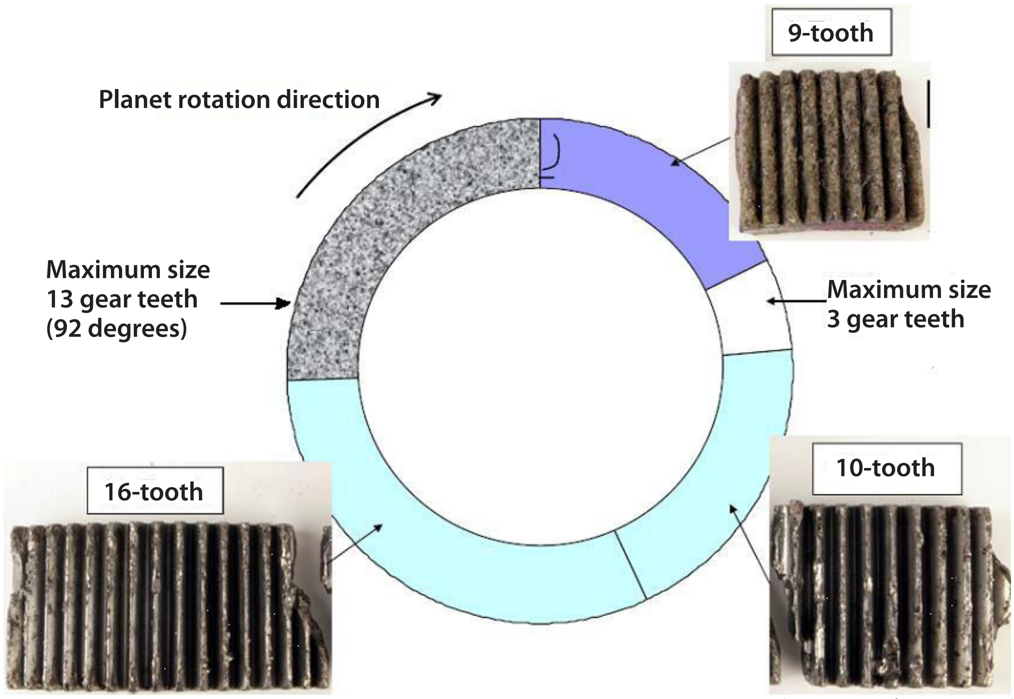


Figure 23

Recovered sections of the failed second stage planet gear.

Examination of the recovered pieces allowed their relative positions around the circumference of the gear to be determined. The 16-tooth and 10-tooth sections comprised approximately one half of the gear, with the 9-tooth section being positioned somewhere in the remaining half. Stress analysis showed that the minimum separation of the 9-tooth section from the 16- and 10-tooth samples was equivalent to the span of three gear teeth, and the maximum separation was equivalent to 13 gear teeth, or approximately 25% of the circumference (see Figure 24).



(Courtesy of Eurocopter)

Figure 24

Relative position of recovered second stage gear sections

Both fracture faces on the 16- and 10-tooth samples were found to be the result of overload, as was one fracture face of the 9-tooth section. The other fracture face of the 9-tooth section consisted of a complex fracture made up of five conjoined fracture faces, with the majority showing characteristics of crack propagation in fatigue (see Figure 25). Some of the definition of the fracture faces had been lost due to mechanical damage and corrosion from exposure to sea water.

It was determined that the first of the fractures to form was Zone 1, which comprised of a 'scallop' shaped fracture face and appeared to have originated from a single point in a region at, or close to, the outer race surface. The precise origin could not be determined due to the severe mechanical damage in this region. However, the nature of the fracture surface suggested that the origin was approximately 14 mm from the gear edge. This coincided with a position on the raceway where loading from the bearing rollers was highest.

The second fracture to form was Zone 2. This consisted of a relatively flat fracture surface which originated from the upper edge of the Zone 1 fracture face and had progressed in fatigue through the body of the gear towards the gear teeth. The Zone 3 and Zone 4 fracture faces also showed evidence of crack progression in fatigue. The Zone 3 fracture face had originated from the edge of the Zone 2 fracture and progressed towards the centre of the gear.

The Zone 4 fracture had originated on the outer edge of the Zone 1 facture and progressed towards the edge of the gear. Zone 5 was a fatigue crack at right angles to the Zone 2 fracture face.

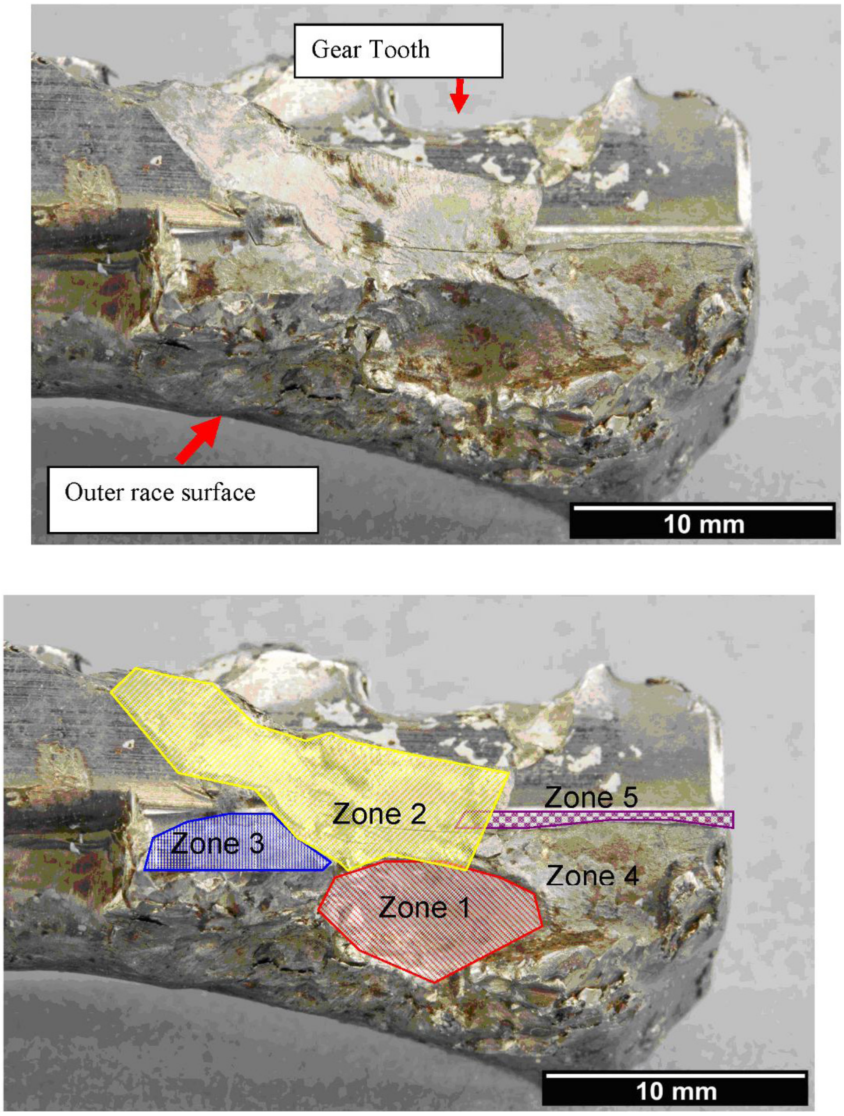


Figure 25

Fatigue crack regions on the 9-tooth section

Extensive non-destructive examination and testing was initially carried out with the assistance of the helicopter manufacturer, QinetiQ, Alicona UK at the National Physical Laboratory, the Open University materials laboratory and Metris (X-Tech Systems Ltd), a manufacturer of X-ray Tomography equipment. This included 3D surface optical mapping, 3D X-ray tomography, Scanning Electron Microscopy and conventional optical microscopy. The results provided significant evidence regarding these fractures and allowed the development of a programme of tests and examinations to be undertaken.

These tests were designed to identify the initiation point of these fractures and the reason for their initiation.

After examination, the 9-tooth sample was sectioned to allow detailed inspection of the fracture surfaces. Three dimensional tomographic images of the area surrounding the fracture faces showed the presence of an additional crack in the area of material immediately below the Zone 1 crack face, (see Figure 26), which was not apparent during the visual examination.

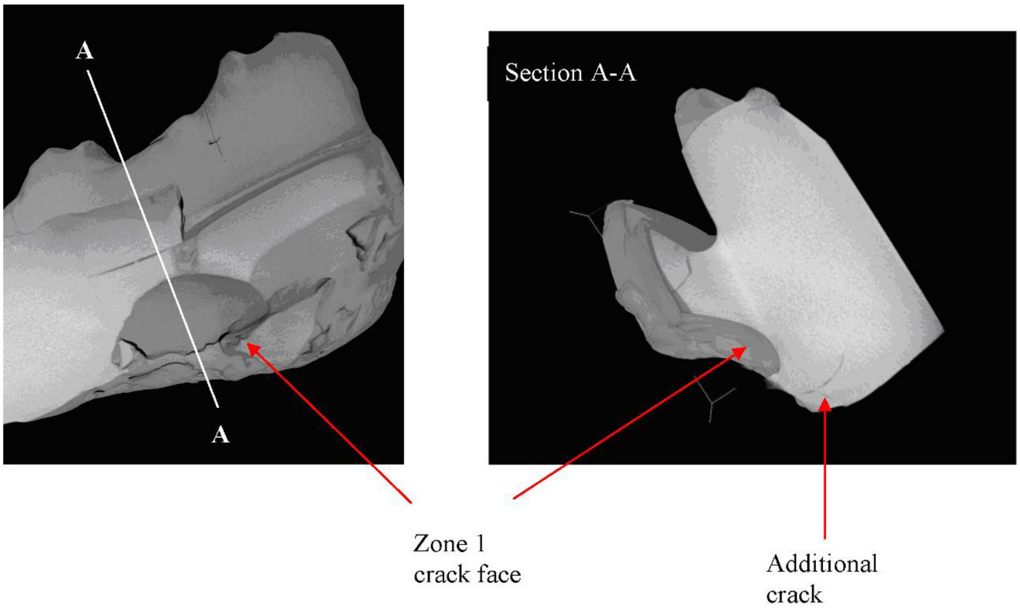


Figure 26

Tomographic image of section of 9-tooth section fracture face

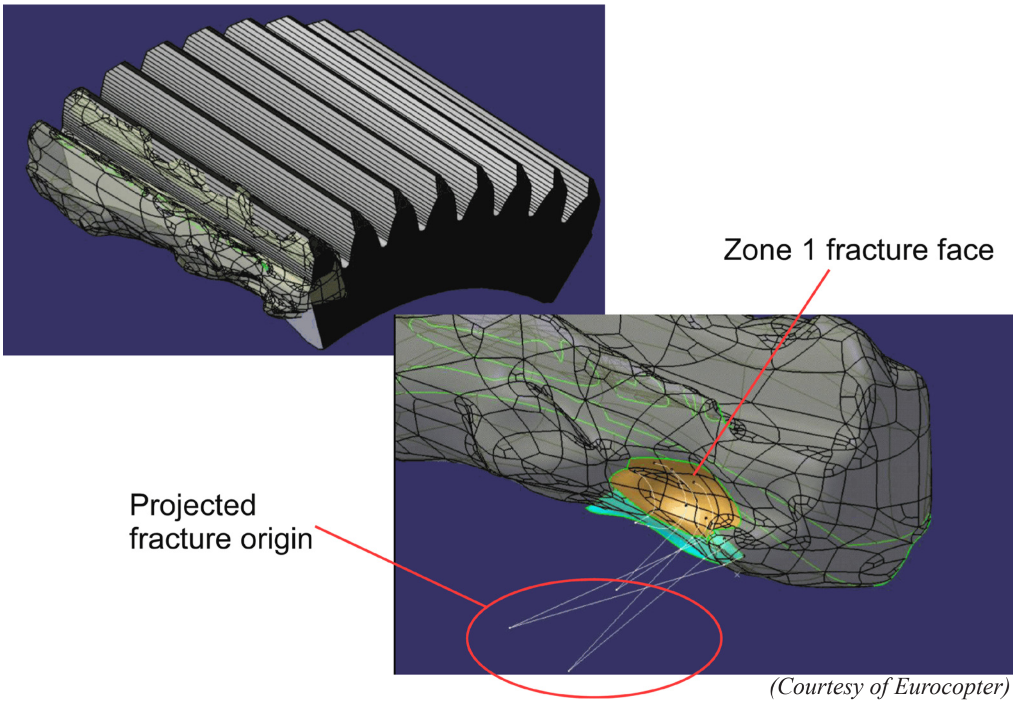
The extent of mechanical damage in this area prevented visual identification of the crack. No other material defects could be identified in the 9-tooth section.

Examination of the fracture faces using a high resolution Field Emission Scanning Electron Microscope, (FESEM) confirmed the presence of crack propagation in fatigue within four of the zones. However the resolution of the images was not sufficient to allow the identification and counting of the fracture striations. In order to obtain higher resolution images a facsimile of the fracture surfaces was made for use in a Transmission Electron Microscope, TEM. The resulting images were of insufficient fidelity to allow a complete count of the striations to be carried out. A count of the visible beach-marks[11] was carried out and, based on the helicopter manufacturer's understanding of the loading cycle of the gearbox components it was determined that each beach mark could be equated to one main rotor start/stop cycle. This indicated a growth of the visible portion of the fracture faces

11 The progression marks appearing on a fatigue fracture surface indicating successive arrest positions of an advancing crack front.

on the 9-tooth sample of between 36 and 100 flying hours before failure, based on G-REDL's operational history. If account is taken of the crack propagation in the unrecovered sections of the failed gear it is possible that more than 100 flying hours could have elapsed between crack initiation and the failure.

In order to determine the possible location of the origin of the Zone 1 crack, the dimensions of the fracture face were recorded and projected into a computer generated model of a second stage planet gear. The results showed that the origin of the Zone 1 fracture face was approximately 2.5 mm forward of the nine tooth sample, in a section of the gear which had not been recovered (see Figure 27).



(Courtesy of Eurocopter)

Figure 27

Computer generated model of the projected origin of the Zone 1 fracture

A detailed metallurgical examination of all the recovered sections of the failed gear confirmed that they complied with the material specification of 16NCD13 steel and no other abnormalities were identified during this examination. The hardness of the raceway of the 9-tooth section was also measured to identify any variation in the material hardness which may have contributed to the failure of the gear. These measurements were taken 0.15 mm below the surface of the raceway where the nominal material hardness, for a new second stage gear, was expected to be greater than 660 on the Vickers Hardness scale. The results were plotted onto an image of the 9-tooth section (see Figure 28). This showed that there appeared to be a relative hardening of the gear material throughout the bulk of the section.

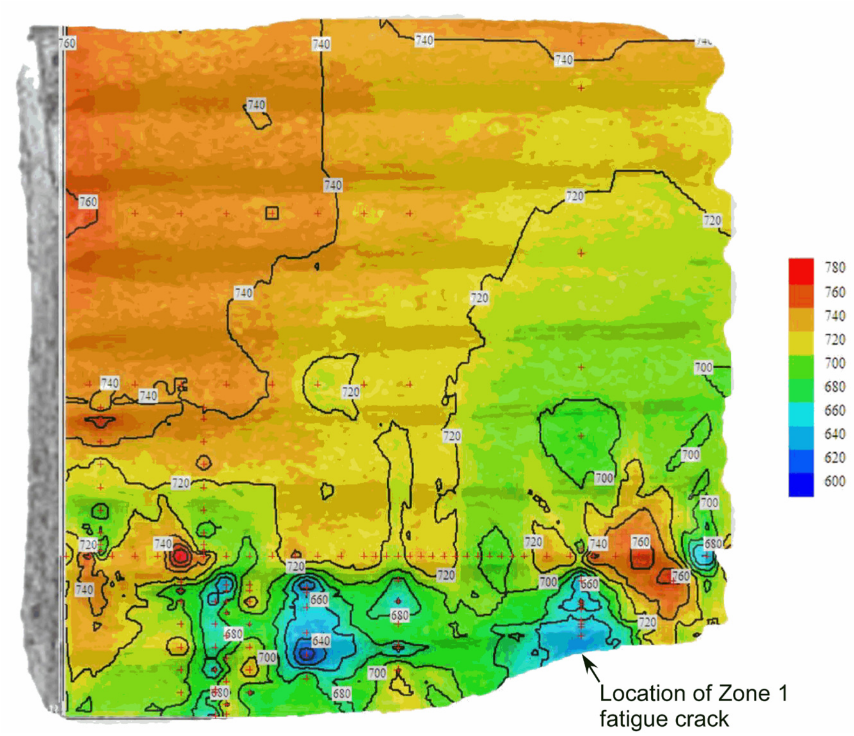
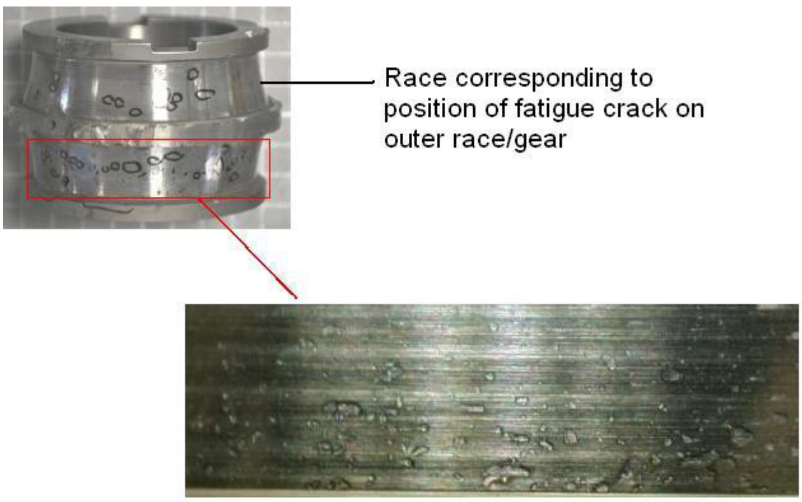


Figure 28

Hardness plot of the 9-tooth section

Examination of the inner race of the failed gear, which had remained attached to the second stage planet carrier, showed numerous small pits around the circumference of the race. This pitting was found predominantly on the highest loaded section of the inner race bearing tracks. The extent of this pitting was less evident on the bearing track corresponding to the position of the fatigue crack on the outer race/gear, (see Figure 29).



(Courtesy of Eurocopter)

Figure 29

Pitting on the loaded arc of the inner race of the failed second stage planet gear

1.12.3.6 Examination of the magnetic particle of 25 March 2009

Detailed examination was performed on the metallic particle removed from the epicyclic module magnetic chip detector on 25 March 2009; 36 flying hours before the accident. The particle measured 2.88 mm by 0.8 mm. SEM analysis confirmed that the particle was 16NCD13 steel, planet gear outer race/gear material. On one side, the particle exhibited evidence of honing marks, a characteristic of the surface of the outer race of a second stage planet gear bearing. Comparison of these marks with an identical intact second stage planet gear established that it came from a location on the raceway in the wear track of one set of rollers. This was close to where the maximum surface loading from the rollers was to be expected, 14 mm from the edge of the gear, (see Figure 30).

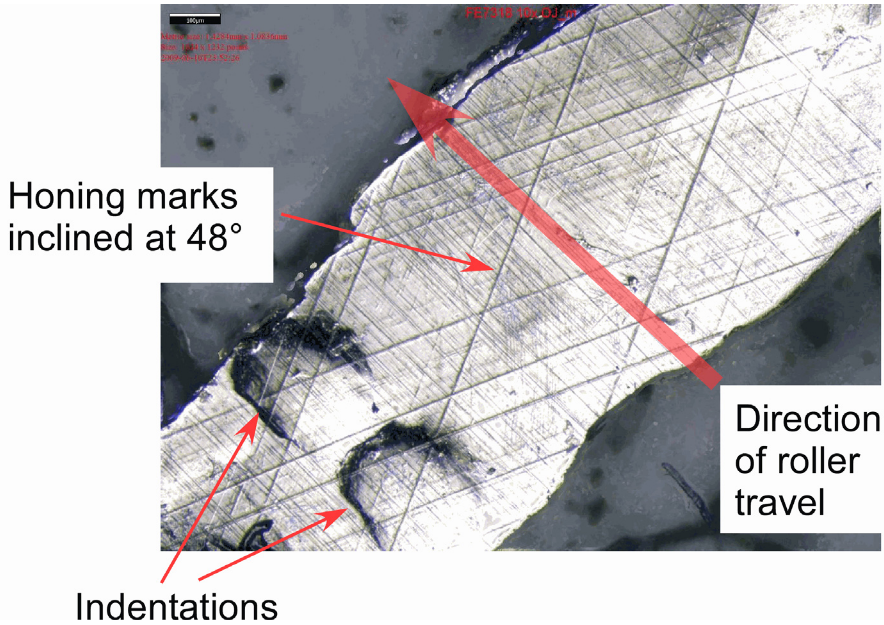


Figure 30
Metallic particle of 25 March 2009

The absence of missing material on any of the outer raceways of the other planet gears confirmed that the particle had come from the outer race of the failed second stage planet gear. There was no evidence to show that the particle had been liberated from one of the three sections of gear that had been recovered and therefore it follows that it must have been released from an un-recovered section of the failed gear.

Two horseshoe shaped indentations were observed on the outer bearing surface of the particle. These two indentations were aligned with the rolling axis of the bearings and were characteristic of a small object being repeatedly rolled into the particle. The positioning of the indentations, parallel to the rolling direction of the bearing rollers, and their similar shape confirmed that they had been formed whilst the particle had still been attached to the raceway surface. The forward edge of the second indentation coincided with the edge of the particle. Measurement showed that they were between 14.5 and 17.1 microns deep. The presence of these two features on the particle confirmed that, prior to its release, at least one other particle was being carried within the oil system. It could not be determined if this additional particle had been released from a gearbox component or was an external contaminant.

1.13 Medical and pathological information

All occupants suffered fatal injuries. Autopsy examinations of all the occupants were performed at the direction of the Procurator Fiscal. These showed they received multiple injuries consistent with impact related forces. There were no significant differences in the patterns of injuries between any of the occupants. The injuries suggested that they had been exposed to peak decelerations within the range of 100 – 200 g.

The pathologist considered that the forces involved were such that the accident was not survivable, and no additional or alternative safety equipment would have affected the fatal outcome of this accident.

1.14 Fire

There was evidence of fire on some of the floating items of wreckage recovered from the scene shortly after the accident, particularly on sections that were adjacent to the MGB. The fire was subsequently determined to have been oil-fed, and of short duration. This was probably caused as a result of the break-up of the main rotor gearbox.

1.15 Survival aspects

The accident was not survivable.

1.16 Tests and research

1.16.1 Lightning strikes

When a helicopter is struck by lightning, the current flow is dissipated through numerous paths throughout the airframe, including the MGB cases and transmission. Both the operator and the helicopter manufacturer were able to provide documentation of the damage sustained to G-REDK in February 2007 when it was fitted with the G-REDL accident gearbox. This showed that the lightning strike had not caused a significant amount of damage to the helicopter and it was therefore judged that the lightning strike was of relatively low energy.

The possibility remained, however, that this event may have introduced a material abnormality in the failed second stage planet gear which could have remained undetected during the MGB's last overhaul. In order to determine if this was possible, a number of planet gears were subjected to a series of simulated lightning discharges. The results of these tests showed that even with an exceptionally high discharge being passed solely through a planet gear, any change in material hardness was very small and restricted to localised areas of the raceway. In addition, the physical effects on the raceway surface would have resulted in the gear being rejected during the subsequent overhaul process.

1.16.2 Stress modelling and analysis

As detailed in section 1.6.5.3, the design of the AS332 L2 (and other models of the Puma helicopter) epicyclic gears requires that a single piece of metal performs the function of both a gear and the outer race of a bearing. The stresses experienced by a gear and those experienced by a bearing are understood as separate entities but, when combined as a single element, it results in a more complicated stress field as the gear loading (volumetric stress) interacts with the bearing roller loads (Hertzian stress). A third stress which must also be taken into account is the residual stress introduced by the carburising process.

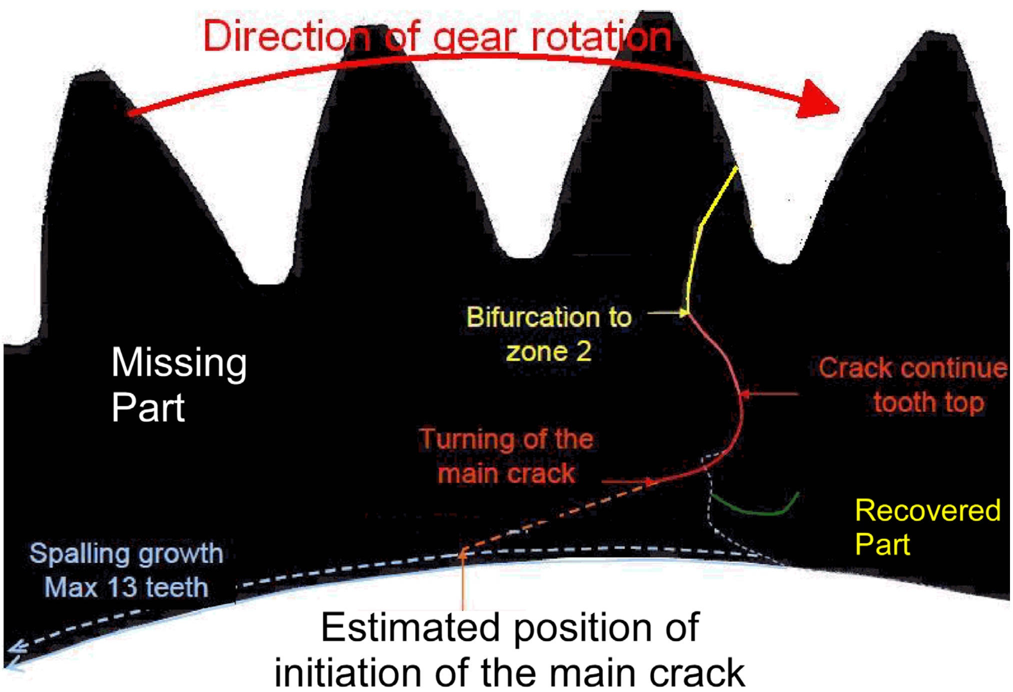
This results in a complex set of calculations when estimating the stress levels and the shape of the stress field. Such information is necessary when predicting whether fatigue cracks might propagate and which path they would follow. Since the shape and number of fatigue cracks on the failed gear from G-REDL could not be explained, a detailed analysis, using advanced methods, was undertaken by the helicopter manufacturer to build a three-dimensional stress model of the component. A separate analysis tool was used for the Hertzian stresses.

The three-dimensional model was only valid up to a depth of 4 mm from the surface; after that it was necessary to continue using a two-dimensional analysis.

The study concluded that in normal operation (bearings rolling) the shear forces would remain parallel to the raceway surface and fatigue should not initiate from surface or sub-surface defects because the stress levels are not high enough. However, spalling of the outer raceway remained possible for reasons which the manufacturers state are random but inevitable and is prevented from becoming catastrophic by their existing maintenance procedures (the installation of magnetic chip detectors and operational life limits). The analysis further showed that fatigue could propagate from damage (including spalling) which progressed beyond the residual stress field created by the carburised layer.

The crack was predicted to progress initially approximately tangentially to the raceway surface, (see Figure 31) but also moving inwards. As it leaves the carburised layer, the increasing tensile stresses cause the crack to turn and follow the line of maximum tensile stress. This was predicted to create a 'dished' shape similar to that seen in Zone 1 of the fracture surface of the 9-tooth section.

As the crack progresses, theory suggests that it should propagate towards the tooth root. However, the model showed that this area, and the tooth flanks, has significant compressive stresses, so the crack tends to follow the tensile stresses in the middle of the tooth, until the gear fractures in overload. The possibility of a bifurcation of the crack was also predicted, creating a feature similar to that observed in Zone 2 of the actual failure.



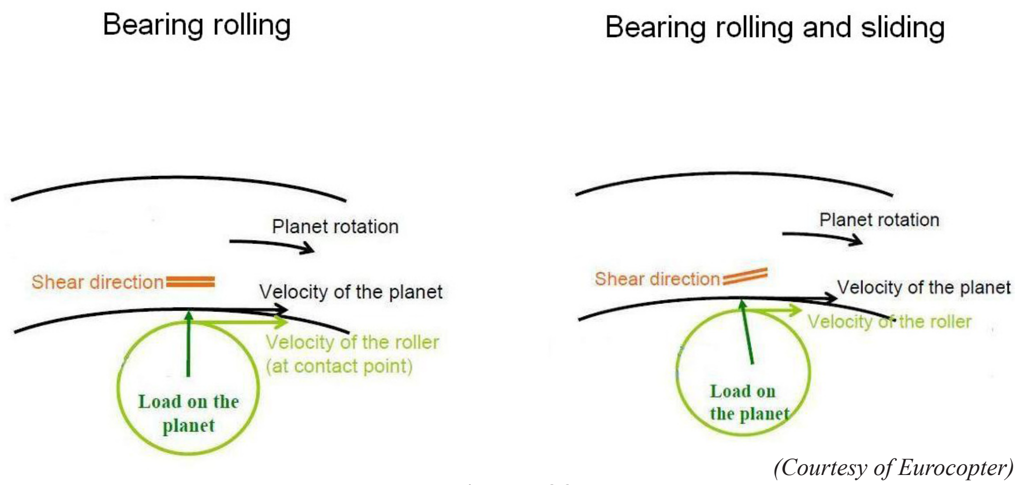
(Courtesy of Eurocopter)

Figure 31

Stress model prediction of crack growth

The conclusion of the stress analysis was that it could explain most of the features of the fatigue morphology observed on the fatigue fracture face of the failed second stage gear. It also suggested that the origin of the fatigue would have been several millimetres away from the fracture face (ie on a segment of the gearwheel which was not recovered).

The stress analysis also showed that, in normal operation, a crack within the carburised layer would not progress into the body of the gear. There were no identifiable material defects within the recovered sections of the failed gear. Current theories and experience of spalling failed to provide a process whereby spalling could progress deep enough into the gear to compromise the carburised layer without detection. As a result of this, further stress analysis was carried out to analyse the shear loads produced with the bearing rollers sliding (see Figure 32). This showed that, in this case, the shear forces became inclined, which, in combination with the volumetric stresses, could result in crack progression beyond the carburised layer.



(Courtesy of Eurocopter)

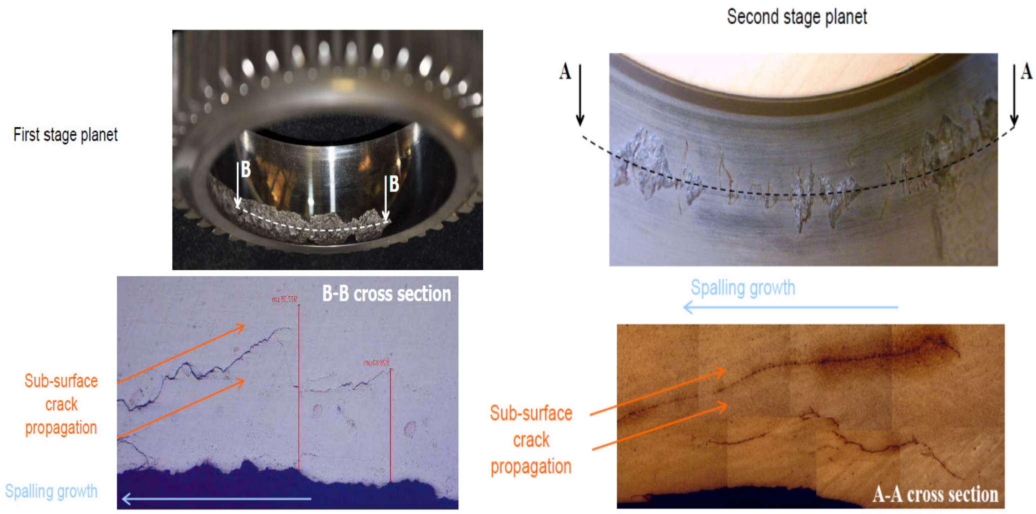
Figure 32

Bearing rolling and sliding

1.16.2.1 Manufacturer's actions as a result of stress analysis

The helicopter manufacturer had previously sectioned two planet gears. These had been removed from epicyclic gearboxes as a result of significant spalling. When removed, these gears had been subject to laboratory examination, but no unusual failure modes were identified.

A first stage planet gear with spalling on one bearing track over 190° of its circumference had been removed in 2009. A second stage planet gear which had near-continuous spalling around 360° of one bearing track, had been removed in 2005. Photographs of sections cut through the spalling damage revealed sub-surface cracks propagating tangentially inwards, extending beyond the carburised layer, in a manner which the stress analysis had suggested the crack path could follow in its early stages.



(Courtesy of Eurocopter)

Figure 33

Spalled gears exhibiting cracking within the carburised layer

The inner raceway of the 2009 cracked first stage planet gear showed that the inner race roller track corresponding to the damage on the outer race had also suffered from significant amounts of spalling on the loaded arc, (see Figure 34). In addition a number of smaller 'pits' were present on the second bearing track of the inner race. Minor pitting was the only damage observed on either bearing track of the 2005 cracked second stage gear's inner race. This pitting was consistent with the presence of particles within the planet gear bearing and was probably caused by spalled debris.

(Courtesy of Eurocopter)

Figure 34

Spalling on inner raceway of first stage gear found cracked by the helicopter manufacturer

1.17 Organisational and management information

1.17.1 The Operator

The operator held an Air Operator's Certificate (AOC) which authorised it to operate AS332 and EC225 helicopter types. It was also approved as a Type Rating Training Organisation (TRTO) and both pilots had completed their AS332 L2 type ratings with the operator. They had completed all the mandatory training and testing requirements to operate in their respective capacities.

In accordance with Joint Aviation Authorities (JAA), JAR-OPS, Part 3 requirements, the operator had set out in an Operations Manual the company policies and procedures for the operation of its helicopters. Included in Part A of that document was the management structure appropriate to the operation. The UK CAA was the regulating body for the acceptance and approval of the Operations Manual.

The operator's engineering organisation held EASA Part 145 approvals to carry out maintenance on the AS332 and EC225 helicopter types. As part of this approval the operator was subject to routine audit and inspection by the UK CAA to ensure that it satisfied the requirements of the approvals it held. These approvals required the operator to maintain its fleet of helicopters in accordance with the relevant Approved Maintenance Programme using approved documentation and procedures. This included the AMM and the Standard practices manual (MTC)

The operator had designated three engineers to carry out HUMS vibration monitoring and analysis. Two engineers had, after training, undertaken this function for a number of years whilst the other had not yet completed his training.

1.17.2 Helicopter manufacturer's technical support

In addition to its design and manufacturing activities, the helicopter manufacturer provides support to operators of its helicopters through its Technical Support department. As part of this, a manufacturer's technical representative is based in Aberdeen to provide direct support to local operators. This representative was not available in Aberdeen on 25 March 2009 due to a pre-planned commitment. In addition, a section of this department, Technical Support Services, was responsible for providing 24 hour technical support to operators. Technical Support Services makes use of Product Managers to provide a focal point for customer contact together with a pool of technical 'experts' who specialise in specific systems of each helicopter type. The technical experts can, should the need arise, request assistance from manufacturer's Design department. Technical Support Services also includes a specialist section which provides support relating to the HUMS systems.

Operators requiring assistance with HUMS submit an EDR to the manufacturer. The EDR requires the operator to give details of their query, any HUMS warnings or alerts and any relevant maintenance information. This form is then sent to the manufacturer's HUMS specialists who, after reviewing the information in the EDR, provide a response to the operator using a section of the form reserved for that purpose. There is no such system in place to deal with non-HUMS technical queries.

The operator was familiar with the EDR process and had made use of it when dealing with a HUMS issue on another helicopter on 25 March 2009.

In the event that an operator wishes to apply for a variance to the procedures or limitations within the manufacturer's documentation (including the AMM), they are required to provide the manufacturer with detailed substantiation for the reason behind the request. This is then reviewed by relevant personnel within the Technical Support and Design departments, in accordance with Eurocopter instruction EI050-16-012. If the variance is considered to be acceptable, a dispensation document is issued by the manufacturer giving full details of the variance duly authorised by the relevant personnel and an EASA approved Compliance Verification Engineer and stamped with "*Approved under DOA EASA*". Any dispensation is provided with the following caveat: "*before use you are requested by Eurocopter to inform your local authorities about this agreement*". After receiving the dispensation, the operator must then contact their regulatory authority (in this case the UK CAA) to obtain approval to use the dispensation. The operator had previously used this procedure for an event on an AS332 L2 in which particles were found on an epicyclic magnetic chip detector at an outstation. The operator followed the maintenance procedures as far as was practicable at the outstation. They then applied to Eurocopter for a variation to allow the aircraft to return to its base. This was agreed by Eurocopter to allow a flight of the helicopter to its engineering base for completion of the maintenance requirements.

1.17.2.1 Maintenance agreements

As part of a commercial argument with operators, the manufacturer retains ownership of the AS332 L2 MGBs together with a pool of 'spare' units. These units are then 'leased' to operators for a fixed charge per helicopter flying hour. This provides several benefits to operators, one of which is the ability to remove and replace MGB's before they have achieved their planned overhaul life without incurring additional expenditure.

1.17.3 Overhaul agencies

At the time of this report, there are two workshops approved to carry out overhauls on the AS332 L2/EC225 MGB in Europe. One is based in Norway and the other, owned by the manufacturer, is located at its facility in France.

The maintenance records for the MGB fitted to G-REDL showed that it had been maintained at the manufacturer's facility. The processes and procedures in operation at this workshop were examined and found to be compliant with all the regulatory requirements.

In accordance with the requirements of EASA Part 145.A.60, Part M.A.302(g) and Part 21.A.3 the helicopter manufacturer operated a Continued Airworthiness programme to investigate and analyse component failures which may have had an adverse effect on the continuing airworthiness of its products.

Components rejected, in operation or during overhaul, were inspected in accordance with the Continued Airworthiness programme. Those which were considered to show new or unusual failure modes were then routed by the manufacturer to its materials laboratory for further analysis. However, the laboratory did not have the capacity to carry out an investigation of every component rejected during gearbox overhaul. When the Continued Airworthiness programme for the AS332 L2 was initiated it was determined, based on previous operational history, design calculations and the maintenance programme requirements, that damage to the planet gear outer race would not adversely affect the continued airworthiness of the helicopter. Therefore, planet gears which had been rejected for spalling were not routinely routed to the laboratory for additional investigation.

1.18 Additional information

1.18.1 Condition monitoring

1.18.1.1 HUMS Advanced Anomaly Detection

As part of ongoing research, the CAA identified that potential improvement could be made to HUMS analysis methods. In 2004, they commissioned a research programme titled "Intelligent Management of Helicopter Vibration Health Monitoring Data: Application of Advanced Analysis Techniques In-Service" with the objective of improving analysis methods and the fault detection performance of HUMS. This programme was undertaken by GE Aviation between 2004 and 2009, using an analysis method known Advanced Anomaly Detection (AAD). GE Aviation provided a final report to the CAA in 2010 which the CAA is due to release in the near future. The final report stated:

> *'Health and Usage Monitoring Systems (HUMS), incorporating comprehensive rotor drive system Vibration Health Monitoring (VHM), have contributed significantly to improving the safety of rotorcraft operations. However, experience has also shown that, while HUMS has a good success rate in detecting defects, not all defect related trends or changes in HUMS data are adequately detected using current threshold setting methods.'*

Rather than relying on thresholds set on each CI, the research used a method to attempt to identify abnormal behaviour in a set of data. This was achieved by comparing the data set to a population of data generated from fleet operation where no faults were present. Before in-service operation, a computer model of 'normal' vibration operation is generated for each gearbox component, using CI data from a fleet of gearboxes. HUMS data downloaded from each flight can then be compared to these 'normal' models in an attempt to identify whether or not the data is anomalous. This alleviates the need for individual thresholds set for each CI and multiple CIs can be used to build each model. It still requires some form of threshold to establish the point at which the data has become anomalous and the component requires further investigation.

Among the report conclusions were:

> *'The results from two in-service trial periods also confirmed that AAD represents a significant advance in HUMS data analysis, resulting in improved fault detection performance and increased system effectiveness. The AAD system out-performed the traditional HUMS analysis in successfully highlighting both helicopter problems and HUMS instrumentation faults. It also gave a clearer picture of anomalous data characteristics on particular aircraft and drive system components than is possible with the traditional HUMS analysis.'*

The effectiveness of AAD at identifying incipient failures is only as good as the design of the CIs. If an 'unknown' defect does not lead to any change in the CI behaviour which would take it outside the boundaries of the 'normal' model, then AAD will not flag the defect as anomalous.

1.18.1.1.1 Application of AAD to G-REDL HUMS

As the initial results from the CAA AAD trial highlighted potential improvements in the analysis of HUMS data, the AAIB commissioned GE Aviation to analyse the G-REDL HUMS data using the same AAD methodology as developed for the CAA trial.

The results generated had to take account of the limitations of the bearing CIs previously described. The report concluded that the AAD methodology could find:

> *'no anomalies that could be related to the upper planet bearing/gear failure*
>
> *It is therefore concluded that there is no evidence in the HUMS CI data of the impending upper planet bearing/gear failure on G-REDL'*

The G-REDL data for the second (upper) stage planet gears and bearings was considered to fit well within the normal fleet data.

This conclusion matched the conclusion drawn from a review of the HUMS CIs from the ground station data. The AAD methodology is designed to enhance the analysis of HUMS data and relies on the effectiveness of the algorithm to calculate the CI.

1.18.1.2 HUMS detection capability

The installation of HUMS has been recognised as providing a significant safety improvement to helicopter operations. Prior to its mandatory fit to G-REDL, the AAIB made a number of Safety Recommendations promoting the use of component condition monitoring in helicopters. In some cases, it was considered that accidents could have been prevented had some form of condition monitoring been in place.

However, the effectiveness of the vibration analysis for each component depends on the distance of the accelerometer from the component, the transmission path of the vibration and the quality of the electronic signal acquired by HUMS. If any one of these conditions is affected then the HUMS ability to detect component degradation diminishes. Epicyclic module bearing monitoring is particularly challenging, with multiple components rotating on a moving axis. Epicyclic gears are affected to a lesser extent as the energy produced by the meshing of gears tends to be higher than that produced by bearings.

Vibration produced by bearings is of high frequency and low amplitude, which attenuates with distance, meaning that the accelerometer must be located in close proximity to the bearing for effective monitoring. For components such as the tail rotor drive shaft bearings, the accelerometers are mounted close to the bearings and monitoring has proven to be effective. The EuroHUMS system manufacturer's training notes highlighted these limitations:

> *'Experience has shown that if the sensor is more than one outer race diameter from the bearing then the chance of acquiring useful diagnostic signals from the bearings is reduced.'*

In addition:

> *'Setting up the process to monitor a planetary bearing can prove very difficult due to the variable transmission path and other noise sources from the planetary rotation itself'.*

As bearing information is not synchronous with shaft rotation, signal averaging is not used in bearing vibration signal acquisition. This means that components generating signal noise, in the same frequency range as the bearing acquisition, will contribute to the levels of noise in the bearing signal.

The helicopter manufacturer confirmed that the primary method of detecting planet gear bearing degradation was by relying on them shedding metallic debris before failure. Between the accident and August 2010, a review of the HUMS data for all cases of planet bearing gear outer race spalling on this helicopter type, showed no evidence of any change in the vibration signature. All components were rejected due to the release of metallic debris.

1.18.1.2.1 Confirming HUMS effectiveness

CAP 753 defines a Controlled Service Introduction (CSI) which the CAA requires the manufacturer to perform prior to the approval of the HUMS. This approval includes the detection effectiveness along with the means by which thresholds evolve and in-service support is carried out. Once in service, the effectiveness of the systems continues to evolve by threshold adjustment, alongside experience in how component degradation manifests itself in the HUMS data.

It is often clear when maintenance action has had an effect as CIs, which were previously of concern, return to levels below a threshold. While this provides a useful indicator that maintenance action has had an effect, sourcing a component strip report from the component repair / overhaul workshop would close the feedback loop on how effective the HUMS is. At the time of the accident, no formal process existed between the operator and manufacturer to close this loop, but had been achieved on an ad-hoc basis.

The absence of feedback strip reports was raised during the CAA AAD programme which identified some unusual vibration data which was not highlighted by an exceedance of the in-service HUMS thresholds. The report commented:

> *'During the two trial periods it was not possible to obtain any strip reports on gearboxes rejected for anomalous HUMS CI trends or metal contamination. The lack of feedback information on the condition of drive system components removed from aircraft, often prevents any meaningful interpretation of CI trends in terms of component condition. This type of feedback is critical to the on-going development of HUMS data analysis capabilities, and the absence of such information is seriously hindering this development.'*

The report went on to recommend developing a process where operators can have access to feedback of the condition of rejected components.

1.18.1.3 HUMS Monitoring improvements

After the G-REDL accident, a cross-industry Helicopter Task Group (HTG) was set up, chaired by Oil and Gas UK, to address issues concerning helicopter safety. The HUMS AAD featured as part of the HTG work; the outcome of which was full endorsement of the system and the request for implementation with operators in the UK oil and gas industry as soon as possible.

EuroHUMS was first introduced in 1994 and is the equipment manufacturer's second generation of HUMS. The latest is a fourth generation system which includes enhancements such as threshold setting on bearing CIs, new CI algorithms and monitoring of individual planet gears. While this offers some improvement on the EuroHUMS, the difficulties in planet gear bearing monitoring remain.

1.18.1.4 Oil debris monitoring and analysis

Until the mid-1980s, the normal method of detecting distress in components within helicopter gearboxes was through the use of oil debris monitoring. This involves the use of magnetic chip detection, inspection of oil filters and gearbox oil analysis. Oil samples were taken at regular intervals for analysis, which was capable of detecting and categorising the presence of microscopic metallic particles held in suspension in the oil. This process has been used successfully for many years on numerous gas turbine engines as well as helicopter gearboxes.

Given the nature of a helicopter gearbox, microscopic metallic particles will be continually produced during gearbox operation. In order to detect deterioration within a gearbox a 'normal' particle signature had to be established for each gearbox over a number of sample points. Once this was defined any changes to this normal signature could be identified and the appropriate actions taken. This process had the disadvantage that the analysis results had to take into account any oil replenishment. It was however capable of detecting the early signs of distress within gearbox components before particles of sufficient size to be captured by the magnetic chip detectors were generated.

The GE Aviation report on the use of AAD methods on the G-REDL HUMS data stated:

> *'For oil washed internal gearbox bearings, oil debris monitoring is generally recognised as the primary method of detecting bearing raceway damage. HUMS VHM represents a secondary bearing detection method but, depending on the component, may have a lower fault detection capability (this does not apply to gears). Oil debris monitoring and VHM are complementary techniques.'*

In 1986 Aerospatiale (Eurocopter) issued Service Letter (LS) 759-00-86 to all operators of their helicopters. The letter notified them that spectrometric analysis of gearbox lubrication oil was no longer supported by the manufacturer. It stated:

> *'Over the last 15 years Aerospatiale helicopter operators have turned to SOA as a complement to the conventional monitoring means.*
>
> *This policy can be evaluated as follows:*
>
> - *Even though SOA enables certain failures to be detected early, in no instances is the aircraft safety jeopardised by waiting until the warning signals are given by the conventional monitoring means.*
>
> - *The advantage of the resulting anticipated removal operations is sometimes wiped out by:*

> - *The additional maintenance costs incurred*
> - *Transport costs*
> - *Operating time lost because the early warning is not compensated by the repair costs which remain virtually the same.*
>
> \- *SOA programmes require strict, rapidly completed procedures, which are often incompatible with civil operation missions.*
>
> \- *Imprecise application of the procedures and the lack of detailed analysis of the results lead to a number of unjustified removal operations.*
>
> *As far as we are concerned, we are not prepared to accept any claims against guarantee based on preliminary SOA information, for gearboxes with specified TBOs.*
>
> *Operating safety is fully ensured by approved conventional monitoring means: magnetic plugs, filters, display of additional parameters such as oil pressure and temperature value, clearances, etc…*
>
> *However, since from economic and logistical standpoints it is advantageous for a number of our customers or operators to use SOA monitoring, we will continue to provide relevant information in our documents…'*

1.18.2 Epicyclic gearbox spalling events on the AS332 L2 helicopter

Data provided by the helicopter manufacturer indicated that between 2001 and 2009 there were nine recorded cases of planet gear spalling on the AS332 L2 (see Table 2).

In addition, information provided by the operator showed that there had been seven events in 2010 on their fleet where magnetic particles had been found on the MGB magnetic chip detectors which had resulted in the removal of the gearbox for repair.

The information provided by the manufacturer regarding the number of planet gear rejections due to spalling was incomplete. During the investigation anecdotal evidence was provided that indicated that overhaul facilities disposed of rejected gears without routing them for investigation.

	RIU	Date	A/C	Detection mean	Quantity of particules: Epicyclic magnetic plug	Quantity of particules: Magnets	Stage	Estimated surface spalled: inner race	Estimated surface spalled: outer race	Estimated surface spalled: rollers	Depth of spalling	TSN of spalled part	TSO of spalled part
EC	SP 837	2001	332 L2	EuroArms alarm of epicyclic magnetic plug	small quantity	lots of particules	2	1200 mm2+1050 mm2 + other planet (less important)	**1 mm2 + 25 mm2**	small		859	
	SP 1000	2004	332 L2	Hums alarm + inspection of epicyclic magnetic plug	not quantificd	not quantificd	2	> 1000 mm2 + 200 mm2				2571	
	SP 1038	2005	332 L2	Chip detector alert + inspection of epicyclic magnetic plug	small quantity	lots of particles	2		**>1000 mm2**		0,33 mm		1952
	SP 1088	2005	532 U2	Overhaul inspection	no detection reported	presence of particules (photo)	2	> 150 mm2				2703	
	SP 1304	2009	332 L2	Epicyclic magnetic plug (25h check)	<100 mm2 (photo)	Lots of particules (photo)	1	>500 mm2	**>1200 mm2**	small	0,25 mm	626	
		2010	*332 L2*	*Epicyclic and bottom magnetic plug*		*No more magnetic elements*	2	*XXX*					*1335*
H1		2005	332L2	Overhaul inspection			1	XXX				2961	
		2006	332L2	Overhaul inspection			2			XXX		3201	
		2009	*332L2*		*small quantity*	*No more magnetic elements*	2			*XXX*		*4156*	*1433*

Table 2

Manufacturer reported spalling events

1.18.3 Events with G-REDN

In July 2010, magnetic particles were found on all three magnetic chip detectors of an AS332 L2 MGB (G-REDN), during a routine 25 hour inspection. The main module chip detector light in the cockpit had not operated and there were no chip detection warnings recorded by HUMS. No particles had been found on the epicyclic chip detector during its last routine inspection, 10 hours prior to the discovery of the particles. After completion of the required maintenance actions, the number of particles collected exceeded the prescribed limitations and the gearbox was removed for investigation. When the gearbox was disassembled, the particles were found to have been generated as a result of a failure within the left accessory gearbox drive module bearings.

In March 2011, several small magnetic particles were found on the main module magnetic chip detector of the MGB installed on G-REDN in July 2010. Analysis of these particles by the manufacturer confirmed that one of these was 16NCD13 steel, but of insufficient size to bridge the contacts of the chip detector and illuminate the main module chip detector light in the cockpit. After discussions between the operator and the manufacturer, the helicopter was placed on ‘close monitoring’ for 25 flying hours.

At the end of this period no additional particles had been found and the ‘close monitoring’ procedure was discontinued. During a routine inspection on 27 April 2011, 87 flying hours after the discovery of the first particle, another three particles were found attached to the main module chip detector. One particle was approximately 2 mm in length but there was no indication of the presence of the particle to the flight crew or on HUMS. Removal of the MGB sump plate revealed additional particles and the MGB was removed for investigation. Subsequent analysis of the particles confirmed that some were 16NCD13 steel.

On disassembly, numerous other metallic particles and silica were recovered from the MGB. The source of the metallic particles was found to be a second stage planet gear which had suffered from spalling of the outer raceway. The gear showed five distinct areas of spalling on a single bearing track, the largest of which was 20 mm^2. In addition, there was also evidence of damage around the complete circumference of the bearing track which was consistent with debris, released during spalling, having been rolled into the raceway surface. The planet gear had operated for 669 flying hours prior to the removal of the MGB.

1.18.4 Accident to Aerospatiale SA330J, 9M-SSC, 16 December1980

On 16 December 1980, an Aerospatiale SA330J Puma helicopter, 9M-SSC, crashed in a swamp forest near Kuala Belait in the State of Brunei. The crew of two and all 10 passengers were fatally injured in the accident, which resulted from an MGB failure similar to that which occurred on G-REDL. The MGB of the SA330J is fundamentally similar in layout to those of the AS332 series of helicopters, although the components are not interchangeable and the gear material specifications are different. The gearbox in the 9M-SSC accident had a recent history of quantities of metallic debris being found on the magnetic chip detector in the main module. The epicyclic module was not equipped with a detector.

The synopsis of the report on this accident contained the following:

> *'The accident occurred following the loss of the main rotor assembly, together with the attached bell housing containing the second stage gears of the epicyclic gearbox. Almost simultaneously, the entire tail boom section parted from the aircraft.*
>
> *It is concluded that the most likely cause of the accident was a planetary gear failure in the second stage of the two stage epicyclic main gearbox reduction gear; the associated metal debris caused jamming within the rotating assemblies, generating forces which fractured the common epicyclic ring gear and the main gearbox*

casing. This resulted in the gross instability in the rotor system, which caused blades to strike the fuselage.

The initial cause of the accident was due to the mistaken health monitoring of the gearbox, leading to a deterioration of the mechanical condition of the gearbox components.'

The Findings in the report contained the following:

' 2. Gross contamination of the main gearbox magnetic plug and filter had occurred during the six weeks preceding the accident. The particles had undoubtedly originated from the second stage planet pinion bearing surfaces. Maintenance personnel had wrongly interpreted the amount of allowable debris as defined in the Aerospatiale Standard Practices Manual, due to the mistaken interpretation of an unfamiliar metric term.

6. Gross instability in the rotor system was caused by the jamming of the gearbox [epicyclic] reduction gear due to the disintegration of a pinion [planet] gear in the second stage of the reduction gear [epicyclic gearbox].'

The first of two causes stated in the report was as follows:

'The accident was caused by the disintegration of a secondary stage planet pinion [gear] within the gearbox following a seizure of its associated roller bearing.'

The break-up of the second stage planet gear in this accident was precipitated by a maintenance error which allowed a severely deteriorated gear to fail. No part of the failed gear was recovered and the entire first planetary stage was missing. However, the break-up of the gear resulted in circumferential failures of the ring gear casing, above and below the epicyclic stages, together with a vertical rupture.

In Appendix 1 to the report, the manufacturer (at that time Aerospatiale) made various comments, some of which are included below:

> *'....the assumption of the box bursting as the accident first cause is negated by the following.*
>
> *-- No fragments of the missing second stage [planet gear] have been found*
>
> *-- Relatively correct condition of high speed stages, which should have shown epicyclic gear jamming marks (especially on flexible couplings and torquemeter shafts)'*
>
> *-- When a planet gear rupture generated by its race chippings occurs, it is necessarily preceded by the initiation of fatigue cracks through the rim*
>
> *Now, no fatigue crack whatsoever was evidenced on the planet gears, in spite of their marked degradation through chipping.'*

Gearbox health monitoring essentially consisted of daily checks of the magnetic plug, together with regular Spectrographic Oil Analysis Programme (SOAP) samples. However, the manner in which the latter was conducted did not result in pertinent or timely information being presented to the operator.

A retrospective analysis of SOAP results, taken during the weeks that preceded the accident, was completed using processes then in use by the UK Royal Air Force. The results validated the SOAP process by demonstrating that timely indication of the deterioration of the MGB was possible.

1.18.5 Helicopter FDM

Installation of a Helicopter FDM (HFDM) on G-REDL was not mandatory. ICAO Annex 6 Part III recommends HFDM for operators of helicopters with a certified takeoff mass exceeding 7,000 kg or having more than nine seats and being fitted with a flight data recorder. For fixed wing applications, an FDM system is mandatory for aircraft with a maximum takeoff weight of more than 27,000 kg. The CAA provides advisory material for FDM in CAP 739 'Flight Data Monitoring' which specifically references fixed wing operations. There is currently no CAA advisory material for HFDM.

1.18.6 Design standards

The AS332 L2 was originally certified by the Direction générale de l'Aviation civile (DGAC) in April 1989 and the FAA Federal Aviation Regulations (FAR) 29

Amendment 24 were used as the basis for this certification. In addition, the CAA used British Civil Airworthiness Requirement (BCAR) 29 Issue 1 dated December 1986 as the basis for the validation of the original certification.

At that time, FAR 29 Amendment 24 had, as a requirement, FAR 29.571 which dealt with the fatigue evaluation of structure including the main rotor drive system. The text of that requirement was:

> *'Sec. 29.571*
>
> *Fatigue evaluation of flight structure.*
>
> *(a) General. Each portion of the flight structure (the flight structure includes rotors, rotor drive systems between the engines and the rotor hubs, controls, fuselage, and their related primary attachments) the failure of which could be catastrophic, must be identified and must be evaluated under paragraph (b), (c), (d) or (e) of this section. The following apply to each fatigue evaluation:*
>
> *(1) The procedure for the evaluation must be approved.*
>
> *(2) The locations of probable failure must be determined.*
>
> *(3) Inflight measurement must be included in determining the following:*
>
> *(i) Loads or stresses in all critical conditions throughout the range of limitations in Sec. 29.309, except that manoeuvering load factors need not exceed the maximum values expected in operation.*
>
> *(ii) The effect of altitude upon these loads or stresses.*
>
> *(4) The loading spectra must be as severe as those expected in operation and must be based on loads or stresses determined under subparagraph (3) of this paragraph.*
>
> *(b) Fatigue tolerance evaluation. It must be shown that the fatigue tolerance of the structure ensures that the probability of catastrophic fatigue failure is extremely remote without establishing replacement times, inspection intervals or other procedures under [Sec. A29.4 of Appendix A.]*
>
> *(c) Replacement time evaluation. It must be shown that the probability of catastrophic fatigue failure is extremely remote within a replacement time furnished under [Sec. A29.4 of Appendix A.]*

(d) Failsafe evaluation. The following apply to failsafe evaluations:

(1) It must be shown that all partial failures will become readily detectable under inspection procedures furnished under Sec. 29.1529(a)(2).

(2) The interval between the time when any partial failure becomes readily detectable under subparagraph (1), and the time when any such failure is expected to reduce the remaining strength of the structure to limit or maximum attainable loads (whichever is less), must be determined.

(3) It must be shown that the interval determined under subparagraph

(2) is long enough, in relation to the inspection intervals and related procedures furnished under Sec. 29.1529(a)(2), to provide a probability of detection great enough to ensure that the probability of catastrophic failure is extremely remote.

(e) Combination of replacement time and failsafe evaluations. A component may be evaluated under a combination of paragraphs (c) and (d) of this section. For such components it must be shown that the probability of catastrophic failure is extremely remote with an approved combination of replacement time, inspection intervals, and related procedures furnished under Sec. 29.1529(a)(2).

Amdt. 29-20, Eff. 10/14/80'

Extremely remote is a probability of occurrence that is less than 1 x 10^{-7} but greater than 1 x 10^{-9} per flight hour. Parts of the AS332 L2 structure were certificated against either 29.571 paragraph b) fatigue tolerance evaluation or paragraph c) replacement time evaluation.

The second stage planet gears were certified against paragraph c) replacement time evaluation. At the time of certification the manufacturer applied service life limits and design assessments to demonstrate to the regulator that the probability of occurrence was extremely improbable (less than $1x10^{-9}$). In addition, the approved maintenance programme included in-service condition monitoring of the gearbox (see 1.6.5.5, 1.6.7.1 and 1.18.1).

In 1989 FAR 29.571 was significantly amended to introduce flaw tolerance requirements and was intended to reduce catastrophic fatigue failures in transport category rotorcraft and is the current requirement.

At the time of application for certification of the EC225 in 2000, JAR 29 Change 1 was the certification basis. However, under the reversions and exemptions granted, fatigue evaluation of certain structure was carried out to the earlier FAR 29.571 requirements in Amendment 24. This was because any principal structural elements which were not changed significantly from the previous AS332 L2 design were certified against the earlier requirements. As the first and second stage planet gears and sun gear in the epicyclic module had not changed significantly from the AS332 L2, the earlier requirements were used.

The current design standards applicable to helicopters concerning their tolerance to fatigue are also laid out in EASA Certification Standard (CS) 29.571. This states that the catastrophic failure of principal structural elements within the rotor drive train due to the presence of fatigue must be avoided. It further states in section 2 that:

> ***'(2) Failsafe (residual strength after flaw growth) evaluation***.
>
> *It must be shown that the structure remaining after a partial failure is able to withstand design limit loads without failure within an inspection period furnished under paragraph A29.4 of appendix A. Limit loads are defined in CS 29.301 (a).*
>
> *(i) The residual strength evaluation must show that the remaining structure after flaw growth is able to withstand design limit loads without failure within its operational life.*
>
> *(ii) Inspection intervals and methods must be established as necessary to ensure that failures are detected prior to residual strength conditions being reached.*
>
> *(iii) If significant changes in structural stiffness or geometry, or both, follow from a structural failure or partial failure, the effect on flaw tolerance must be further investigated.'*

This showed that inspection methods must be sufficiently robust to detect the deterioration of a critical component before the ability of the component to carry its design load is compromised.

Due to advances in the understanding of fatigue tolerance evaluation, a joint working group was formed between the JAA (EASA), the Federal Aviation Administration (FAA), the rotorcraft industry and the Technical Oversight Group for Ageing Aircraft (TOGAA) in 2000. The working group evaluated proposals from the industry, TOGAA recommendations, and the continuing activities and results of rotorcraft damage tolerance research and development. As a result of this review, the working group recommended changes to the fatigue evaluation requirements for CS 29.571. This resulted in the publication of EASA Notice of Proposed Amendment 2010-06[12], published on 27 May 2010, which proposes to introduce improvements in the ability to avoid catastrophic failures of primary structure, including rotor transmission components.

1.18.7 Safety actions

During the early phase of the investigation, two Interim Reports and one Special Bulletin were published. A summary of the Safety Recommendations is included in Special Bulletin S5/2009:

> *'An initial report on the circumstances of this accident was published by the AAIB on 10 April 2009; this report contained three Safety Recommendations relating to additional inspections and enhanced monitoring of the main rotor gearbox. EASA responded immediately to these recommendations by issuing the Emergency Airworthiness Directive No 2009-0087-E, dated 11 April 2009.'*

The helicopter manufacturer had issued Emergency Alert Service Bulletin (EASB) 05.00.81 on 10 April 2009; the EASA issued AD 2009-0087-E which mandated a routine inspection of the epicyclic magnetic chip detector every 10 flight hours or after the last flight of the day. It also required operators to inspect their maintenance records to ensure that task 60.00.00.212 had been followed correctly following the discovery of particles on the epicyclic magnetic chip detector.

In Initial Report No 2, published by the AAIB on 17 April 2009, Safety Recommendation 2009-051 was issued, which stated:

12 http://www.easa.eu.int/rulemaking/r-archives.php#npa.

Safety Recommendation 2009-051

'It is recommended that Eurocopter, with the European Aviation Safety Agency (EASA), develop and implement an inspection of the internal components of the main rotor gearbox epicyclic module for all AS332 L2 and EC225LP helicopters as a matter of urgency to ensure the continued airworthiness of the main rotor gearbox. This inspection is in addition to that specified in EASA Emergency Airworthiness Directive 2009-0087-E, and should be made mandatory with immediate effect by an additional EASA Emergency Airworthiness Directive.'

The EASA responded by issuing Emergency Airworthiness Directive 2009-0095-E, dated 17 April 2009. In addition to the repeat inspection requirements of the epicyclic magnetic chip detection in AD 2009-0087-E, this mandated a one-time inspection of the MGB epicyclic module.

On 18 April 2009 the manufacturer amended EASB 05.00.81 to revision 1 which gave instructions for the removal of the ring of magnets on the gearbox oil separator plates instead of the one time inspection requirement. The EASB was raised to revision 2 (Appendix J) on 23 April 2009 and mandated by EASA with AD 2009-0099-E, dated 23 April 2009, which stated the following:

'Emergency Airworthiness Directives 2009-0087-E and 2009-0095-E were issued following the accident of the AS 332 L2 helicopter registered G-REDL that occurred on April 1, 2009, off the coast of Scotland near Aberdeen. Early investigations showed that a failure within the epicyclic reduction gear module of the Main Gear Box (MGB) resulted in the rupture of the MGB case, which allowed the main rotor head to separate from the helicopter. In the light of this information, enhancement of the means for detection of MGB contamination was deemed of the utmost importance. As an initial precautionary measure AD 2009-0087-E dated 11 April 2009 was published with that aim. Additionally, AD 2009-0095-E dated 17 April 2009 was issued to require a one-time inspection for absence of particles in the MGB epicyclic reduction gear module on the entire fleet. While the investigation is still in progress with the aim of determining as soon as possible the sequence of the failure(s) and initiating cause(s), this new AD, which retains the main requirements of the superseded ADs 2009-0087-E and 2009-0095-E, requires

modifying the chip collector inside the MGB – located between the epicyclic module and the main module – to enhance the early detection capability of the magnetic plugs of the gearbox sump and the epicyclic module. To that aim, this AD requires removing the magnetic elements installed on the chip collector, and the flanged edged from the chip collector (MOD 07.52522). After accomplishment of the modification, this AD specifies also how to further monitor the MGB epicyclic reduction gear module magnetic plug.'

The following two additional Safety Recommendations were also made in Special bulletin S5/2009, which was published on 16 July 2009.

Safety Recommendation 2009-074

It is recommended that the European Aviation Safety Agency, in conjunction with Eurocopter, review the instructions and procedures contained in the Standard Practices Procedure MTC 20.08.08.601 section of the EC225LP and AS332 L2 helicopters Aircraft Maintenance Manual, to ensure that correct identification of the type of magnetic particles found within the oil system of the power transmission system is maximised.

In response to this Safety Recommendation, the manufacturer issued Safety Information Notice No. 2075-S-63, dated 9 July 2009, which introduced a revised, more comprehensive, version of the Standard Practices Procedure MTC 20.08.01.601. This revised document contains colour illustrations of types of chip and debris that may be found, as an aid to operators in determining the significance of a chip. Page 1 of the Safety Information Notice lists the helicopter types to which the document applies, and page 2 includes the following statements:

'In-service experience shows that despite the wide safety margins provided for the sizing of the components installed on your helicopter, some very exceptional events may lead to incipient fatigue cracks or even fracture.

Compared to possible surface degradation resulting from operation (for example: wear resulting from operation, spalling of bearing races or gear teeth seats), the growth of a fatigue crack produces a small number of particles captured at the magnetic plugs.

In addition, it is relevant to note that fatigue crack growth develops more quickly than surface degradation.

In order to enhance detection of these possible and exceptional events at best, Eurocopter has decided to complete the procedures to be applied if and when particles are discovered.

These procedures, initially defined to detect any slowly worsening degradation resulting from operation and generating a great number of particles, are redefined in order to reinforce the detection of this exceptional occurrence of a fatigue crack, without considerably impairing the availability of your aircraft'.

The original procedure is shown at Appendix E, and the revised procedure in Appendix I.

Safety Recommendation 2009-075

It is recommended that the European Aviation Safety Agency, in conjunction with Eurocopter, urgently review the design, operational life and inspection processes of the planet gears used in the epicyclic module of the Main Rotor Gearbox installed in AS332 L2 and EC225LP helicopters, with the intention of minimising the potential of any cracks progressing to failure during the service life of the gears.

In response to this Safety Recommendation, the EASA stated that significant work had already been carried out with respect to re-assessing the planet gear design, safe operating life and methods of inspection. The manufacturer also undertook a comprehensive review of the planet gear design.

1.19 Useful and effective investigation techniques

The use of three-dimensional X-ray tomography proved a useful tool to detect sub-surface cracks. It is an established technique but the size of the specimen which can be examined is limited by the current level of technology. This technology is constantly being improved.

In this investigation the combined use of three-dimensional finite element and analytical analysis was challenging, but it enabled a fuller understanding of the volumetric stresses within the gear and explained the fracture morphology.

2 Analysis

2.1 Introduction

G-REDL struck the sea following separation of the main rotor assembly in-flight. The accident was non-survivable for the 16 persons on-board. The crew were not aware of any anomalies with the helicopter until a MGB oil low pressure warning was recorded on the CVFDR. This was accompanied by a continuous "grinding" sound associated with the break-up of the MGB which continued to the end of the CVFDR recording. Within two seconds the helicopter ceased responding to pilot control inputs due to the failure of the epicyclic module case and ring gear; this resulted in the separation of the MGB from the conical housing of the main rotor.

The main rotor remained attached to the helicopter for approximately 20 seconds from the time of the MGB oil pressure warning. As it broke away, the main rotor blades severed the tailboom in a series of strikes and the fuselage descended into the sea.

The investigation found that the epicyclic ring gear of the MGB had been disrupted by severe internal damage caused by a fatigue failure of a second stage epicyclic planet gear. This analysis reviews the factual information presented in Part 1 of this report, in particular:

- The sequence of events which led to catastrophic failure of the MGB and detachment of the main rotor
- The possible reasons for the development of the fatigue crack in the failed second stage planet gear
- Comparison with an accident to an SA330J Puma helicopter which occurred in 1980 and which shares some similar features to the G-REDL accident
- Consideration of the design and maintenance philosophy of the MGB
- Examination of the effectiveness of systems and procedures designed to provide early warning of degradation of MGB components, including HUMS and magnetic chip detectors
- How these procedures were applied to G-REDL in the days leading up to the accident

2.2 Operational aspects

The flight crew were properly licensed and qualified to carry out their respective roles. The radio transmission made by the co-pilot, stating that the helicopter was serviceable three seconds before the MGB low oil pressure warning confirmed that the crew were unaware of an impending failure of the MGB. After the triggering of the MGB low oil pressure warning, the crew transmitted a MAYDAY. Analysis of the recorded data confirmed that within two seconds of the warning, the helicopter failed to respond to the crew's control inputs.

The investigation was unable to determine the noise reported by some of the passengers of the inbound flight to the Miller Platform. However, approximately five minutes prior to landing on the platform, in accordance with normal procedure, the engine bleed air was turned off, as confirmed by the CVFDR data. While this could not be confirmed as the noise described by the passengers, it is considered to be the most likely source.

2.3 Technical investigation

2.3.1 General

Initial examination of the helicopter revealed that it had suffered a catastrophic failure of the MGB, leading to the separation of the main rotor. The extensive, complex and detailed investigation determined that the failure initiated within a second stage planet gear. A crack had formed, which propagated in fatigue and produced a fracture through the gear. It continued to operate in this condition for a short period of time, during which pieces of the gear, including bearing rollers, were released into the epicyclic module.

The gear finally broke into several sections, one of which was entrained between the ring gear and one of the other epicyclic module planet gears. This caused the epicyclic module case and ring gear to split vertically, the loss of MGB oil pressure and the subsequent failure of the first stage planetary system.

Failure of the case also resulted in the torque loads generated by the main rotor system being transmitted to the helicopter fuselage by the three MGB lift bars and a 'twisting' of the upper section of the MGB in relation to its base. This twisting produced a change in the geometry of the control system for the main rotor blades and prevented the helicopter from responding normally to the crew inputs, just after the loss of MGB oil pressure.

The lift strut attachment points subsequently failed due to this torque loading, releasing the main rotor blades, the rotor head and conical housing. The main rotor blades then severed the tailboom in a series of strikes. These strikes were thought to have occurred approximately 20 seconds after the MGB oil low pressure warning, after fault messages recorded by the SMDs recorded loss of electrical connection to the tail section.

2.3.2 Detailed wreckage examination

A comprehensive examination of the helicopter systems revealed no evidence of any identifiable pre-existing defects within the electrical, navigation, autoflight, hydraulic or fuel systems. All the damage observed to the helicopter's structure was confirmed to have been caused as a result of the failure of the MGB or the helicopter's subsequent impact with the sea.

The helicopter's tail boom had separated from the fuselage after being struck by the main rotor blades. The lack of damage to the blade aerial located on the top of the rear housing of the MGB and the position and angle of the main rotor blade strikes to the tail boom confirmed that the main rotor blades could only have struck the helicopter's tail boom after the main rotor and conical housing had separated from the MGB.

2.3.2.1 Engines

Inspection of the engines confirmed that they had both been operating at the time of impact and that the damage observed had been caused as a result of the impact with the sea. There was no evidence of any pre-existing defect or abnormality with the engines that could have contributed to the accident.

2.3.2.2 MGB lift struts and mounting plate

The damage to the three MGB lift struts confirmed that they had become detached from the fuselage of the helicopter due to the application of torque loads, which they are not designed to carry. This indicated that the normal path for the transmission of these loads, through the MGB casings, had been compromised prior to the failure of the lift struts. The lack of damage to the MGB mounting plate indicated that it had not carried any of the main rotor lift loads. This, together with the failure mode of the three lift struts, confirmed that the epicyclic reduction gearbox module case and ring gear had failed prior to the separation of the three lift struts from the helicopter fuselage.

2.3.2.3 Main rotor head and conical housing

All the damage observed during examination of the main rotor head was consistent with having been caused as a result of the failure of the epicyclic module and subsequent separation of the main rotor head from the lower portions of the MGB.

2.3.2.4 MGB main module

The examination of the MGB showed that there was little damage to the main module. The epicyclic module separator plates had been destroyed in the break-up sequence. The damage observed to the teeth of the first stage epicyclic sun gear, located at the top of the main module, was consistent with having been caused after the failure of the epicyclic module case and ring gear. Failure of the case and ring gear allowed the first stage of the epicyclic gearbox to move in relation to the first stage sun gear. This relative movement, together with the presence of metallic debris within the epicyclic module, resulted in the rapid deterioration and damage of the sun gear teeth.

2.3.2.5 Epicyclic module

The fracture faces on the ruptured epicyclic reduction module case and ring gear confirmed that it had failed as a result of tensile overload. The ‘straightening’ of the nine tooth section of the failed second stage planet gear showed that it had been entrained between the remaining second stage planet gears and the case and ring gear during the failure sequence. This would have significantly increased the hoop stresses within the epicyclic module case and ring gear causing them to rupture. This resulted in the disruption of a number of the fasteners securing the epicyclic module to the main module and the conical housing. The main rotor torque loads could then not be transmitted to the mounting plate on the bottom of the MGB and ultimately led to the failure of the three lift struts and the final release of the rotor head.

Rupture of the epicyclic case and ring gear disrupted the flow of lubricating oil to the oil pressure sensor on the top of the epicyclic case and triggered the MGB low oil pressure warning. The loss of structural integrity would have resulted in a change in the relative position of the upper and lower ends of the three main rotor hydraulic control actuators leading to the loss of normal function of the helicopter’s flying controls.

The presence of impressions made by both first stage and second stage planet gear bearings in both stages of the ring gear confirmed that the epicyclic module was operating for a period of time with a significant amount of liberated material within it, prior to the separation of the conical housing and main rotor.

The damage to the teeth of the first stage planet and ring gears showed that some, if not all the first stage planet gears had continued to operate after the case rupture. No evidence of a primary failure was identified within any of the first stage planet gears, all the damage being consistent with the planetary system continuing to rotate after the rupture of the epicyclic module case. The damage to the seven second stage planet gears, which had remained attached to the second stage planet carrier, was also consistent with their continued rotation after the failure of the epicyclic module case.

2.3.2.6 Failed second stage planet gear

A fracture face on the recovered 9-tooth section of the failed second stage planet gear showed evidence of crack progression in fatigue. All the other fracture surfaces of the recovered sections of the failed gear showed the characteristics of overload failures.

The morphology of the fatigue crack was consistent with it having formed at or near to the raceway surface of the gear before progressing radially outward until the gear failed in overload. Analysis of the stress fields within the gear showed that the stresses within the gear would result in the formation of the complex, multi-directional fracture surface observed on the 9-tooth section of the failed second stage gear.

After failure, the gear continued to operate for a short period of time, releasing bearing rollers and cage material. It is probable that the released material was also responsible for the epicyclic module chip detection recorded on HUMS prior to the rupture of the epicyclic case. The gear eventually broke into several sections, one of which became entrained between the epicyclic module ring gear and the remaining second stage planet gears, which caused the failure of the ring gear and epicyclic module case.

The formation and progressive growth of the fatigue crack within the second stage gear was considered to be the primary cause of the failure of this gear and subsequent rupture of the epicyclic module case.

No material abnormalities were identified during the examination of the recovered sections of the failed gear. The hardness profile of the 9-tooth section, described in section 1.12.3.5.1, showed a relative hardening of the section when compared to the expected values. This was considered to have been caused by work hardening of the 9-tooth section, when the curvature of the section was reduced, after it became entrained between the epicyclic module ring gear and the remaining second stage planet gears. Therefore, the change in hardness of the 9-tooth section did not contribute to the failure of the gear.

The results of the examination of the particle recovered from the epicyclic module magnetic chip detector on 25 March 2009 confirmed that it had originated from the outer raceway of the failed gear. This was from an area that was subject to the highest loading from the bearing rollers. The two indentations in the particle suggested that other, much smaller particles, had been present within the gearbox oil system before its liberation. This may have been an indication of the presence of spalling or foreign object debris.

The lack of damage to any of the recovered sections of the outer race confirmed that the liberated particle and associated damage must have been restricted to an unrecovered portion of the failed gear. Therefore, only about 25.5% of the gear raceway surface could have exhibited damage, although the actual amount could have been less.

The nature of the damage to the inner raceway of the failed gear had some similarities with previous examples of spalling debris being rolled into the raceway surface. However, it is also possible that this occurred during the continued operation of the epicyclic module immediately prior to main rotor separation.

An investigation of two planet gears which had been removed from other gearboxes, due to the presence of spalling, confirmed that cracks could form within the carburised layer of the gear. These two examples showed spalling around their circumference, but the cracks that had formed from these had progressed beyond the carburised layer. In contrast, due to the lack of damage to the recovered sections of G-REDL's failed gear, any spalling must have been restricted to a maximum of 25.5% of its circumference. The failure of the second stage gear is not entirely consistent with the current understanding of spalling therefore the initiation of the failure may not have been the result of spalling alone.

Spalling typically produces significant amounts of small particles of debris which, operational experience with the AS332 L2 and EC225 has shown, would be detected by the collection of multiple particles on the epicyclic module chip detector. The fact that the epicyclic chip detector on G-REDL only collected a single particle may have been influenced by the ring of magnets fitted to the oil separator plates. The possibility remains that the failure mode differed from that observed on the two examples of cracked gears examined by the helicopter manufacturer.

The reason for these differences could not be determined. The possibility remains therefore, that a material defect existed close to the limit of the carburised layer, which acted as an initiator for the formation of the fatigue crack. This could then have progressed into the body of the gear and towards the surface of the outer race. Such a crack would remain undetectable until it reaches an external surface. This failure mode is significantly different to crack initiation from spalling, as metallic particles will not be released into the oil system until the crack reaches a surface. After broaching the surface such a crack may not immediately generate particles of sufficient size and quantity to be detected by the magnetic chip detectors. However, it may generate microscopic particles which could remain suspended within the MGB oil. The presence of a crack leads to the deterioration of the surface in the immediate vicinity of the crack, and the generation of particles which will be capable of detection by the magnetic chip detectors. By the time such particles are released, the crack will have penetrated deeper into the body of the gear than a crack initiated from spalling. However, the manufacturing records for the gears show that there were no abnormalities with the production process and that they had met the required quality tests and inspections. Any such material defect must also have been present since manufacture, some 3,623 flying hours prior to the accident.

There was also the possibility that the failure was initiated by the presence of Foreign Object Debris (FOD), introduced either during gearbox overhaul or during routine maintenance. Given the time that the MGB had operated since its last overhaul, 2,354 flying hours, it is considered unlikely that FOD had been introduced during the overhaul process. FOD could also have been introduced during the replacement of the conical housing on 1 March 2009, 150 flying hours prior to the accident. Examination of the procedures and processes used by the operator during the rotor head and conical housing replacement showed that all reasonable precautions were taken to prevent the ingress of FOD. Given the disruption of the MGB it was not possible to determine if FOD had been present prior to the failure of the second stage gear. There was no evidence of the presence of FOD on any of the recovered components examined during the investigation. However, the indentations discovered on the particle that had been found on 25 March 2009 may have been an indication of an external contaminant, although it may also have been caused by spalling debris.

2.3.3 Condition monitoring

The condition monitoring of the transmission system on the AS332 L2 and EC225 helicopter makes use of magnetic chip detectors. In order to maximise the efficiency of these devices, their positioning within the gearbox is critical. In gas turbine engine applications such devices are typically placed in scavenge oil lines, where oil from the bearing cavities is drawn directly over the chip detector. In these applications it is widely recognised that a chip detector will not collect all the magnetic particles that pass over it.

The position of the main module chip detector on the AS332 L2 means that heavy magnetic particles which drop onto the sump plate should gravitate towards it, but as it is not situated in a return oil line there is a possibility that particles suspended in the oil will not pass within the influence of the detector. In this case they will be drawn into the oil lines where they will pass through the oil filter and be retained.

The epicyclic module chip detector is positioned in the outer circumference of the module and is reliant on a combination of oil being thrown outward from the first stage and second stage planet systems and gravitational flow of oil past the detector. Given its small size in comparison to the size of the epicyclic module case, its ability to collect magnetic particles is limited.

Until the mid-1980s, the condition of the MGB oil system was monitored by the analysis of oil samples in conjunction with magnetic chip detectors and the inspection of oil filters. This method of condition monitoring has been shown to successfully detect deterioration within gas turbine engines and other complex mechanical systems at an early stage and is currently used on a number of military and civil applications. The monitoring of oil by spectrometric means was in place with the helicopter manufacturer until 1986 and was acknowledged by them that it enabled certain failures to be detected early. However, in 1986 the manufacturer issued LS 759-00-86 to operators which removed support for spectrometric oil analysis, although documentary information was provided to those who wished to continue using it.

The gearbox failure on G-REDL was similar in many respects to an accident that occurred to an SA330J Puma helicopter 9M-SSC, in Brunei, in December 1980 (1.18.4). The ring gear failure mode was essentially identical in both cases, and resulted from the failure of a second stage planet gear.

In the accident to 9M-SSC, a misinterpretation of the amount of allowable debris collected from the main module chip detector and oil filter led to serious spalling on the second stage epicyclic bearing surfaces (the first stage was not recovered). It was concluded that the deteriorated state of the surface led in turn to a seizure of a roller and the subsequent disintegration of the associated gear. However, no fragments of this gear were recovered. The accident report contained the following comment from the manufacturer:

> *'When a planet gear rupture generated by its race chippings occurs, it is necessarily preceded by the initiation of fatigue cracks through the rim.'*

Thus, this accident bears many similarities to the G-REDL accident, inasmuch as failure of a second stage planet gear led to a rupture of the epicyclic module ring gear and loss of the main rotor. However, in the 1980 accident to 9M-SSC there was clear evidence that large amounts of metallic debris were being generated in the preceding weeks and, from examination of the components, it was clear that severe spalling was taking place. However, on G-REDL only one particle was captured by the helicopter's magnetic chip detectors prior to the accident flight.

MGB oil analysis on 9M-SSC was being conducted in parallel with debris monitoring, but due to the manner of its implementation, did not provide meaningful results to the operator. However, a retrospective evaluation of the SOAP results demonstrated that the process was capable of providing timely indication of the deterioration of MGB components.

The experience with G-REDN, (see paragraph 1.18.3), has also shown that it is possible for metallic particles, generated within the MGB, to be captured by the main module chip detector without closing the electrical bridge of the detector and not generate a warning on HUMS.

The lack of additional debris collected by MGB chip detectors on G-REDL after 25 March 2009, and the inability of the HUMS system to identify epicyclic bearing degradation shows that the current methods for identifying gearbox deterioration are unlikely to detect the rapid deterioration of a component in the epicyclic module. The routine analysis of gearbox oil, in addition to routine chip detector inspections and filter inspections, could provide an additional means of timely indication of deterioration, when used correctly and in conjunction with the other detection methods. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2011-032

It is recommended that, in addition to the current methods of gearbox condition monitoring on the AS332 L2 and EC225, Eurocopter should introduce further means of identifying in-service gearbox component degradation, such as debris analysis of the main gearbox oil.

2.3.4 Separator plate magnets

The inclusion of magnets on the epicyclic module separator plates was intended to prevent particles released by the module contaminating the main module below it. This step was taken based on previous operational experience with earlier variants of the AS332. The inclusion of the epicyclic module chip detector was intended to provide an indication of deterioration within the module. The design and location of this chip detector was based on the assumption that the primary failure mode of the planet gears would be raceway spalling. Typically this would generate significant quantities of metallic particles, some of which would be collected by the epicyclic chip detector. Some particles would also be collected by the magnets fitted to the oil separator plates, hence the AMM requirement to examine them.

The effectiveness of the epicyclic chip detector to detect the deterioration of a component is reduced by its limited exposure to oil draining from the epicyclic module. Furthermore, the presence of the magnets on the oil separator plates would tend to impede any particle from reaching the main module chip detector. As a result, the helicopter manufacturer issued a Service Bulletin (Appendix J) which gave instructions for the removal of the magnetic elements on the oil separator plates. The EASA issued Emergency Airworthiness Directive 2009-0099-E which mandated the service bulletin.

2.3.5 Planet gear failure monitoring

The review of the design and loading of the second stage epicyclic gear as a result of previous AAIB Safety Recommendations showed that the ultimate load factor of the gear was lower than that predicted in the original design case, but still exceeded the minimum design requirements. This load factor reduction was due to advances in the numerical methods used to calculate the gear's loading. The analysis did, however, identify the potential for shear stresses to become inclined as the bearing rollers slide and can result in crack formation within the carburised layer of the outer race. This could then propagate into the main body of the gear. At the time of the design, this situation had not been anticipated. The identification of cracks within the two 'spalled' planet gears examined by the helicopter manufacturer, one of which had been removed in 2005, demonstrated that this failure mode may have been present in the failed G-REDL gear.

As mentioned in paragraph 1.17.3, components removed during overhaul or in service were inspected in accordance with the helicopter manufacturer's Continued Airworthiness programme. Whilst damage to the outer raceway of epicyclic gears was not considered to adversely effect the airworthiness of the helicopter, this accident and the loss of SA330J, registration 9M-SSC, in 1980 (see 1.18.4) has confirmed that a failure of an epicyclic gear, for whatever reason, could have catastrophic results. The two gears removed from other gearboxes in 2005 and 2009 due to raceway spalling had been subjected to a laboratory examination as part of the continued airworthiness programme, but no abnormal failure modes were identified. Had the cracking within the 'spalled' planet gear removed in 2005 been identified during this examination, it is possible that mitigating actions could have been developed at that time. Indeed, planet gears that have been rejected due to spalling are not routinely examined. Therefore, the following Safety Recommendations are made:

Safety Recommendation 2011-033

It is recommended that Eurocopter review their Continued Airworthiness programme to ensure that components critical to the integrity of the AS332 L2 and EC225 helicopter transmission, which are found to be beyond serviceable limits are examined so that the full nature of any defect is understood.

Safety Recommendation 2011-034

It is recommended that the European Aviation Safety Agency (EASA) review helicopter Type Certificate Holder's procedures for evaluating defective parts to ensure that they satisfy the continued airworthiness requirements of EASA Part 21.A.3.

Safety Recommendation 2011-035

It is recommended that the Federal Aviation Administration review helicopter Type Certificate Holder's procedures for evaluating defective parts to ensure that they satisfy the continued airworthiness requirements of Federal Aviation Regulation Part 21.3.0.

2.3.6 Gearbox design criteria

The geometry and kinematics of the bearing rollers installed in the first and second stage epicyclic module planet gears may result in some sliding of the roller against the raceway surfaces. The presence of raceway spalling could increase any such sliding.

Re-evaluation of the loading of the second stage planet gear demonstrated that sliding causes changes in the shear stresses and could result in crack formation within the carburised layer of the outer race. The initial stages of this failure mode had been found in two epicyclic gears removed from other helicopters, one first stage and one second stage, which had been rejected due to spalling. This phenomenon had not been considered during the design and certification of the AS332 L2 and EC225 epicyclic reduction gearbox module or the development of the approved maintenance programme of the MGB.

The discovery of the magnetic particle on 25 March represented the only indication of deterioration of the gear prior to the catastrophic failure of the epicyclic module. At the time of certification of the AS332 L2 the applicable FAR 29.571 requirement stated that under either fatigue tolerance evaluation or replacement time evaluation *"the probability of catastrophic failure is extremely remote..*". In 1989 the certification requirements were changed to introduce flaw tolerance requirements. These were not applicable at the time of certification of the AS332 L2 and were not applied to certain components of the EC225, as the design of the gearbox had not changed significantly.

Although the design satisfied the certification requirement in place at the time of certification, the current requirements of CS 29.571, see 1.18.6, states:

> *'Inspection intervals and methods must be established as necessary to ensure that failures are detected prior to residual strength conditions to be reached.'*

Therefore, it would appear that if the current requirements were applicable they may not have been met. Section 6 and 8 of the EASA Notice of Proposed Amendment 2010-06[1], provides additional guidance on the determination of suitable inspection techniques and intervals to ensure that the defects within critical components can be reliably detected before the airworthiness of the helicopter is affected.

1 http://www.easa.eu.int/rulemaking/r-archives.php#npa.

During the earlier stages of this investigation several Safety Recommendations were made (2009-048, 2009-049, 2009-050, 2009-051 and 2009-075) regarding the continued airworthiness of the MGB. These have resulted in the EASA and the helicopter manufacturer issuing changes to the maintenance requirements and a re-evaluation of the design of the second stage planet gear. Given the response to these previous recommendations, see 1.18.7, the findings of this investigation and the proposed amendments to the certification requirements, the following Safety Recommendation is made:

Safety Recommendation 2011-036

It is recommended that the European Aviation Safety Agency (EASA) re-evaluate the continued airworthiness of the main rotor gearbox fitted to the AS332 L2 and EC225 helicopters to ensure that it satisfies the requirements of Certification Specification (CS) 29.571 and EASA Notice of Proposed Amendment 2010-06.

2.4 HUMS

Analysis of HUMS data between the date of MGB installation and the last CI acquisition prior to the accident did not reveal any unusual CI trends. There were no CI acquisitions for any of the epicyclic stage components after the epicyclic chip detections and the amplitude step change identified in the audio analysis. The final second stage ring gear CI acquisition was 33 minutes before this step change. It is not known whether HUMS would have identified any change in the vibration signature following the chip detections and amplitude step change.

2.4.1 HUMS multiple chip detections

The investigation identified that, on 24 March 2009, HUMS recorded 667 epicyclic chip detection warnings. In addition, during G-REDL's operations of 25 March 2009, a total of 170 chip detection warnings were recorded and on 1 April 2009, four chip detection warnings in 1 minute 43 seconds were also recorded.

As has been previously stated in paragraphs 1.6.5.5 and 1.6.6.3, the electronically monitored epicyclic module magnetic chip detector fitted to G-REDL was designed to retain any magnetic particles which came within its influence, generating a HUMS alert once the size or quantity of particles was sufficient to bridge the detector elements for 15 seconds. Once a particle was retained, additional particles caught by the detector would not generate multiple alerts.

The helicopter manufacturer considered an explanation for the multiple detections as a ‘loose’ chip making and breaking the electrical contactors of the chip detector elements. However, the logic in the EuroHUMS is designed to help prevent multiple detections in the event of a ‘loose’ chip. Additionally, of the multiple detections, a large number were recorded at between 15 and 16 seconds apart. For this to have occurred, a metallic particle would have to have bridged the detector elements for exactly 15 seconds, then been removed for exactly 0.5 seconds and then immediately bridged the contactors again for at least 15 seconds. As a result, the theory of a ‘loose’ chip on the detector was considered as unlikely.

No particle was found during the physical inspection of the detector immediately after the last flight of 25 March 2009, although multiple chip detections warnings were recorded on HUMS. A particle was discovered on the epicyclic magnetic chip detector on a subsequent examination later that day. During the period of additional monitoring in the 31 flight hours prior to the accident, no chip warnings were recorded on HUMS and no particles were identified during the physical inspections of the epicyclic chip detector. During the final minutes of the accident flight, epicyclic chip detection warnings were recorded at a time which could be expected, given the deteriorating condition of the MGB. It is possible that the chip detector was functioning correctly and that the multiple chip detection warnings recorded by HUMS were due to a problem in the recording system. However, this does not support the operations of 25 March where no particles were found on the detector during the examination of the detector immediately after the last flight. As a result the exact reason for the HUMS multiple chip detections could not be concluded.

2.4.2 HUMS card lockup

The operator began investigating the epicyclic chip detections on 25 March 2009, although the first chip detection warnings were recorded during the operations of 24 March 2009. The ground station summary screens did not provide an alert to the operator for these detections of 24 March 2009, due to the HUMS data card not being correctly closed down. The helicopter manufacturer has since issued an ‘Information Notice’ on this subject to operators.

2.4.3 HUMS Planet gear bearing monitoring

The EuroHUMS, along with VHM systems in general, have limitations in detecting degradation of planet gear bearings. Addressing these will improve the detection capability of HUMS and the chances of detecting degradation. For this reason, the following Safety Recommendation is made:

Safety Recommendation 2011-041

It is recommended that the European Aviation Safety Agency research methods for improving the detection of component degradation in helicopter epicyclic planet gear bearings.

2.4.4 Strip reports for components removed due to HUMS alerts

In order to advance both in-service operational effectiveness and future HUMS developments, an industry best practice would be to ensure reliable feedback is provided to confirm the effect of a change in vibration on specific component degradation.

Although some component strip reports have been provided by repair/overhaul agencies on an ad-hoc basis, there are currently no formal requirements to ensure this is in place and that reports are received by the operator in a timely manner. Feedback is not required for every component rejected for VHM reasons but, as part of the initial and continued HUMS operation, an effective process should be demonstrable. This is not specifically referenced in CAP 753 and as such, the following Safety Recommendation is made:

Safety Recommendation 2011-042

It is recommended that the Civil Aviation Authority update CAP 753 to include a process where operators receive detailed component condition reports in a timely manner to allow effective feedback as to the operation of the Vibration Health Monitoring system.

2.4.5 VHM advances

HUMS has evolved since the design of EuroHUMS with different CI calculations and the addition of bearing CI thresholds. Epicyclic stage planet gears can now be monitored individually, instead of as separate stages, using additional accelerometers mounted on the helicopter gearbox. Nevertheless, the planet gear bearings are still identified as an area which is difficult to monitor.

The CAA trial into AAD has identified improved methods in analysing HUMS CIs and the offshore oil and gas industry has indicated that it is actively seeking to implement such a system.

2.5 Audio analysis

There were no findings which directly identified any frequencies associated with damage to a second stage planet gear. Those of note which were identified were consistent with the presence of second stage ring gear damage and a possible increasing misalignment of the left accessory gearbox oil cooler drive shaft. This occurred three minutes 24 seconds prior to the MGB oil low pressure warning and, based on other engineering evidence, was considered to indicate secondary damage. The HUMS CIs did not show any change in the vibration trend for these components, but the final HUMS CI acquisitions preceded the detected amplitude step changes.

The unidentified 1,022 Hz frequency showed no notable amplitude change throughout the flight. No conclusions could be drawn by the AAIB or the helicopter manufacturer as to the source of this frequency, only that it represented the highest amplitude signal of any frequency from the recording, and that it was gearbox-related. This frequency was not present in the August 2008 G-REDL recording, but it was noted that some gearbox components had been replaced between the date of this recording and the date of the accident.

2.6 Flight crew warnings

Both the AS332 L2 and EC225, when equipped with HUMS, generate a maintenance alert message on the HUMS ground station after a particle is collected by the epicyclic module chip detector. Such an alert would result in the serviceability of the gearbox being investigated each time the HUMS data is reviewed. In addition, the EC225 provides a caution message to the flight crew when a particle is collected by the epicyclic chip detector. If this is triggered prior to take off it would require the condition of the epicyclic module to be verified before continuing with the flight.

The identification of defects within the epicyclic module of a non HUMS-equipped AS332 L2 relies on the routine physical inspection of the epicyclic chip detector. This could result in a helicopter operating in a degraded condition for up to ten hours before the opportunity to identify the problem arises. The investigation has shown that the possibility exists for a defect within a planet gear to deteriorate with limited opportunity for detection. In order to improve the capability of the AS332 L2 to provide indication to operators of a potential problem within the epicyclic module of the MGB, the following Safety Recommendation is made:

Safety Recommendation 2011-043

It is recommended that Eurocopter introduce a means of warning the flight crew, of the AS332 L2 helicopter, in the event of an epicyclic magnetic chip detector activation.

2.7 Maintenance activity on 25 March 2009

Despite all the monitoring methods used to identify deterioration within the MGB there was only a single indication of degradation of the second stage planet gear. This was the collection of the magnetic particle on the epicyclic module chip detector on 25 March 2009. This event and the subsequent maintenance actions were an opportunity to identify the degradation of the planet gear prior to the accident.

2.7.1 Communication between the operator and helicopter manufacturer

The EDR procedure has been in place since the introduction of HUMS (but prior to the routine use of email and other forms of electronic communications) to allow information regarding HUMS issues to be passed between the operators and manufacturer in a clear and concise manner. The communications between the operator and manufacturer personnel on 25 March 2009 consisted of a series of telephone conversations and emails which were sent to follow up aspects of the telephone conversations. The established EDR procedure was not used.

The statements provided by the operator's maintenance personnel and the reports produced by the manufacturer's personnel involved on 25 March 2009 show clear differences in their recollections. The investigation was unable to clarify how these disparities arose but clearly, had a complete audit trail of the communications been available, these differences could have been resolved.

The manufacturer stated that the maintenance actions that were recommended in the final email of 25 March 2009 were based on their understanding that several small particles had been found on the main module chip detector, together with the issue of a potential HUMS trend on the bevel/combiner gear. This email (see 1.6.7.2.2) did give the reference of the procedure used to classify particles after collection, which would apply to particles recovered from anywhere in the gearbox. As the magnetic chip detectors had already been removed and examined by the operator, the manufacturer believed that the actions of AMM procedure 60.00.00.212 had already been accomplished. It is possible that if the initial AMM procedure 60.00.00.212, and the exact details of where the particle was found, had been referenced in the email communications, it may have provided an additional opportunity for the issue to have been clearly understood and any misunderstanding corrected.

The use of telephone conversations to relay complex technical issues which are not backed up by written communication allows for the possibility of a misunderstanding or miscommunication and the issues remaining unidentified, with potentially significant consequences. The disparities between the statements and reports show that this situation arose on 25 March 2009. Had written confirmation of the telephone conversations been provided or requested it is possible that the disparity would have been identified, by one or both parties, and rectified.

The helicopter manufacturer has confirmed that it has reviewed its procedures for dealing with issues raised by operators and overhaul agencies to ensure that sufficient measures are in place to minimise the potential for the misunderstanding or miscommunication of an issue to go unnoticed.

Since the accident, the operator has carried out a review of their procedures for communicating technical queries (including HUMS) with manufacturers. This has led to the introduction of a revised procedure which states:

'2.15.10 Communication with 3rd parties OEM's Part 21

Technical queries with a 3rd party such as a manufacturer or Part 21 approved company are to be documented and should contain:

- *Clear details of the query*
- *Maintenance actions performed*
- *Findings of any maintenance actions*
- *All manual references as applicable*
- *Pictures where possible*

The Part M Organisation shall be advised and involved.

All verbal communications by phone or face to face carried out during this process shall always be followed up by a written confirmation of the conversation detailing the above.

> *This also applies to any other Queries of a technical nature that Bond require assistance with i.e. Stores, Logistics, Technical records etc*
>
> *Provided that this protocol is followed, e-mail exchange is an acceptable method of compliance.'*

2.7.2 Maintenance documentation

The AMM for the AS332 L2 in use at the time of the accident confirmed that Section 60.00.00.212 included instructions to remove the epicyclic module from the MGB and collect any particles adhering to the ring of magnets on the separator plates. Following this, analysis of the particles should be completed in accordance with the Standard Practices Manual procedure (MTC 20.08.01.601).

The standard practices procedure used for the identification of metallic particles recovered from the gearbox was generic. The use of written descriptions and basic chemical tests to determine the significance of metallic particles recovered from the gearbox had drawbacks. It was possible for the description of one particle type to be seen as an accurate description of another particle type.

The statements provided by the operator's engineers showed that that they had, when trying to classify the particle removed from the epicyclic chip detector, paid particular attention to the descriptions within the procedure. They had identified the particle as a piece of scale, but it was determined by them, using visual examination, to be silver or cadmium plating.

Had the particle been identified as nickel or carbon steel then, as the particle alone was less than 50 mm^2 , the helicopter should have been put onto 'close monitoring' IAW 05.53.00.218 (Appendix D). However, as the particle was misidentified as silver or cadmium, the MTC indicated that the operator did not need to carry out any additional inspection requirements, although the operator did carry out additional monitoring of the gearbox through the inspection of the magnetic chip detectors for the next 31 flight hours.

As a result of the limitations of the original procedure and the mis-classification of the particle recovered on 25 March 2009, AAIB Safety Recommendation 2009-074 was issued in AAIB Special Bulletin S5/2009. As a result of this recommendation the helicopter manufacturer revised the procedure (see Appendix I).

2.7.3 Maintenance actions

The operator was EASA part 145 approved and their engineers were deemed capable of determining the serviceability of G-REDL's MGB without recourse to the manufacturer. Had the magnetic particle recovered from the epicyclic chip detector been found in isolation, it is probable that the appropriate maintenance manual tasks would have been applied without consulting the helicopter manufacturer.

The engineers were aware of the possible generation of particles arising from the recent main rotor mast replacement. However, the interviews indicated that the engineers had made a link between the HUMS bevel/combiner gear trend, the multiple epicyclic chip detections on the previous flights and the discovery of the particle on the epicyclic chip detector. This appears to have led them to believe that they were dealing with a complex problem with the gearbox and that it was therefore appropriate to bring the matter to the attention of the manufacturer's HUMS specialists. This also initiated the decision to examine the possibility of replacing G-REDL's MGB with a unit from a helicopter undergoing major maintenance.

Although no direct discussion with the manufacturer's mechanical specialists took place, the operator's engineers nevertheless believed that the manufacturer was aware that a particle had been found on the epicyclic chip detector. They therefore assumed that the email provided by the manufacturer, giving a series of 'recommended' maintenance actions, provided all the actions needed to determine if the MGB should remain in service. As a result the operator's engineers did not refer to the appropriate section of the AMM (task 60.00.00.212.001), that detailed the actions to take when removing a magnetic chip detector for inspection and the subsequent discovery of a particle on the epicyclic chip detector. This also meant that the epicyclic module was not removed in order to examine the magnets on the separator plates. Had it been removed it is possible that additional particles may have been found on the separator plate magnets, which may have led to a more accurate determination of the MGB's serviceability.

Since the accident the operator has completed a review of its maintenance practices and procedures and has measures in place to ensure that reference is made to the approved documentation when completing maintenance tasks. In addition, subsequent independent audits of the operator's engineering procedures and practices were carried out by third parties. These audits did not identify any issues relating to the procedures and practices used by the operator concerning maintenance tasks.

The helicopter manufacturer published Safety Information Notice 2247-S-00[2] in December 2010 reminding operators of their helicopters to follow the published approved procedures when completing maintenance tasks.

2.8 Accident data availability

Both the CVFDR and HOMP recordings ceased early due to different reasons. This limited the amount of data analysis that could be performed and highlighted areas which could affect data availability in future accident investigations.

2.8.1 Loss of CVFDR data

A review of the recorded data indicated that the CVFDR recording ceased prior to other onboard systems. Both the voice and data recordings stopped at the same time, suggesting that power to the CVFDR was removed. The DFDAU, which supplied the CVFDR with data, continued to operate after the CVFDR stopped, as data continued to be collected by the HUMS data card.

Loss of power to the CVFDR is likely to have been caused either by a loss of electrical power supply or power interruption by the g-switch. Recorded VHF transmissions, radar data and downloads from the SMD memory and the HUMS data card suggest that electrical power was still available to those systems sharing the same power supply as the CVFDR, after the CVFDR recording ceased.

The use of g-switches as a 'crash sensor' in helicopters is a common means of compliance to stop the voice recording in the event of an accident. As part of their acceptance criteria, the airworthiness authorities did not have installation guidelines available, but accepted the devices on the basis of the proposed system from the airframe manufacturer. There was no defined magnitude of g or duration of the acceleration pulse.

Previous AAIB investigations have encountered events where the flight recorders have stopped recording prior to the end of the accident sequence. In some events, the g-switch was identified as the most likely cause of the loss of data and several recommendations have been made on the subject[3]. Specification guidelines for flight recording systems have evolved to reflect the use of mechanical g-switches as a 'crash sensor' and as such, the latest requirements[4] stipulate:

2 http://www.eurocopter.com/site/docs_wsw/RUB_36/2247-S-00.pdf.

3 AAIB reports G-TIGK (Report 2/97), G-BWZX (AAIB Bulletin November 1999), G-BMAL (AAIB Bulletin October 2001), VP-CRC (AAIB Bulletin December 2008).

4 EUROCAE document ED112 Minimum Operational Performance Specification (MOPS) for Crash Protected Airborne Recorder Systems.

> *'Negative acceleration sensors ('g' switches) shall not be used because their response is not considered to be reliable'*

There are currently no programmes to modify in-service systems which were qualified prior to the release of ED112. As such, some existing flight recording systems may suffer a loss of data early in the accident sequence. Simply removing the existing switches means that some systems would no longer be compliant with the requirement to stop the cockpit voice recording within 10 minutes of an accident. One possible solution would be to change the existing mechanical g-switches for a more reliable or improved sensor.

Some Emergency Locator Transmitters (ELT) are fitted with an automatic activation device, which is triggered by a sensor which is able to determine whether an accident has occurred by measuring acceleration. Rather than activate the ELT at a fixed level of acceleration, the current Minimum Operational Performance Specifications (MOPS)[5] for ELTs details a specific profile of acceleration against the duration of the acceleration pulse. For a high g impact, the duration of the acceleration is lower than that of a low g impact.

ED 112 refers to 'negative acceleration sensors', referring to mechanical devices used to sense acceleration, and proposes that they "*shall not be used*". The sensors referred to in the ELT MOPS are more sophisticated devices that are able to determine an acceleration profile. In October 2010, EUROCAE Working Group (WG) 90 was convened to update ED112. As part of this update, acceleration sensors will be addressed, with a view to standardise the ED112 requirements in line with those in ED62A.

There remains, in service, a number of helicopters which continue to use g-switches which can lead to the premature removal of power to CVFDR systems. For this reason, the following Safety Recommendations are made:

> **Safety Recommendation 2011-045**
>
> It is recommended that the European Aviation Safety Agency require the 'crash sensor' in helicopters, fitted to stop a Cockpit Voice Recorder in the event of an accident, to comply with EUROCAE ED62A.

5 EUROCAE ED62A and RTCA DO204A.

Safety Recommendation 2011-046

It is recommended that the Federal Aviation Administration require the 'crash sensor' in helicopters, fitted to stop a Cockpit Voice Recorder in the event of an accident, to comply with RTCA DO204A.

2.8.2 Loss of HOMP data

Although its primary purpose is not for accident investigation, data from HFDM and FDM programmes has frequently been used in accident investigations. Use of memory buffers in these systems is not unusual but can present limitations when data is recovered. There are currently no requirements for these systems to minimise the use of memory buffers, and advisory material for HFDM does not currently exist. For this reason, the following Safety Recommendation is made:

Safety Recommendation 2011-047

It is recommended that the Civil Aviation Authority update CAP 739, and include in any future Helicopter Flight Data Monitoring advisory material, guidance to minimise the use of memory buffers in recording hardware, to reduce the possibility of data loss.

3 Conclusions

(a) Findings

1. The flight crew were properly licensed and qualified to conduct the flight and were well rested. Their training was in accordance with the operators requirements.

2. The helicopter was certified, equipped and maintained in accordance with the existing regulations.

3. The helicopter was in cruising flight at 2,000 ft in daylight when the accident occurred. Neither weather nor the crew's actions were factors in the accident.

4. The first indication to the crew of a problem with the helicopter was the loss of MGB oil pressure and triggering of the master warning. Two and a half seconds prior to this indication, the co-pilot had made a radio transmission stating that the helicopter was serviceable.

5. Immediately after the loss of MGB oil pressure the helicopter began to descend and failed to respond to control inputs.

6. The main rotor system separated from the helicopter approximately 20 seconds after the loss of MGB oil pressure.

7. Separation of the main rotor occurred after the conical housing had become separated from the remainder of the MGB, thus forcing the lift struts to react engine torque. They were not designed for this and their attachments failed as a consequence.

8. During separation, the main rotor blades struck the helicopter's tail boom in several locations, severing it from the fuselage.

9. The fuselage fell into the sea at a high vertical speed and the impact was non-survivable for all occupants.

10. The loss of MGB oil pressure and subsequent separation of the main rotor system were the result of a rupture of the MGB epicyclic module case, which is integral with the epicyclic ring gear.

11. A section of a failed second stage epicyclic planet gear become entrained between the remaining second stage planet gears and the ring gear overloading the ring gear and module case, causing them to rupture.

12. The second stage planet gear failed due to the presence of a crack in the outer race of the gear bearing which propagated in fatigue until the gear failed. It then broke into several sections, three of which were recovered.

13. The morphology of the fatigue crack in the second stage planet gear, suggested that it had initiated from a point at or close to the surface of a highly loaded section of the bearing outer race, approximately 14 mm from the edge of the raceway.

14. The origin of the crack was in a section of the failed gear which was not recovered.

15. Production records for the failed gear showed that it met the quality control standards applicable during manufacture.

16. During the investigation, the use of advanced computational techniques, confirmed that the design of the second stage planet gear met the requirements applicable at the time of certification.

17. Stress analysis identified the possibility of crack propagation, in a manner similar to that observed on the failed gear, should a crack of sufficient depth, originating at or close to the race surface, exceed the depth of the carburised layer.

18. Two planet gears removed from other MGBs, due to extensive spalling, were found to exhibit cracks associated with the spalled area and within the carburised layer which showed a radial growth component. These cracks had grown beyond the carburised layer.

19. Computer modelling showed that the radial growth of spalling cracks could be explained by the bearing rollers sliding.

20. A metallic particle was discovered on G-REDL's epicyclic module magnetic chip detector on 25 March 2009, 36 flying hours prior to the accident.

21. The particle had been released from a position approximately 14 mm from the edge of the outer race of the failed gear. It had been released from a section of the failed gear which was not recovered.

22. Two indentations in the particle suggested that other debris was present in the epicyclic module.

23. No material or manufacturing process anomalies were found on the recovered pieces of the failed gear.

24. Spalling may have contributed to the failure of the second stage gear, however, the spalled area must have been less than is typically observed in such cases and have been confined to a maximum of 25.5% of the gear, which was not recovered.

25. The reason for the initiation of the crack in the failed second stage gear could not be established fully and the possibility of a material defect within the gear or foreign object debris could not be discounted.

26. The helicopter manufacturer operated a Continue Airworthiness programme in which components rejected in operation or during overhaul were inspected.

27. When the Continued Airworthiness programme for the AS332 L2 was initiated, it was determined that damage to planet gear outer races would not adversely affect the continued airworthiness of the helicopter.

28. Not all planet gears which had been rejected for spalling were sent to a laboratory for additional investigation.

29. The AS332 L2 does not provide an alert to the flight crew when the epicyclic module magnetic chip detector detects a particle.

30. An accident to a SA 330J Puma helicopter in 1980 bore many similarities to the G-REDL accident and also resulted from a stage 2 planet gear failure. In the former accident, large quantities of metallic debris had been collected over a number of weeks before failure and the inner race had typical evidence of severe spalling.

31. The use of oil analysis may have assisted in the identification of the deterioration of the MGB components.

32. The ring of magnets, introduced on the AS332 L2 and EC225 MGBs, reduced the possibility of detection of metallic debris, generated in the epicyclic module, by the main module magnetic chip detector or by inspection of the oil filter.

33. The discovery of a magnetic particle on the epicyclic module chip detector, during the initial stages of the 25 hour check on 25 March 2009, was the only indication of the degradation of the second stage planet gear.

34. The identification of a potential HUMS trend on the MGB combiner / bevel gear at the time the magnetic particle had been discovered, together with multiple epicyclic magnetic chip detection alerts, indicated to the operator's engineers that they were dealing with a complex MGB problem for which they sought the assistance of the manufacturer.

35. The EDR procedure was not used.

36. The use of verbal and email communication between the operator and manufacturer on 25 March 2009 led to a misunderstanding or miscommunication of the issue.

37. The maintenance recommendations provided by the helicopter manufacturer were based on their belief that small particles had been found on the main module chip detector and that the maintenance actions contained in AMM task 60.00.00.212 had already been completed.

38. The maintenance task to remove the epicyclic module and examine the ring of magnets on the oil separator plates, contained in AMM task 60.00.00.212.001, was not carried out.

39. The standard practices procedure used to identify the origin of metallic particles within the MGB was generic and open to interpretation.

40. The particle discovered on 25 March 2009, from visual examination, was identified as 'scale', but the material was misidentified as being silver or cadmium plating.

HUMS and recorded flight data

41. HUMS recorded 667 epicyclic magnetic chip detection warnings on 24 March 2009. These were not investigated due to the absence of an alert generated by the HUMS ground station.

42. Alerts will not be displayed on the HUMS ground station summary screens,if the HUMS data card is not closed down correctly.

43. HUMS recorded 76 chip detection warnings for the first operation from Aberdeen on 25 March 2009, and 94 for the second operation, also from Aberdeen. For both operations, the first recorded detection was during engine start.

44. The CVFDR was fitted in accordance with regulatory requirements.

45. CVFDR audio analysis revealed that three minutes and 24 seconds prior to the first warning to the flight crew, frequencies were identified which were consistent with the presence of second stage ring gear defect and a possible increasing misalignment of the left accessory gearbox oil cooler drive shaft.

46. Three minutes and three seconds prior to the loss of MGB oil pressure, HUMS recorded an epicyclic chip detection warning. Three further detections were recorded over the next minute and 43 seconds.

47. HOMP ceased recording 34 seconds prior to the CVFDR due to the presence of a memory buffer.

48. After the loss of MGB oil pressure, atmospheric pressure data recorded by radar and CVFDR became inaccurate.

49. The CVFDR ceased recording prior to other onboard systems, probably due to the activation of the g-switch.

50. Review of HUMS vibration data available at the time of the accident revealed no unusual trends related to the epicyclic module.

51. HUMS vibration monitoring capability of detecting degradation in epicyclic stage planet gear bearings is limited.

52. There is currently no formal requirement or process for component strip reports to be provided after components are removed from service due to HUMS alerts.

(b) Causal and Contributory Factors

The investigation identified the following causal factor:

1. The catastrophic failure of the Main Rotor Gearbox was a result of a fatigue fracture of a second stage planet gear in the epicyclic module.

In addition, the investigation identified the following contributory factors:

1. The actions taken following the discovery of a magnetic particle on the epicyclic module chip detector on 25 March 2009, 36 flying hours prior to the accident, resulted in the particle not being recognised as an indication of degradation of the second stage planet gear, which subsequently failed.
2. After 25 March 2009, the existing detection methods did not provide any further indication of the degradation of the second stage planet gear.
3. The ring of magnets installed on the AS332 L2 and EC225 main rotor gearboxes reduced the probability of detecting released debris from the epicyclic module.

4 Safety Recommendations

The following Safety recommendations were made during the course of this investigation.

4.1 **Safety Recommendation 2009-048:** It is Recommended that Eurocopter issue an Alert Service Bulletin to require all operators of AS332 L2 helicopters to implement a regime of additional inspections and enhanced monitoring to ensure the continued airworthiness of the main rotor gearbox epicyclic module.

4.2 **Safety Recommendation 2009-049:** It is Recommended that the European Aviation Safety Agency (EASA) evaluate the efficacy of the Eurocopter programme of additional inspections and enhanced monitoring and, when satisfied, make the Eurocopter Alert Service Bulletin mandatory by issuing an Airworthiness Directive with immediate effect.

4.3 **Safety Recommendation 2009-050:** It is Recommended that Eurocopter improve the gearbox monitoring and warning systems on the AS332 L2 helicopter so as to identify degradation and provide adequate alerts.

4.4 **Safety Recommendation 2009-051:** It is recommended that Eurocopter, with the European Aviation Safety Agency (EASA), develop and implement an inspection of the internal components of the main rotor gearbox epicyclic module for all AS332 L2 and EC225LP helicopters as a matter of urgency to ensure the continued airworthiness of the main rotor gearbox. This inspection is in addition to that specified in EASA Emergency Airworthiness Directive 2009-0087-E, and should be made mandatory with immediate effect by an additional EASA Emergency Airworthiness Directive.

4.5 **Safety Recommendation 2009-074:** It is recommended that the European Aviation Safety Agency, in conjunction with Eurocopter, review the instructions and procedures contained in the Standard Practices Procedure MTC 20.08.08.601 section of the EC225LP and AS332 L2 helicopters Aircraft Maintenance Manual, to ensure that correct identification of the type of magnetic particles found within the oil system of the power transmission system is maximised.

4.6 **Safety Recommendation 2009-075:** It is recommended that the European Aviation Safety Agency, in conjunction with Eurocopter, urgently review the design, operational life and inspection processes of the planet gears used in the epicyclic module of the Main Rotor Gearbox installed in AS332 L2 and EC225LP helicopters, with the intention of minimising the potential of any cracks progressing to failure during the service life of the gears.

The following additional Safety Recommendation are made.

4.7 **Safety Recommendation 2011-032:** It is recommended that, in addition to the current methods of gearbox condition monitoring on the AS332 L2 and EC225, Eurocopter should introduce further means of identifying in-service gearbox component degradation, such as debris analysis of the main gearbox oil.

4.8 **Safety Recommendation 2011-033:** It is recommended that Eurocopter review their Continued Airworthiness programme to ensure that components critical to the integrity of the AS332 L2 and EC225 helicopter transmission, which are found to be beyond serviceable limits are examined so that the full nature of any defect is understood.

4.9 **Safety Recommendation 2011-034:** It is recommended that the European Aviation Safety Agency (EASA) review helicopter Type Certificate Holder's procedures for evaluating defective parts to ensure that they satisfy the continued airworthiness requirements of EASA Part 21.A.3.

4.10 **Safety Recommendation 2011-035:** It is recommended that the Federal Aviation Administration review helicopter Type Certificate Holder's procedures for evaluating defective parts to ensure that they satisfy the continued airworthiness requirements of Federal Aviation Regulation Part 21.3.0.

4.11 **Safety Recommendation 2011-036:** It is recommended that the European Aviation Safety Agency (EASA) re-evaluate the continued airworthiness of the main rotor gearbox fitted to the AS332 L2 and EC225 helicopters to ensure that it satisfies the requirements of Certification Specification (CS) 29.571 and EASA Notice of Proposed Amendment 2010-06.

4.12 **Safety Recommendation 2011-041:** It is recommended that the European Aviation Safety Agency research methods for improving the detection of component degradation in helicopter epicyclic planet gear bearings.

4.13 **Safety Recommendation 2011-042:** It is recommended that the Civil Aviation Authority update CAP 753 to include a process where operators receive detailed component condition reports in a timely manner to allow effective feedback as to the operation of the Vibration Health Monitoring system.

4.14 **Safety Recommendation 2011-043:** It is recommended that Eurocopter introduce a means of warning the flight crew, of the AS332 L2 helicopter, in the event of an epicyclic magnetic chip detector activation.

4.15 **Safety Recommendation 2011-045:** It is recommended that the European Aviation Safety Agency require the 'crash sensor' in helicopters, fitted to stop a Cockpit Voice Recorder in the event of an accident, to comply with EUROCAE ED62A.

4.16 **Safety Recommendation 2011-046:** It is recommended that the Federal Aviation Administration require the 'crash sensor' in helicopters, fitted to stop a Cockpit Voice Recorder in the event of an accident, to comply with RTCA DO204A.

4.17 **Safety Recommendation 2011-047:** It is recommended that the Civil Aviation Authority update CAP 739, and include in any future Helicopter Flight Data Monitoring advisory material, guidance to minimise the use of memory buffers in recording hardware, to reduce the possibility of data loss.

Appendix A

Extracts from AMM 45.11.02

4.8. Metal Particle Detection

(Figure 9), (Figure 10)

a) Two types of Metal Particle Detection fault may be indicated for the gearboxes or for the engines.

1st case: no particles found following HUMS alarm

The sensors concerned are:

- MGB (sump),
- MGB (epicyclic stage),
- IGB,
- TGB,
- Engine 1,
- Engine 2.

2nd case: cockpit alarm not confirmed by HUMS

The sensors concerned are:

- MGB (sump),
- Engine 1,
- Engine 2.

The corresponding fault tracing procedure for these 2 cases is described in (Figure 9), "Metal Particle Detection Fault".

b) Any oil contamination in the gearboxes (MGB, IGB, TGB) is indicated by the "Debris red" indication for the corresponding chip detector, i.e. MGB (sump), IGB and TGB.

The fault tracing procedure corresponding to this fault is described in (Figure 10), "Metal Particle Detection on Transmission Assemblies".

Appendix A (cont)

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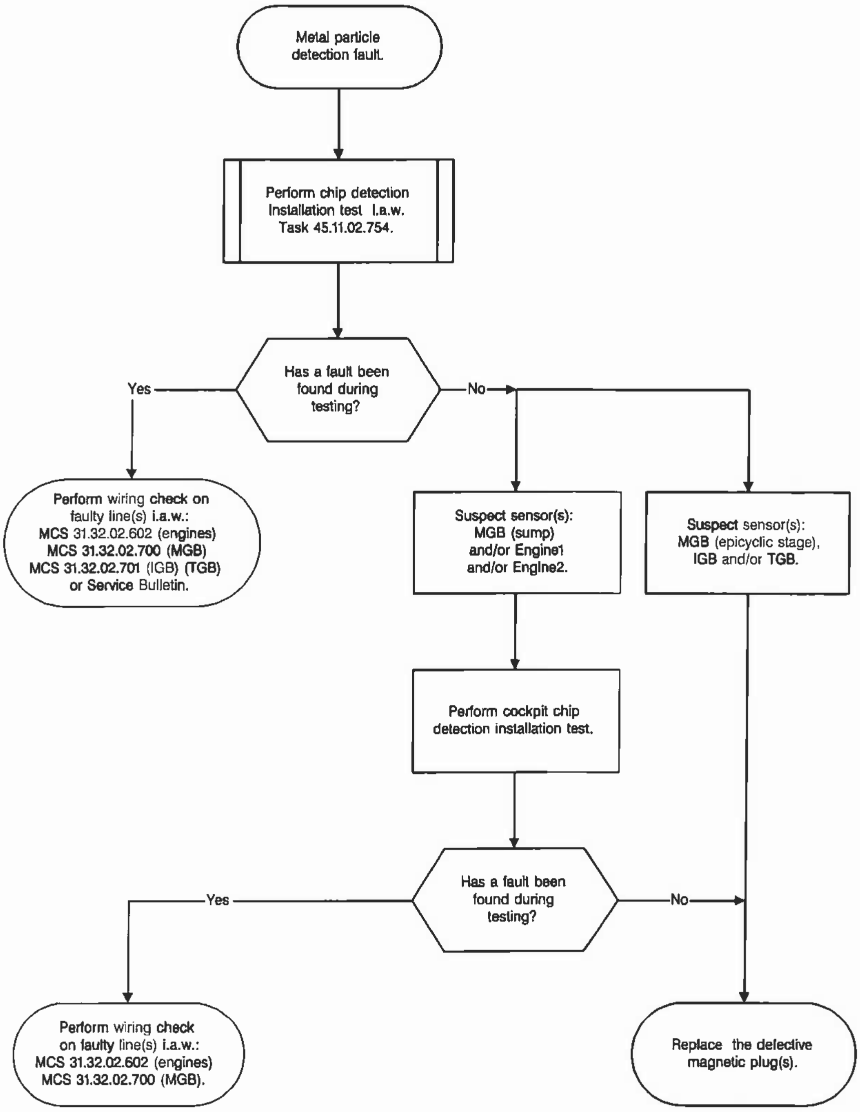
Figure 9.

45.11.02.07



45-11-02-01 Page 55/201

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Appendix A (cont)

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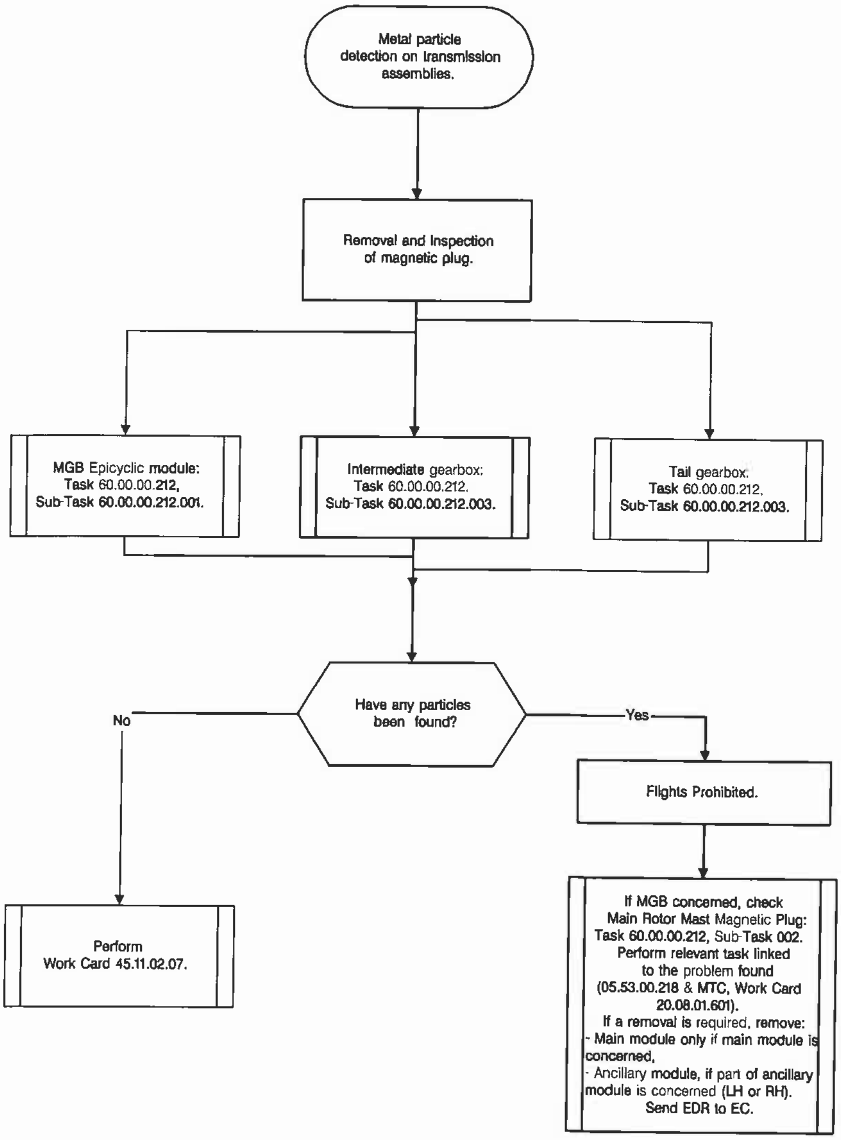
Figure 10.

45.11.02.08



45-11-02-01 Page 57/201
2008.05.28

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Appendix A (cont)

8.2.3. Reporting Procedure

(Figure 56)

The Reporting Procedure is used to report to EC via STK any problems of the HUMS applications or even the HUMS diagnostics.

Concerning these reports, there will be 2 different types:

- Defects linked to HUMS application, they will induce:
  - change of installation definition,
  - change in the system definition (H/W.S/W).
- Defects linked to HUMS diagnostic.

Because the information required for these 2 types of defects is different, there will be 2 forms to guide the customer in sending the correct informations for investigation.

For all these defect reports, some data is required.

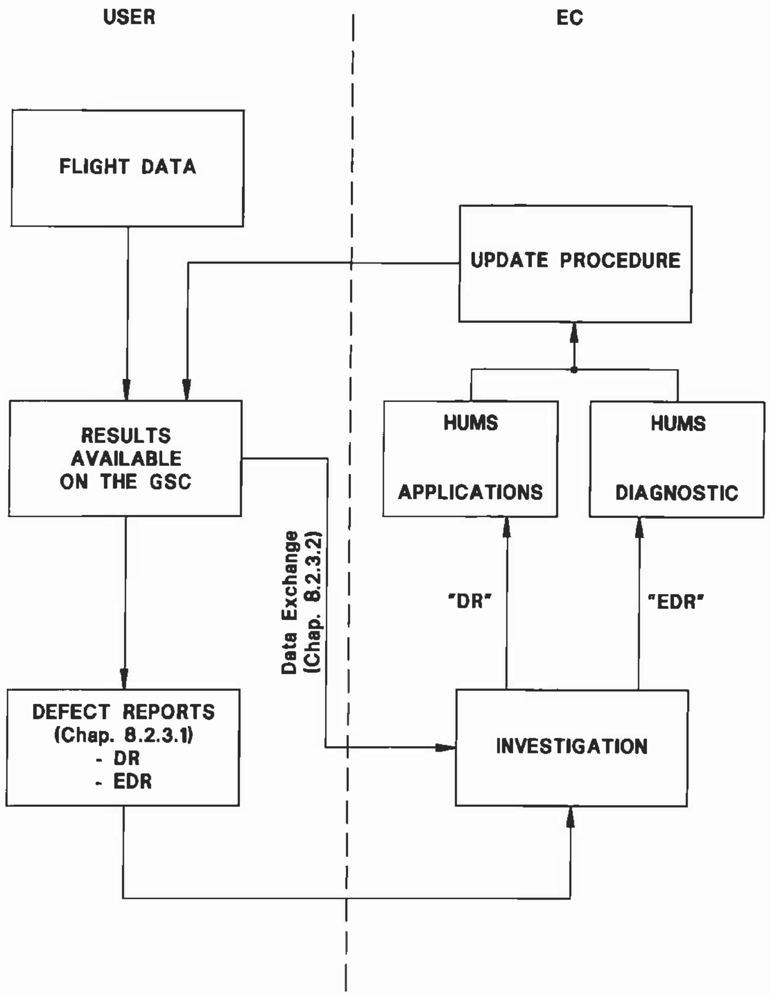
The latest backup sent to EC + data from the last backup to the defect (this data will be sent via modem).

The recommendations provided by EC Support supersede the actions described in the flow charts.

In the event of a mechanical failure on the aircraft, detected or not by the HUMS system, it is advisable to send an EDR to the EC support in order provide feedback.

Appendix A (cont)

REPORTING PROCEDURE



Appendix A (cont)

a. Report Forms

(Figure 57) and (Figure 58)

The 2 forms will be called:

1. Defect Report (DR) for all the defects linked to the HUMS application (Figure 57).
2. EC Diagnostics Report (EDR) for all the defects linked to the diagnostic (Figure 58).

b. Data Exchange

In case of problems the operators will send one of the corresponding forms by fax and keep in touch with the support team in order to provide more information for the investigations (data on removed component for examination...). The usual data exchange shall be performed as described below:

TYPE OF DATA	SOURCE	DESTINATION	SUPPORT
Database backup every 15 days	Operators	STK	D. A. T. Tape
In case of problem: – report form (DR or EDR) – results files from the last backup to the problem (re-save files)	Operators -	STK -	– Fax – Modem
EC answer to DR or EDR	STK	– Operators – Designers	– Fax
Removed component	Operators	STS	

Four possible actions are considered for EDR reply:

Appendix A (cont)

Action	APPROVAL
Maintenance action: Clarification of troubleshooting work card or request for specific action.	EC airworthiness approval can be substantiated.
New threshold setting: Threshold definition is not suitable for a correct monitoring. Thresholds have to be modified outside of threshold policy (fixed threshold instead of statistic, or fixed value modified).	EC airworthiness.
Close monitoring: Type of signal has to be confirmed. EC will specify the trend graph indicators list and the periodicity to be issued by the customer. This information could be sent to EC by fax or e-mail. If flashing alarm is red and close monitoring is requested by EC, red threshold will be reset to prevent continuous red alert after each download. Close monitoring will be specified by fax or update of EDR spreadsheet in monthly report.	Customer support.
Threshold relearning: Threshold setting is not suitable for correct monitoring. EC will provide last number of hours or number of points to be used for the relearning.	Customer support.

Action will be detailed in separate fax referenced on EDR form.

Appendix A (cont)

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System : EURO Customer : ....

☐ Fault report Customer ref.: /......../.......

page : ..../...........

☐ Modification request ECF ref.: ..../..........

Report / Request :
Test site : ....
A/C tail number : ....
DFDAU S/N & S/W version : ....
GSC S/N & S/W version : ....
DRU S/N & S/W version : ....
Date & Flight Report n° : ....

Problem description : ....

Writer : .... Approved by : ....
Visa : Visa :
Transmitted to ECF the .... ☐ by FAX : ....

ECF answer : Evolution decided ? ☐ Yes ☐ No

Units involved : ....

Evolut. description : ....

S/W evolution : ....

Availability : ....

Writer : .... Approved by : ....
Visa : Visa :
Transmitted to Customer the .... ☐ by FAX : ....

Management : ☐ Evolution delivery the : .... by ....

45-11-02-01 Page 326/330
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Appendix A (cont)

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EUROHUMS Diagnostic Report

Customer :		
Customer Ref :	EC Ref :	Page : 1/

Report / Request :	Operating site :
	A/C Tail number :
	Suspect component & Shaft n° :
	Component reference / serial :
	TSO / TSN :
	Date & Flight Report n° :
Warning Identification :	Red : Purple :
GSC maintenance message	
Description of the operations performed after the appearance of the warning (Ref chap 45.11.02)	
Suggested additional maintenance :	

Writer :	Date :	Visa :
Approved by :	Date :	Visa :
DR transmitted By Fax : ☐	By Email : ☐	Graph transmitted By Fax : ☐ By Email : ☐

EC Answer - For EC Use Only

Type of action				EC Mail reference
Maintenance action ☐	Name	Date	Visa	
Writer				
Approval				
Threshold new setting ☐	Name	Date	Visa	
Writer				
Approval				
Close monitoring ☐	Name	Date	Visa	
Writer				
Threshold to relearn ☐	Name	Date	Visa	
Writer				
Others ☐	Name	Date	Visa	
Writer				

Transmitted to customer the :	☐ By Fax

45-11-02-01 Page 329/330

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Appendix B

Bond Technical Information Letter

Bond OFFSHORE HELICOPTERS

TECHNICAL INFORMATION LETTER NO 065

DATE: 23.09.2010

New Euro Hums procedure

Applicable documents:

CAME
ANO 2009
CAP 753 Helicopter Vibration Health monitoring
MMA Chapter 45 Centralised Maintenance System

Following a recent investigation by the AAIB into a Strip Report on a Main Rotor Gearbox removal for metal contamination, an anomaly has been detected in the Euro Hums system fitted to the L2 Fleet.

New Hums Download Procedure

During the acknowledge procedure of the Hums data following the download of a card after a flight/flights a check of the start and stop time must be carried out to ensure they are different for all flight/flights that have been downloaded on that card.

NOTE: - Particular attention to be paid during close monitoring.

If the start and stop times are the same this could be caused by one of the following reasons,

- Card was removed before shutdown
- Faulty weight on wheels switch
- Full card

Appendix B

Bond OFFSHORE HELICOPTERS

TECHNICAL INFORMATION LETTER NO 065

If Start and Stop Time is different

No additional checks required normal procedure to be carried out.

If Start and Stop Time are the same

On discovering the Start and Stop Times are the same the following procedure is to be carried out and documented on an Additional Work Sheet (AWS). With reference to Activation number and Date.

- A check of the four chip indicators on the ground station for the Main, Epicyclic, Intermediate and Tail Gearboxes is to be carried out :-
  a) If the background of the box is black no chip detection has occurred.
  b) If the background of the box is white it shows detection of a chip.

- A visual check of all the Magnetic Plugs fitted to the Transmission system is to be carried out:-
  a) Main Rotor Head Flared Housing
  b) Epicyclic Module
  c) Main Gearbox Sump
  d) Intermediate Gearbox
  e) Tail Gearbox

- Carry out appropriate checks on discovery of any contamination found on the Magnetic Plug.

- Using the Cartridge facility on the ground station, test the cartridge for Serviceability before returning it to the aircraft slot.

Appendix C

AMM Task 60.00.00.212

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AIRCRAFT MAINTENANCE MANUAL AS 332 MK2

For A/C: 1001-9999

Task 60-00-00-212 Checking a Magnetic Element

1. REQUIRED EQUIPMENT

1.1. Special Tools

28 VDC Electrical Ground Power Unit

1.2. Materials

Z2CN18	Lockwire, 0.8 mm (.031 in) dia.
O.155	Oil
	White Spirit

1.3. Replacement Parts

None

1.4. Applicable Documents

– Aircraft Maintenance Manual (MMA):

24-00-00-611	General Instructions
60-00-00-611	General Standard Maintenance Instructions

1.5. General Information

– Aircraft Maintenance Manual (MMA):

05-53-00-218	Contamination of Gearbox Oil
05-53-00-219	Special Check Following Contamination of the MGB Lubrication System
45-11-02-754	Chip Detection Installation Test (Eurohums)
45-11-06-753	Chip Detection Installation Test (Euroarms)
60-00-00-641	Filling and Draining
63-22-00-021	Removal
63-22-00-421	Installation

– Standard Practices Manual (MTC):

MTC 20.01.01.302	Oils
MTC 20.02.06.402	Safetying With Lockwire
MTC 20.08.01.601	Checking Gearbox Oil Contamination on Magnetic Plugs

2. PRELIMINARY STEPS

- Install the access equipment.
- Open or remove doors or panels for access to the relevant magnetic plug or chip detector.

3. PROCEDURE

NOTE:

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60-00-00-212 Page 1/8
2006.11.06

Appendix C (cont)

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AIRCRAFT MAINTENANCE MANUAL AS 332 MK2

Apply the general and standard maintenance instructions as per 60-00-00-611 according to work to be performed.

Subtask 60-00-00-212-001

3.1. Checking a Non-Electric Magnetic Plug on the Epicyclic Reduction Gear Module

(Figure 1)

- Push and turn plug (1) one eight of a turn to the left and extract it.

3.1.1. Examination of the magnetic element (2)

- Examine magnetic element (2) for analysis of the collected particles.

  If there are no particles, comply with paragraph 3.1.2.

- If particles are found, open the epicyclic module.
- Remove the epicyclic module as per 63-22-00-021 .
- Use a magnet to recover all the particles which you find on the magnets (3) of the collector.
- Refer to MTC for the analysis of the recovered particles:
  - if the results of the particle analysis fall within the limits of the acceptable criteria, install the epicyclic module as per 63-22-00-421 ,
  - if the analysis results are out of the limits of the acceptable criteria:
    - send the epicyclic module to an approved repairer's shop for survey;
    - refer to Subtask 05-53-00-218-001 of 05-53-00-218 to check the contamination of the flared housing and of the MGB.

3.1.2. After the examination of the magnetic element (2)

- Insert magnetic plug (1) in its housing, push and turn one eighth of a turn to the right, then release.
- Make sure that the flats on plug (5) are aligned with the flats of the housing hexagon (4) (indication of correct locking).
- If necessary, top up the oil level as per 60-00-00-641 , Subtask 60-00-00-641-004.
- Check for static leaks.

60-00-00-212 Page 2/8
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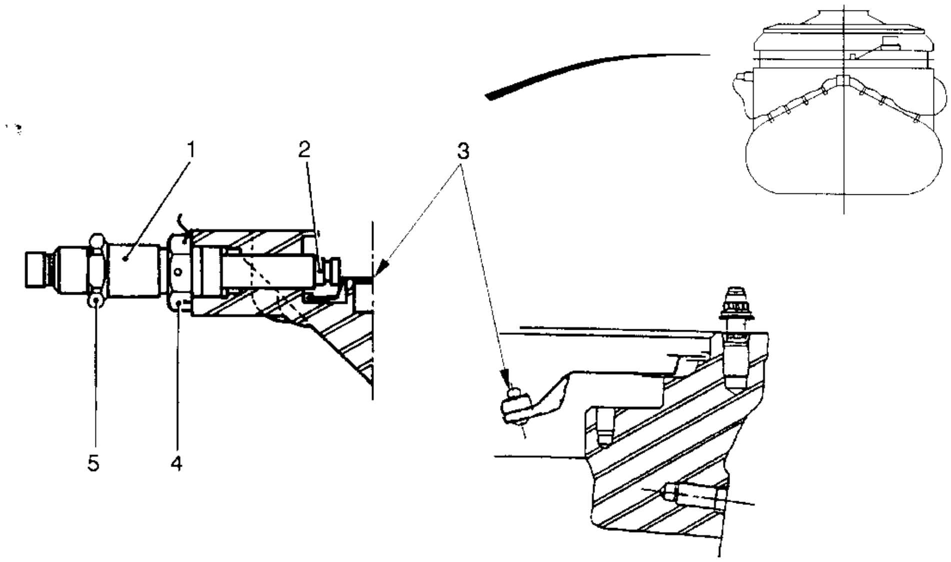
2006.11.06

Appendix C (cont)

Figure 1.



* Subtask 60-00-00-212-002

3.2. Checking the Flared Housing Non-Electric Magnetic Plug

(Figure 2)

- Unlock and remove magnetic plug (4) fitted with felt sleeve (3).
- Examine magnetic element (1) to interpret the results and for instructions if particles are found. If the oil is contaminated drain the MGB as per 60-00-00-641 , Subtask 60-00-00-641-001 and refer to 05-53-00-219 .

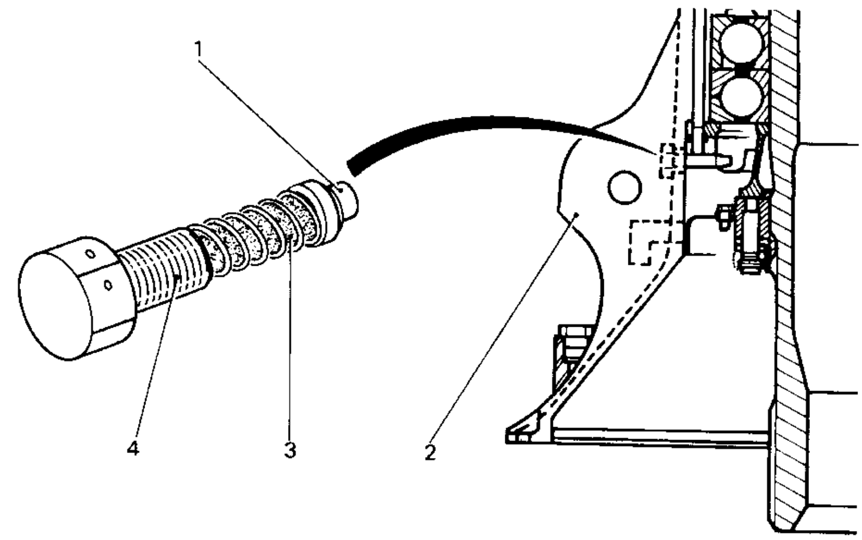
NOTE:

- *The felt sleeve should be impregnated with oil.*
- *The felt sleeve must be 24.5 mm (tolerance - 0 mm, - 0.5 mm) (.96 in (tolerance - 0 in, - .02 in)) long*

- After checking, clean magnetic element (1).
- Install magnetic plug (4) in flared housing (2).
- Tighten and lock with Z2CN18 Lockwire, 0.8 mm (.031 in) dia..
- Check for leaks when the aircraft is next started up.

Appendix C (cont)

Figure 2.



** Subtask 60-00-00-212-003

3.3. Checking the Non-Electric IGB or TGB Magnetic Plug

(Figure 3)

- The following procedure is identical for the IGB (2) and the TGB (4).
  - Unlock and remove the magnetic plug (3).
  - Examine magnetic element (1) to interpret the results and for instructions if particles are found. If the oil is contaminated drain the IGB as per 60-00-00-641 , Subtask 60-00-00-641-002 or the TGB as per 60-00-00-641 , Subtask 60-00-00-641-003.

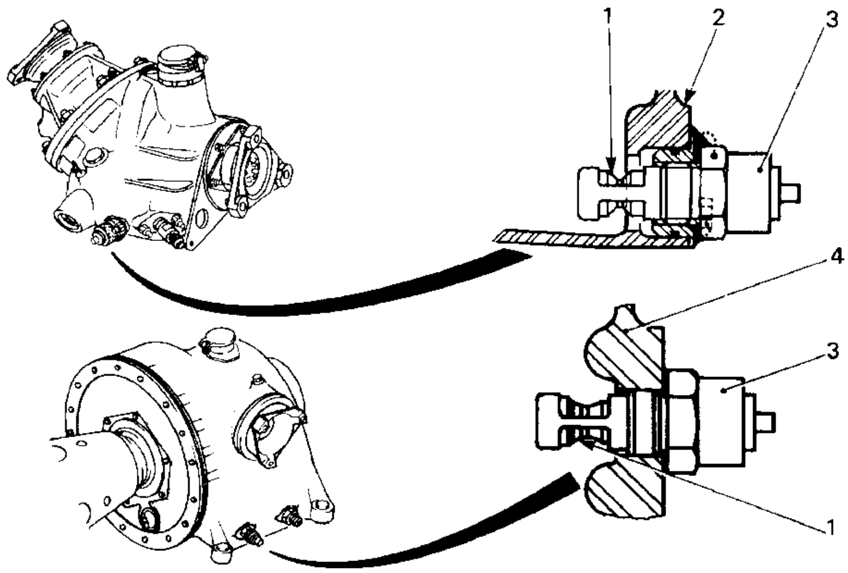
NOTE:

Do not repeat the checking procedure for magnetic elements described in 60-00-00-641 .

  - After checking, clean magnetic element (1).
  - Install magnetic plug (3) in the housing.
  - Lightly torque the magnetic plug (3).
  - Safety the magnetic plug (3) using Z2CN18 Lockwire, 0.8 mm (.031 in) dia..
  - Check for static leaks.

Appendix C (cont)

Figure 3.



** Subtask 60-00-00-212-004

3.4. Checking the Electrical Signalling Chip Detector in the MGB Sump (2) or the Epicyclic Reduction Module (1) or the IGB (12) or the TGB (11)

CAUTION

ALWAYS COMPLY WITH THE GENERAL INSTRUCTIONS AS PER 24-00-00-611 BEFORE PERFORMING ANY WORK ON THE ELECTRICAL SYSTEM.

(Figure 4)

3.4.1. Start of Procedure

- Disconnect the electrical connector (4), (8) or (15).
- Push in and rotate the chip detector (3), (9) or (16) one eighth of a turn anti-clockwise then pull it out.

NOTE:

Do not repeat the chip detector checking procedure described in 60-00-00-641 .

- Examine the magnetic elements (7) and (10) to interpret the results and for instructions to follow if particles are found. If debris is found, drain:

Appendix C (cont)

- the MGB as per 60-00-00-641 , Subtask 60-00-00-641-001,
- or the IGB as per 60-00-00-641 , Subtask 60-00-00-641-002,
- or the TGB as per 60-00-00-641 , Subtask 60-00-00-641-003.

- Examine the magnetic element (17) of the epicyclic reduction module (1) chip detector (16):
  - if particles are found, refer to paragraph 3.1.1 of Subtask 60-00-00-212-001.
- After checking, clean the magnetic element (7), (10) or (17).

NOTE:

Do not repeat the procedure for checking the chip detectors as specified in 60-00-00-641 .

NOTE:

If particles are detected during the visual inspection and if there is no fault indicated during analysis of the monitoring system data, perform a functional test of the chip detector electrical line as per 45-11-02-754 or 45-11-06-753 .

3.4.2. Test of the MGB sump (2) chip detector (3)

- Reconnect the electrical connector (4).
- Connect the (28 VDC Electrical Ground Power Unit) and energize the aircraft electrical power systems.
- Test the chip detector (3):
  - Connect the chip detector (7) to the ground.
  - Check that the MGB.CHIP light illuminates on the warning-caution panel
- De-energize the aircraft electrical power systems.

3.4.3. End of Procedure

- Disconnect the electrical connector (4) from the chip detector (3).
- Insert the chip detector (3), (9) or (16) in its housing, turn it one eighth of a turn to the right, then release the pressure.
- Make sure the protrusions (5) or (14) on the chip detector (3) or (16) are aligned with the points of the hexagon of the housing (6) or (13) (this indicates correct locking).
- Connect the electrical connector (4), (8) or (15).
- If necessary, top up the oil level of the MGB as per Subtask 60-00-00-641-004 or of the IGB as per Subtask 60-00-00-641-005, or of the TGB as per Subtask 60-00-00-641-006, of 60-00-00-641 .
- Make sure there is no static leakage.

4. FINAL STEPS

- Install or close the doors or panels that were removed to gain access to the magnetic plug or chip detector

Appendix C (cont)

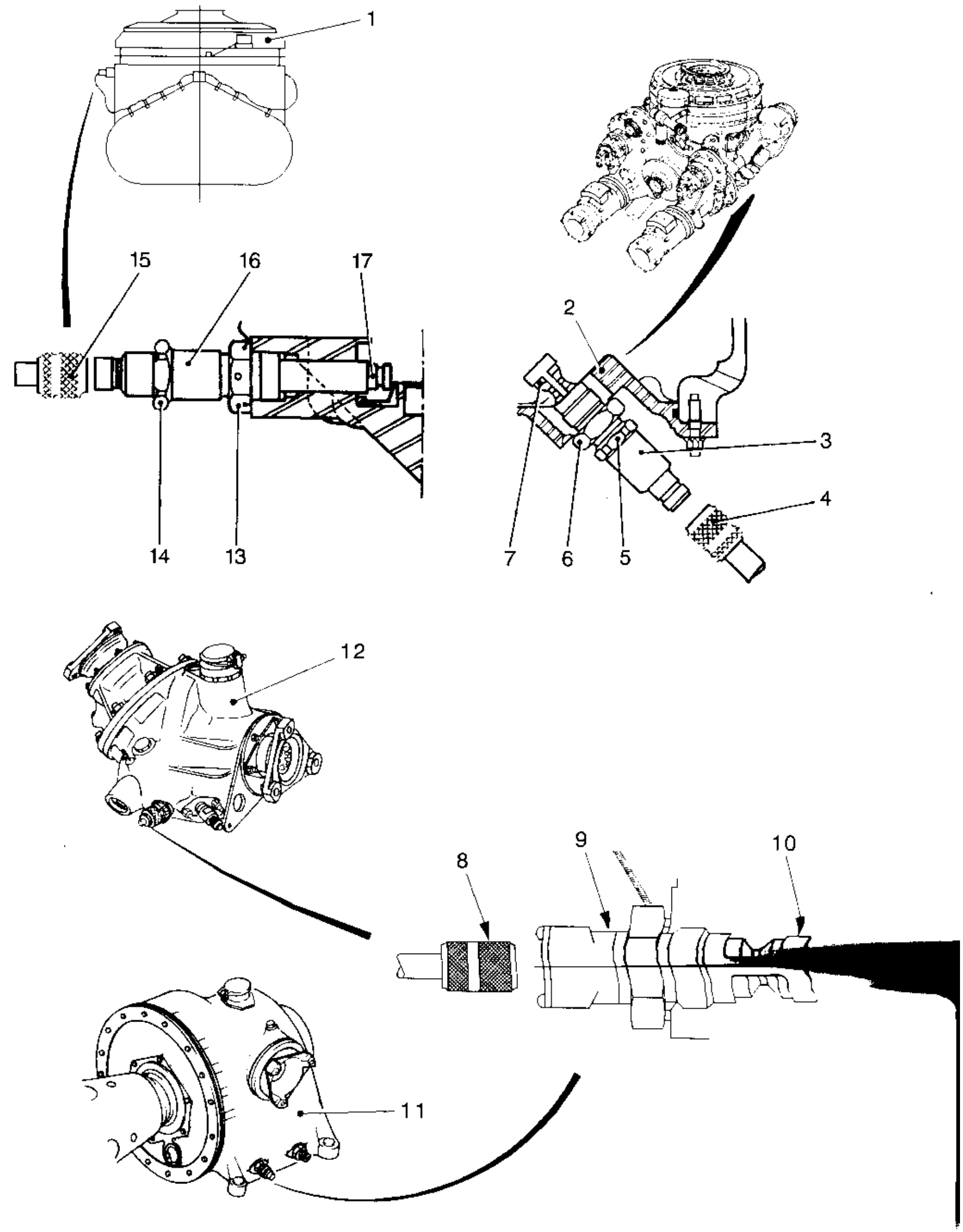
concerned.

- Remove the access equipment.

Appendix C (cont)

AIRCRAFT MAINTENANCE MANUAL AS 332 MK2

Figure 4.



60-00-00-212 Page 8/8
2006.11.06

These printed pages must not be retained for reference

Appendix D

AMM Task 05.53.00.218

AIRCRAFT MAINTENANCE MANUAL AS 332 MK2

For A/C: 1001-9999

* Task 05-53-00-218 Contamination of Gearbox Oil

1. REQUIRED EQUIPMENT

1.1. Special Tools

04.70.00.01.070 Borescope assembly

Not listed in the ICO Drain pan

1.2. Materials

Z2CN18 Lockwire, dia. 0.8 mm (.031 in)

1.3. Replacement Parts

None

1.4. Applicable Documents

- Aircraft Maintenance Manual (MMA):

60-00-00-212	Checking a Magnetic Element
60-00-00-611	General and Standard Maintenance Instructions
60-00-00-641	Filling and Draining
63-21-00-062	Oil Sump Cover Removal-Installation
63-24-01-061	Filter Cartridge Removal- Installation

- Flight Manual (PMV)

1.5. General Information

- Aircraft Maintenance Manual (MMA):

05-53-00-219	Special Check After Contamination of the MGB Lubrication Circuit
62-20-00-021	Removal
63-20-00-021	Removal
63-24-02-061	Removal-Installation
63-24-03-031	Oil Cooler Removal
63-24-03-431	Oil Cooler Installation
64-20-00-021	Removal
65-30-00-051	Removal-Installation

- Standard Practices Manual (MTC):

MTC 20.08.01.601	Checking the Gearbox Oil Contamination on Magnetic Plug
MTC 20.08.01.602 of Gearbox Oils	Determining the Titanium in Presence of Magnesium and Aluminium in the Contamination

2. PRELIMINARY STEPS

05-53-00-218 Page 1/4
2000.03.24

These printed pages must not be retained for reference

Appendix D (cont)

- The procedure detailed below follows the gearbox magnetic plug or chip detector checks as per 60-00-00-212 .

3. PROCEDURE

NOTE:

Refer to the general and standard maintenance instructions as per 60-00-00-611 , according to the operations to be performed.

Subtask 05-53-00-218-001

3.1. MGB Contamination Check

- If the check of the magnetic plug on the flared housing has not been performed, refer to 60-00-00-212 , Subtask 60-00-00-212-002; if particles are found, refer to 05-53-00-219 .
- Place a Not listed in the ICO (Drain pan) below the oil cooler drain plug.
- Drain and strain the oil from the cooler and retain the particles.
- Clean the oil cooler and lines, strain the rinsing mixture and retain the particles.

NOTE:

If there is a large number of particles (particularly if there are very small elements) replace the oil cooler as per 63-24-03-031 and 63-24-03-431 .

- Remove the filtering cartridge as per 63-24-01-061 , Subtask 63-24-01-031-001.

NOTE:

Filter the oil drained from the oil filter.

- Clean the filtering cartridge, strain the rinsing mixture and retain the particles.
- Remove the MGB oil sump cover as per 63-21-00-062 , Subtask 63-21-00-032-001 and check for particles in inside and visible areas using the 04.70.00.01.070 (Borescope assembly) and sealed light source.
- Thoroughly clean the sump cover, the magnetic element and strain cleaning mixture to check for particles.
- Visually check the cleanliness of the oil pump strainers; if further work is necessary, remove the oil pumps as per 63-24-02-061 , Subtask 63-24-02-031-001.
- Check the particles, taking into account all the particles found during the above operations; apply the criteria specified in the MTC 20.08.01.601 and MTC 20.08.01.602 and keep the particles.
- After checking:
  - if necessary, install the oil pumps as per 63-24-02-061 , Subtask 63-24-02-431-001,

Appendix D (cont)

- install the oil sump cover as per 63-21-00-062 , Subtask 63-21-00-432-001,
- install the oil filter cartridge as per 63-24-01-061 , Subtask 63-24-01-431-001,
- fit the seal on the drain plug; install and lock plug on the oil cooler,

- If the contamination criteria are within tolerance as per MTC 20.08.01.601 and MTC 20.08.01.602:
  - connect and lock the oil cooler supply lines,
  - fill the MGB and cooling system with service oil as per 60-00-00-641 , Subtask 60-00-00-641-004,
  - prime the system by rotating the main rotor by hand.
- If the criteria are exceeded, remove the MGB as per 63-20-00-021 and return it for overhaul.

Subtask 05-53-00-218-002

3.2. IGB and TGB Contamination Check

- Analyze the contamination particles as per MTC 20.08.01.601 and MTC 20.08.01.602; keep the particles.
- Clean the magnetic plug.
- Remove the inspection plug on the IGB or TGB; check for particles inside the gearbox using the 04.70.00.01.070 (Borescope assembly).
- After checking:
  - install and lock the IGB or TGB inspection plug and tighten moderately.
- If the contamination criteria are within tolerance as per MTC 20.08.01.601 and MTC 20.08.01.602:
  - fill the gearbox with IGB service oil as per 60-00-00-641 , Subtask 60-00-00-641-005 or TGB service oil as per 60-00-00-641 , Subtask 60-00-00-641-006.
- If the criteria are exceeded, remove the IGB as per 65-30-00-051 , Subtask 65-30-00-021-001 or remove the TGB as per 64-20-00-021 and send them for overhaul.

Subtask 05-53-00-218-003

3.3. MGB Checking Flight and Monitoring Procedure

- If the removal criteria are not exceeded, after checking the particles as per the MTC 20.08.01.601 and MTC 20.08.01.602 and on the first appearance of the particles:
  - carry out a hover flight at the maximum authorized weight specified in the Flight Manual in order to evaluate the damage progression rate. The duration of this flight shall be sufficient to stabilize the gearbox oil temperature + 10 minutes,
  - after this flight, check the MGB chip detectors as per 60-00-00-212 , Subtask 60-00-00-212-004,
  - check the magnetic plug on the tapered housing as per 60-00-00-212 , Subtask 60-00-00-212-002,
  - check the magnetic plug on the epicyclic module as per 60-00-00-212 , Subtask 60-00-00-212-001 or the chip detector as per 60-00-00-212 , Subtask 60-00-00-212-004 if the aircraft is fitted with a EUROHUMS

Appendix D (cont)

or EuroARMS System.

- check the oil filter cartridge as per 63-24-01-061 ,
- check that the contamination criteria are still respected, taking into account all the particles produced since they first appeared:
  - if the contamination criteria are respected, flight may continue and after each flight, check the magnetic plugs or the chip detectors on the MGB, the epicyclic module and on the tapered housing as per 60-00-00-212 ,
  - check the oil filter cartridge every 5 hours as per 63-24-01-061 ,
  - if after 25 hours of flight the amount of particles produced is negligible, return to the normal maintenance cycle; if this is not the case, remove the MGB as per 63-20-00-021 , or the MRH as per 62-20-00-021 .

Subtask 05-53-00-218-004

3.4. IGB or TGB Checking Flight and Monitoring Procedure

- The procedure is identical to Subtask 05-53-00-218-003 for the MGB, except for the MGB and MRH magnetic plug checks. Check the IGB or TGB magnetic plug as per 60-00-00-212 , Subtask 60-00-00-212-003 or the chip detectors, as per 60-00-00-212 , Subtask 60-00-00-212-004 if the aircraft is fitted with EUROHUMS or EuroARMS.
- If the criteria are exceeded, remove the IGB as per 65-30-00-051 , Subtask 65-30-00-021-001 or the TGB as per 64-20-00-021 .

Appendix E

MTC Task Card 20.08.01.601

STANDARD PRACTICES

PERIODICAL MONITORING OF LUBRICATING
OIL CHECKING ELEMENTS
Checking the Power Transmission Assembly
on Magnetic Plug

IMPORTANT NOTE : THE APPLICATION OF THIS CARD IS EXTENDED TO THE LUBRICATION OF THE MRH AND FLARED HOUSING ON SA 330-332 AIRCRAFT (Modification 43.004) FITTED WITH MAGNETIC PLUGS.

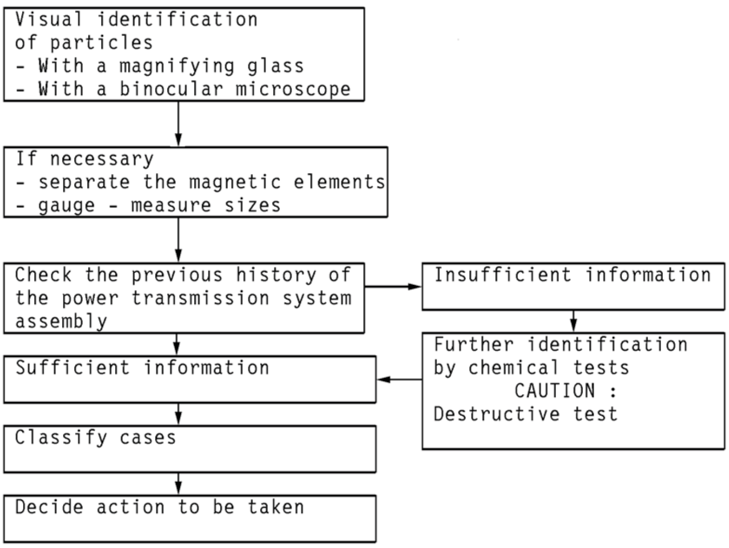
1 GENERAL

The presence of particles on filters, magnetic plugs and strainers is not an absolute proof that a power transmission system assembly is damaged and needs to be replaced.
These particles may belong to different categories and, depending on :
- the identification of particles (shape, type, size and quantity)
- the nature of the occurence (sudden, repeated)
- the history of the power transmission system assembly (operating time, previous failures, running in time, etc ...)

An action has to be taken to avoid removing a transmission assembly unduly or keeping it in service with no guarantee of safety.

The table below sets out the general procedure to be adopted if particles are found in the power transmission system assembly oil.
Classification of cases and actions to be taken are given in paragraph 3.

INVESTIGATION PROCEDURE



Appendix E (cont)

2 IDENTIFICATION OF PARTICLES

2.1 General

Accuracy of identification will depend on the means and methods available to operators. They include :

a) Simple means and methods of analysis, which can be applied quickly to determine :
- The shape of particles by visual inspection :
  . with the naked eye
  . with a magnifying glass
  . with a binocular microscope

- Quantity and size by :
  . gauging
  . sizing
  . counting.

- The nature of the occurence :
  . exceptional
  . repeated
  . progressive

- The nature of the materials by :
  . tests with a magnet (magnetic materials)
  . tests with a soldering iron (metal with low-melting point)
  . chemical tests (other materials)

b) For reference, only special methods involving the use of equipment and trained personnel not readily available to operators.
They include :
- Macrography
- Spectrographic analysis
- X - ray crystallography
- Chemical analysis.

2.2 Description of particle shape

a) Scale R
Scale is caused by damage to the surface of bearing races, ball bearings, rollers and gear tooth flanks.
It appears as very thin particles (a few hundredths of a millimetre), with sharply cut lines. One side is always shiny with parallel scoring caused either by running conditions or by machining. When examined under a binocular microscope or a powerful magnifying glass, the other side is generally granular, sparkling and grey.
The source of particles which have not been forced out of shape by gearing can be determined from a number of special features.
Example : Scale from bearing races, ball bearings or rollers.
Scale of this type is rounded, and split radially so resembling a "rose petal", thickening towards the centre.

Appendix E (cont)

b) Metal flakes
These can come from a broken gear tooth, bearing race, etc ...
They are polyhedral in shape and have machining scratches on one or more surfaces. Other surfaces have the granular appareance characteristic of a brittle break.

c) Splinters are small pieces of metal (less than 0.5 mm3 in volume) and have a granular appearance. The machined surfaces are not easy to identify due to their small dimensions.
They pass through the strainer and are collected by the magnetic plugs.
Normally, they are a sign of serious damage, calling for further investigation to locate, using a magnet, larger fragments in the gearbox sump.
This group also includes :

d) Fragments of split pins, of characteristic shape, when not flattened. Because of their original thickness they can be quite large when distorted.

e) Fragment of lock wire (stainless steel), which are originally 0.8 mm in diameter but can be flattened and distorted by pressure.

f) Swarf
This comes from a number of sources and appears as a few millimetres long curved strip when not forced out of shape by passing through gearing. Swarf can be in the form of rolls or spirals. The inner surface is folded while the smoother, outer surface has longitudinal machining scratches.
Swarf may also be broken up into small flakes (1 to 3 mm long).
Swarf resulting from damage to a gearbox is rarely more than 0.8 mm thick, or more than 2 to 3 mm wide, so that it can be distinguished from bigger, machining swarf (except for finishing swarf).

g) Abrasion particles
These are produced by wear on elements in contact. They are of various origins and types and are found :
- on the magnetic plugs where they form whiskers (steel) or a reddish "rust-coloured" deposit (fretting wear particles + oil). R R
- on the filters (steel, bronze, silver, light alloys),
- suspended in the oil (steel, bronze, silver, light alloys).

They are normally impalpable. On the magnetic plugs, they must not be confused with the splinters, with which they may be mixed.

h) Miscellaneous non-metallic waste
This may have got into the gearbox during assembly or maintenance and generally consists of paint, loctite, sealant, varnish, wood, various fibre, etc ... which do not affect performance in any way.

Appendix E (cont)

2.3 Further identification by chemical tests

2.3.1 General

These quick tests, designed to identify elements by the "cation" method, all involve a measure of uncertainty. They are also destructive, with the result that unless a particle is big it can only be tested once. The test must therefore be chosen by referring to the findings of the previous checks.
If the operator has special facilities or intends to send the power transmission system assembly for overhaul, these quick tests should not be carried out. The best course is to send all particles found during inspection, to the repairer, to enable him to trace the fault. R

a) No. 1 test for nickel

This method is used for scale, metal flakes and splinters which may have come from :
- gearwheels
- bearing races
- rollers
- stainless steel lock wire.

Drop a spot of dimenthylglyoxine on the steel particle which is to be analysed.
The appearance of red streaks indicates the presence of nickel steel. If there is no reaction, carbon steel is present.

b) No. 2 test for copper

This method is used for bronze swarf and small flake from :
- either the "sun/planet carrier" friction washers
- or the bearing cages.
Apply nitric acid (HNO_3) to the particle.
The release of a bright green cloud indicates the presence of copper.

c) No. 3 test for aluminium and magnesium

This method is used for light alloy swarf and small flakes (which are more malleable than steel and non-magnetic swarf) from various sources.
Place the particle in hydrochloric acid (HC1).
If the particle breaks up to form a black precipitate and gives off bubbles, this indicates the presence of a magnesium or aluminium alloy.
Aluminium and magnesium can be distinguished by dropping a bit of the particle (black precipitate) into nitric acid (HNO_3). A reaction indicates the presence of magnesium.

Appendix E (cont)

d) No. 4 test for silver

This method is used for silver scale from the power transmission system assembly splines and the bearing cages. R
Apply nitric acid (HNO3) to the particle.
Add a few drops of hydrochloric acid (HC1).
A white precipitate forms if silver is present.

3 CLASSIFICATION OF CASES AND ACTION TO BE TAKEN

According to the type of particles found and the nature of the occurence, the various possible cases are classified into groups, classes and divisions.

```
GROUP A - SCALE
    |Class A1 - Nickel or carbon steel.
    |       |Divisions A11 and A12 - According to particle surface
    |Class A2 - Silver and cadmium

GROUP B - FRAGMENTS - SPLINTERS (nickel or carbon steel)
    |Class B1 - Both flakes and splinters present
    |Class B2 - Flakes only
    |      |Divisions B21 and B22 - According to size of flake
    |      |Division B23          - Flake originating from outside the
    |                               power transmission system assembly      R
    |Class B3 - Piece of split pin or lock wire
    |      |Divisions B31 et B32 - According to power transmission system   R
                                   assembly operating time                  R

GROUP C - SWARF (Steel, bronze, light alloys)
    |Classes C1, C2, C3 - According to number of particles

GROUP D - ABRASION PARTICLES (All metals)
    |Classes D1, D2 - According to how the particles appear (gradually
    |                 or suddenly)

GROUP E - NON-METALLIC PARTICLES
```

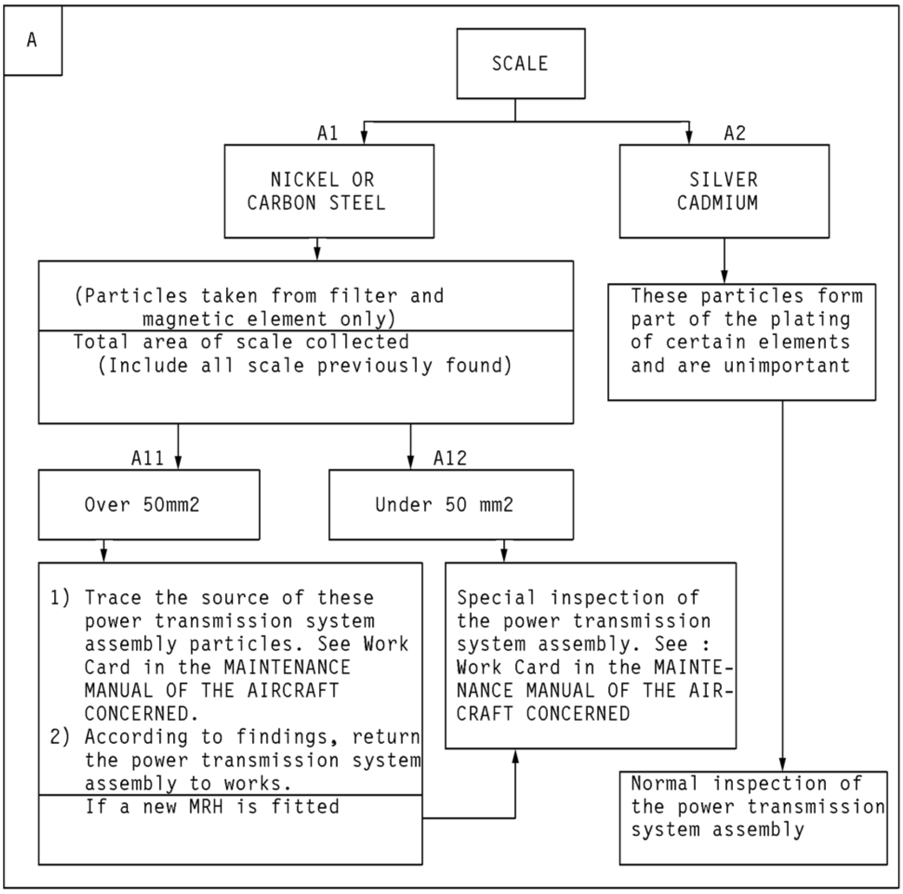

Appendix E (cont)

R

The following tables classify cases on the above basis and indicate the action to be taken. They are designed more specifically for the main transmission system (M.G.B./M.R.H. flared housing) but can be used for the intermediate and tail gear boxes, by ignoring the information concerned specifically with the main transmission system.

NOTE : If a transmission system component is returned to the manufacturer for dismantling it should be accompanied by a sample of the particles together with a report giving details of their location when first discovered.

GROUP A - SCALE



Appendix E (cont)

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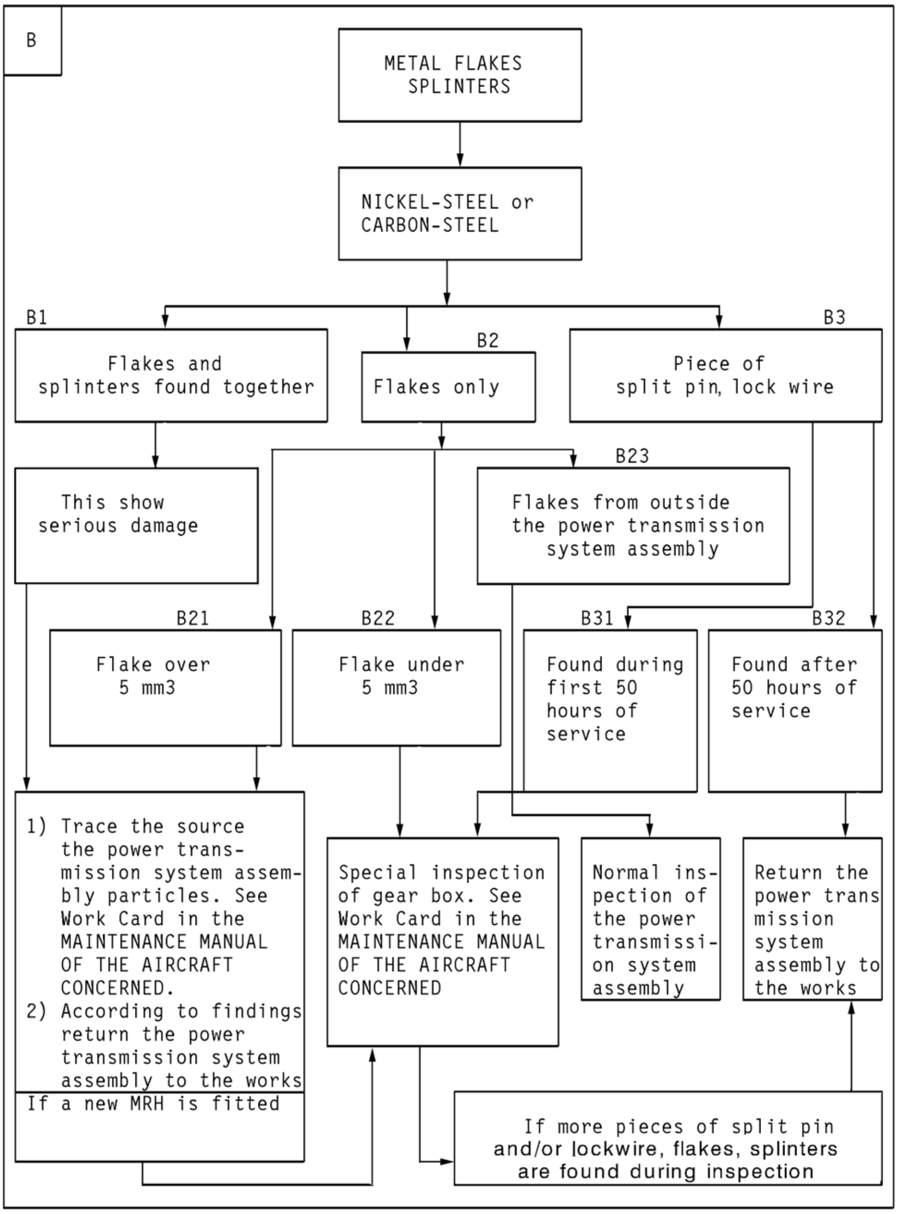
STANDARD PRACTICES

GROUP B - FLAKES - SPLINTERS

R

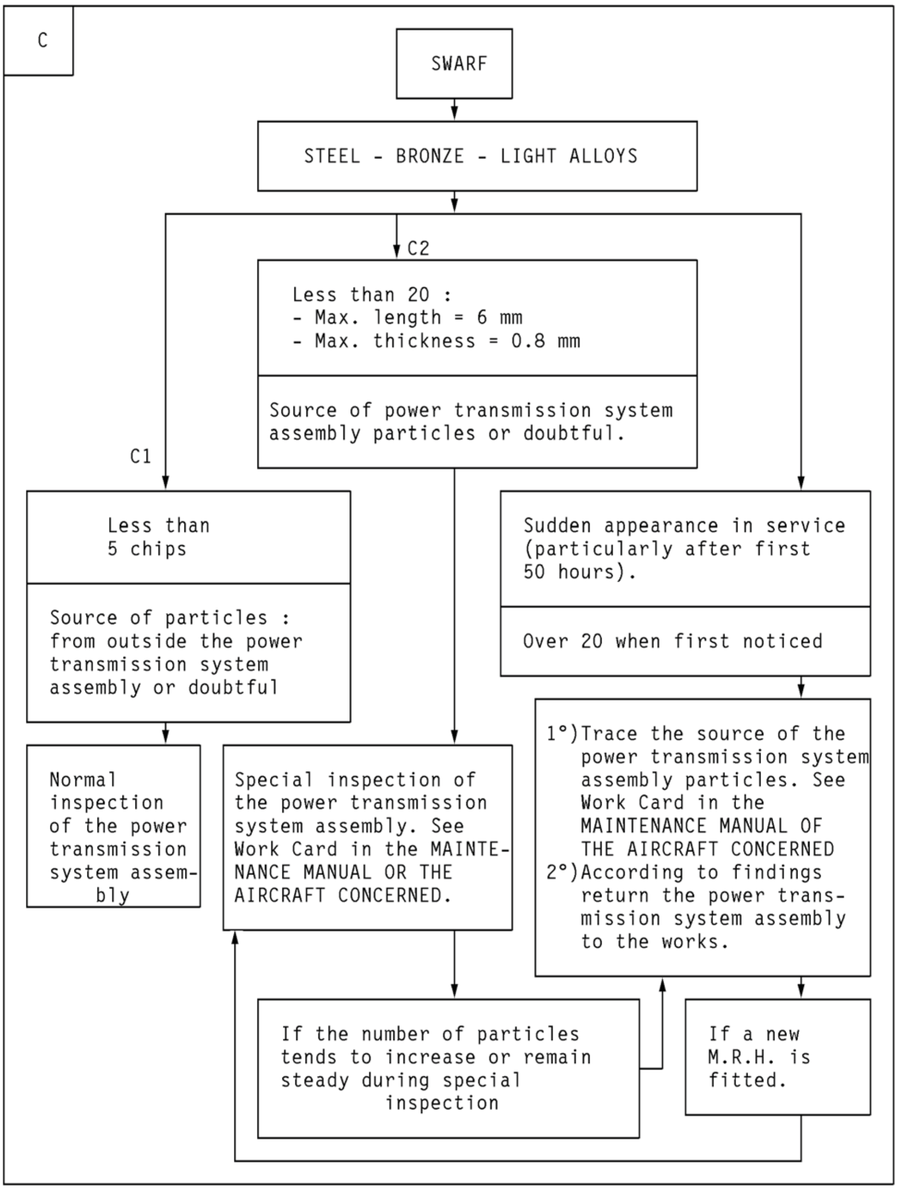


000-999 **MTC.20.08.01.601**
2006.05.08 Page 7/9

Appendix E (cont)

GROUP C - SWARF

R



Appendix E (cont)

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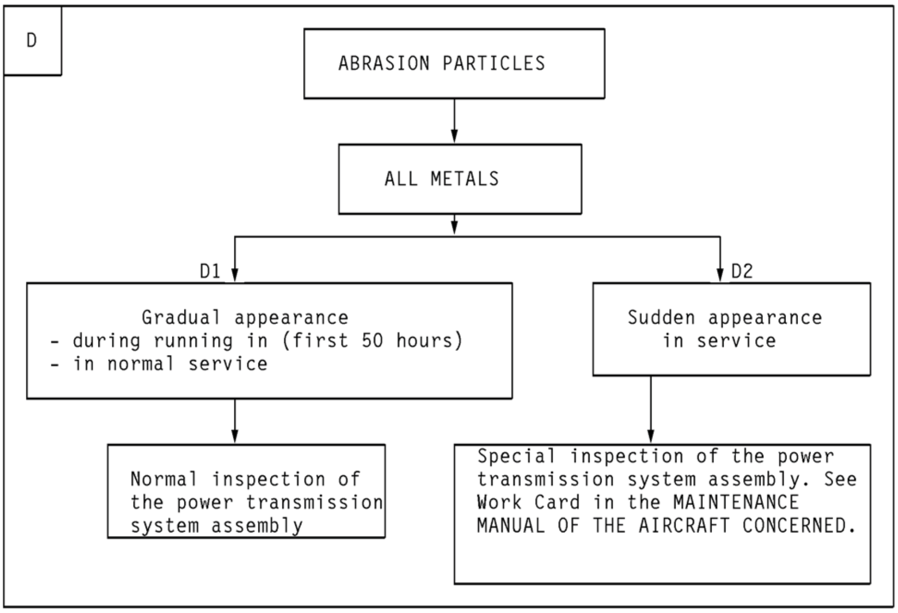
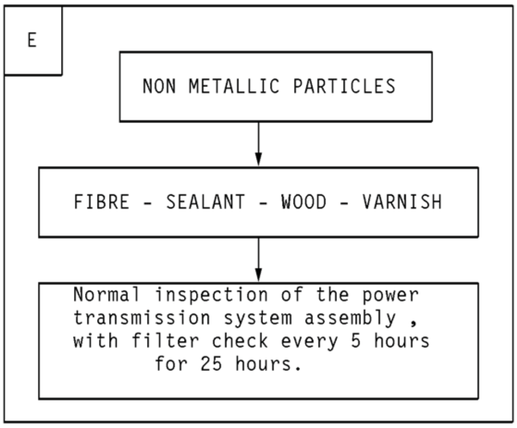
STANDARD PRACTICES

GROUP D - ABRASION PARTICLES

R



GROUP E - NON METALLIC PARTICLES



000-999 **MTC.20.08.01.601**
2006.05.08 Page 9/9

Appendix F

Eurocopter G-REDL FDR simulation report

Note

ETG 129/09 Issue A

Date: 03/06/09

to

Subject: ***AS332L2 MSN2612 G-REDL Accident – results of simulation compared to FDR data***

In order to analyse the FDR recorded data of this accident, we have performed simulations to analyse the consistence between the parameters, especially between commands and attitudes.
We have performed two kinds of simulations.

- Firstly we have simulated the command values recorded by the Flight Data Recorder (FDR) and observed the result on the attitudes in order to compare them with ones recorded by the FDR.
- Then, thanks to the inverted simulation we have imposed the attitudes recorded by the FDR and observed the required commands in simulation.

It is to notice that to be able to perform simulations and because the sample rate of the FDR is large, the variables have been reproduced with smoother evolutions.

- ***Commands replayed in simulation***

When we reproduce in simulation the commands as recorded by the FDR, attitudes obtained by simulation are consistent with those recorded by the FDR during 2 s after the main gearbox oil pressure low warning is displayed. But after these 2 seconds, in simulation with this kind of commands the helicopter adopts a strongly pitch up attitude while the recording shows a pitch attitude constant around zero.

Please find below plotted results:

- DDZ (collective pitch control):
  0% ⇨ minimum collective pitch
  100% ⇨ maximum collective pitch

- DDM (longitudinal cyclic control):
  0% ⇨ maximum pitch up
  100% ⇨ maximum pitch down

- DDL (lateral cyclic control):
  0% ⇨ maximum left
  100% ⇨ maximum right

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1 / 7

Appendix F (cont)

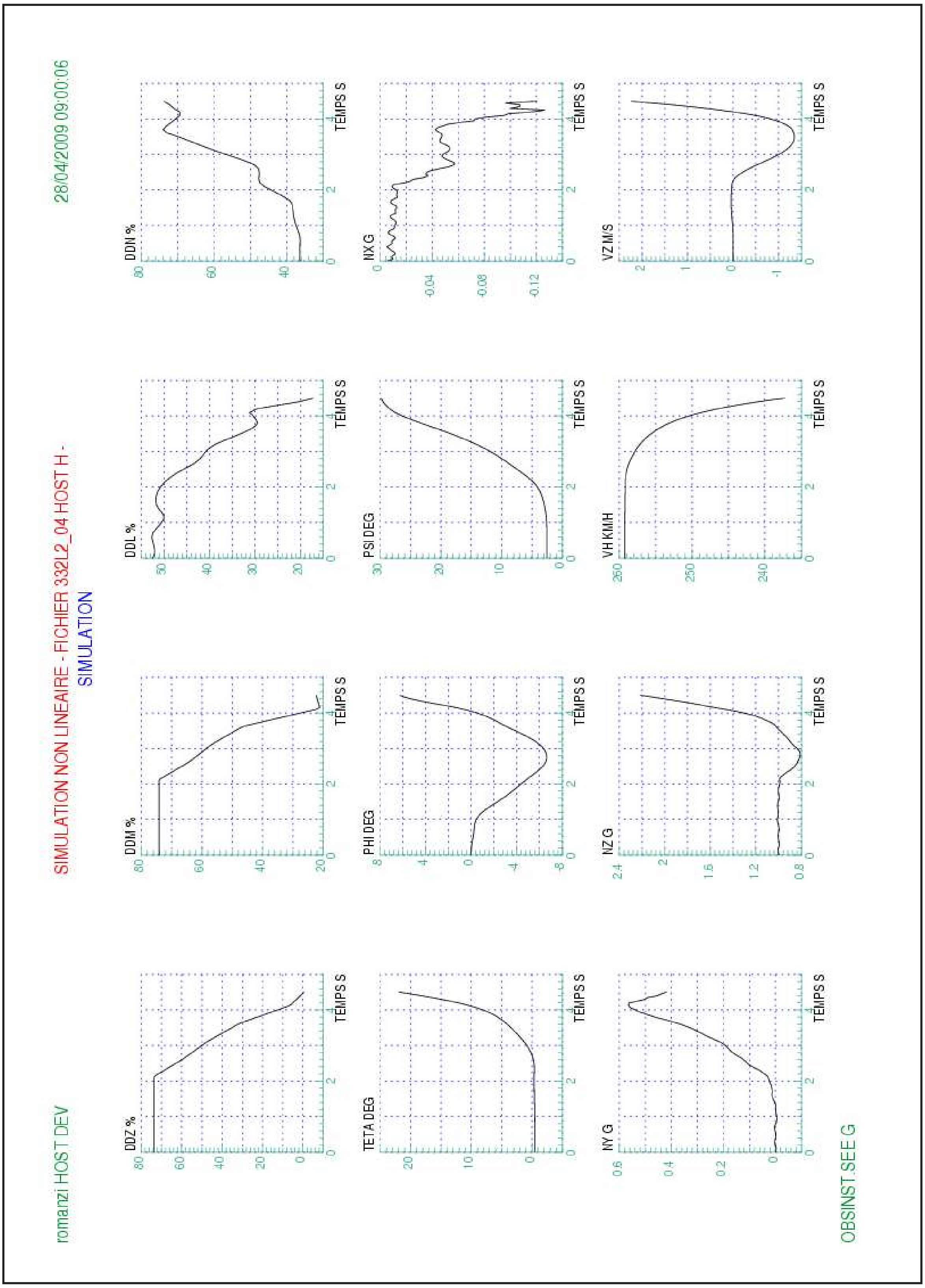
- DDN (yaw rudder controls):
  0% ⇨ maximum left
  100% ⇨ maximum right

- TETA deg = Longitudinal aircraft attitude in degree
- PHI deg = Lateral aircraft attitude in degree
- PSI deg = Magnetic heading in degree

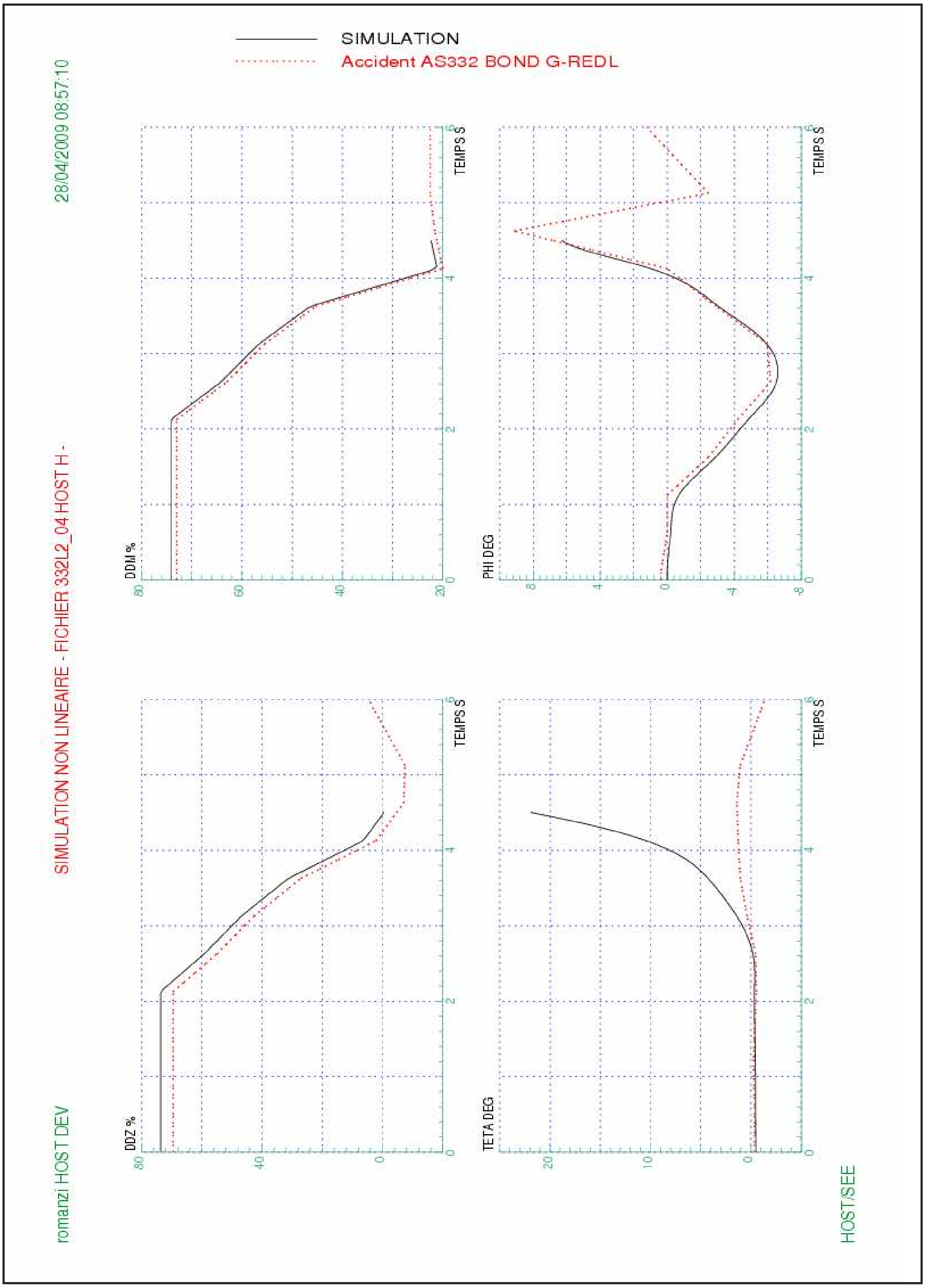
- NX = horizontal acceleration in G
- NY = lateral acceleration in G
- NZ = vertical acceleration in G

- VH = horizontal speed in km/h
- VZ = vertical speed in m/s

Appendix F (cont)



Appendix F (cont)



Appendix F (cont)

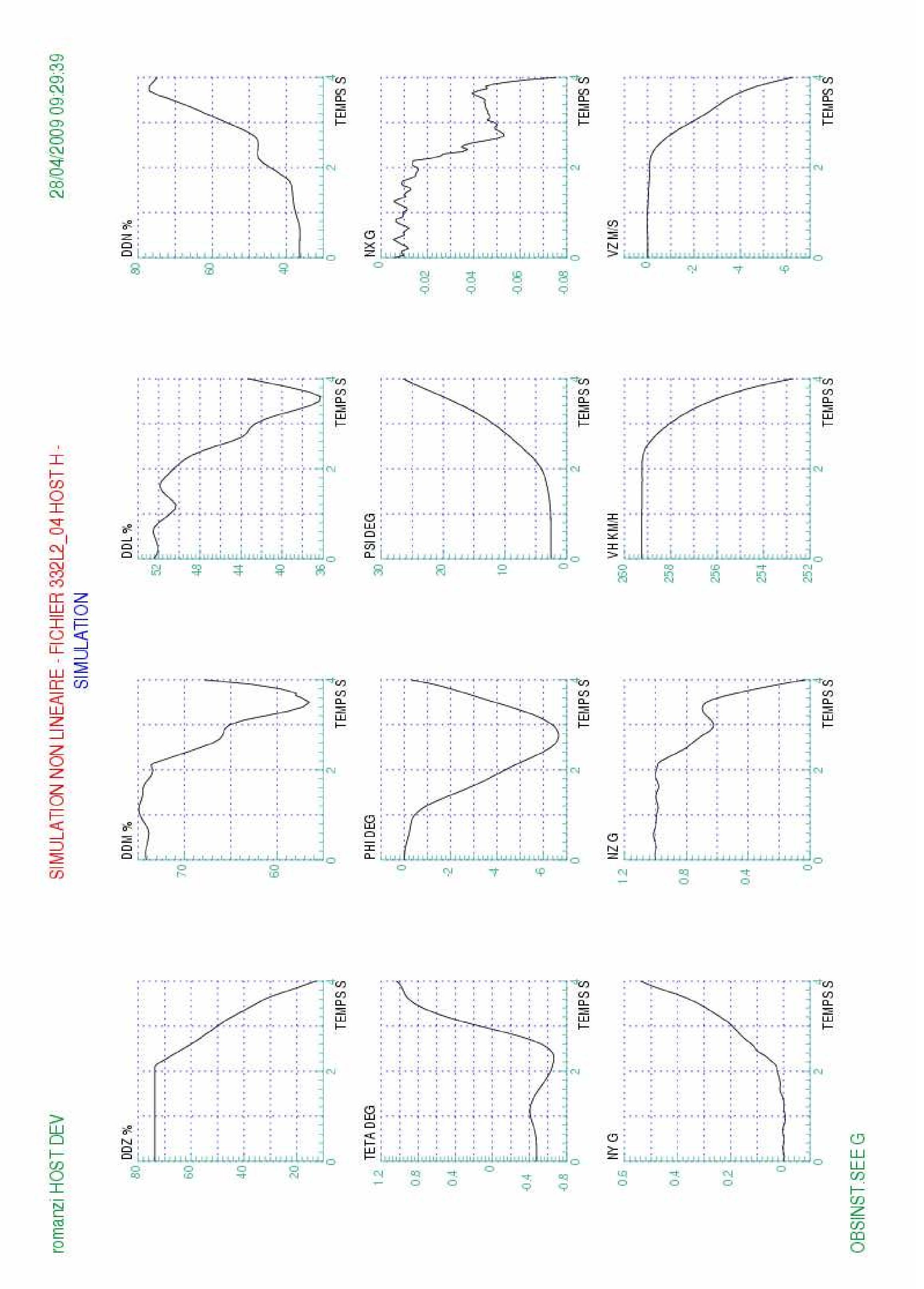
- ***Attitudes issued from the FDR forced as inputs for the simulation***

The attitudes recorded by the FDR have been forced as inputs for the simulation in order to obtain the theoretical commands needed to maintain these attitudes. The commands obtained are consistent with those issued from the FDR during 2 seconds after the main gearbox oil pressure low warning is displayed. After these 2 seconds, the theoretical commands are very different from those issued from the FDR.

Then commands and attitudes are consistent only during 2 seconds after the warning, whereas after these 2 seconds simulations and recording from the FDR are very different. Two seconds after the warning commands and attitudes are no longer consistent.

Please find below corresponding results:

Appendix F (cont)



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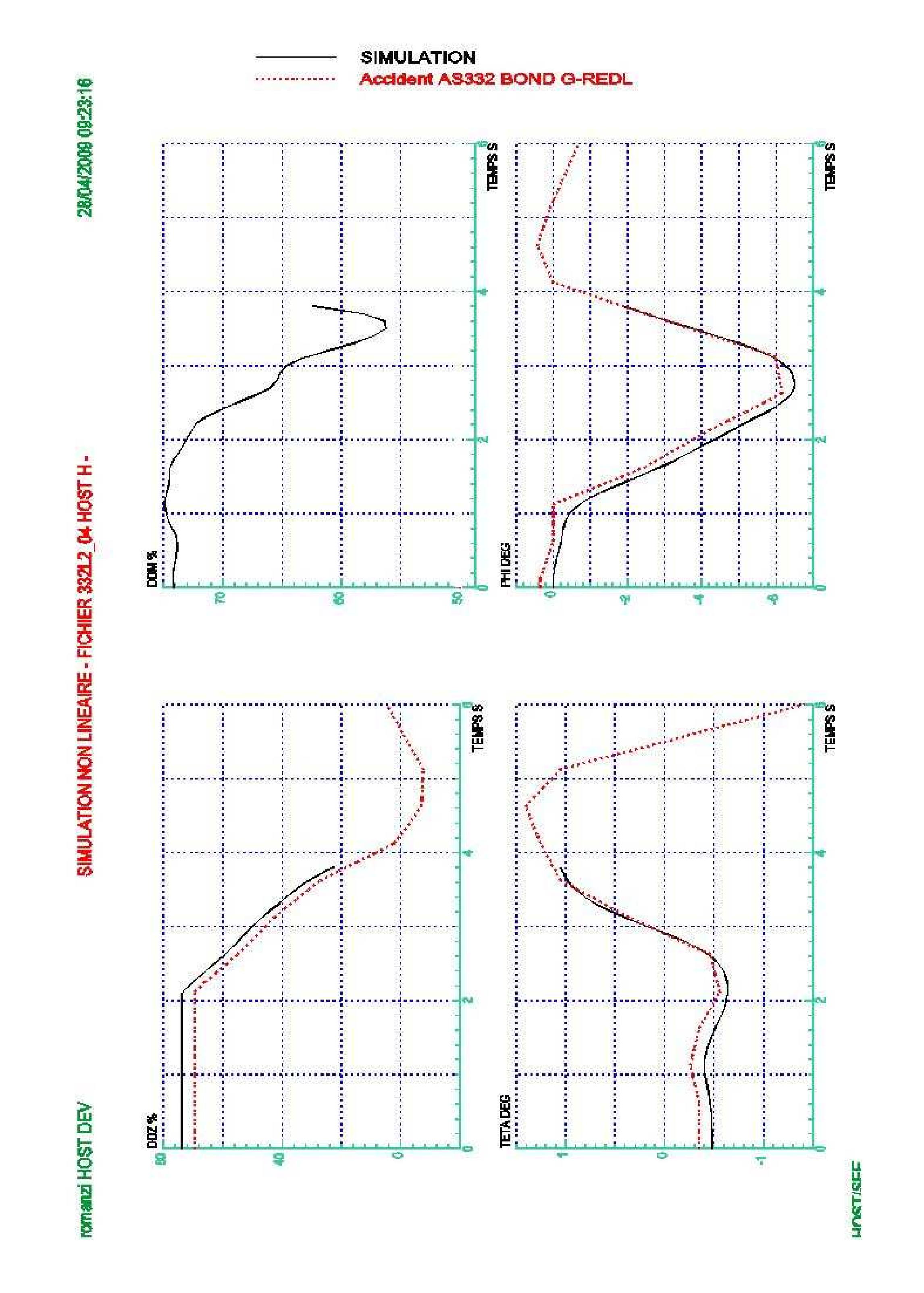

Appendix G

Lower epicyclic planet gear bearings HUMS Condition Indicators

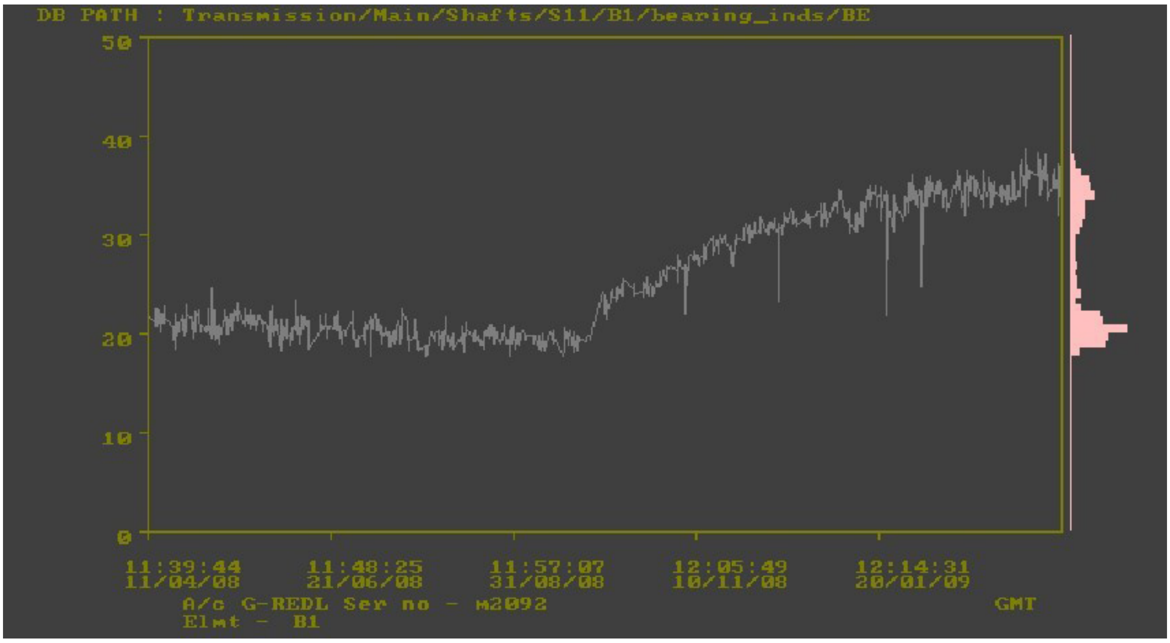

Figure G-1

G-REDL HUMS lower planetary bearings Band Energy

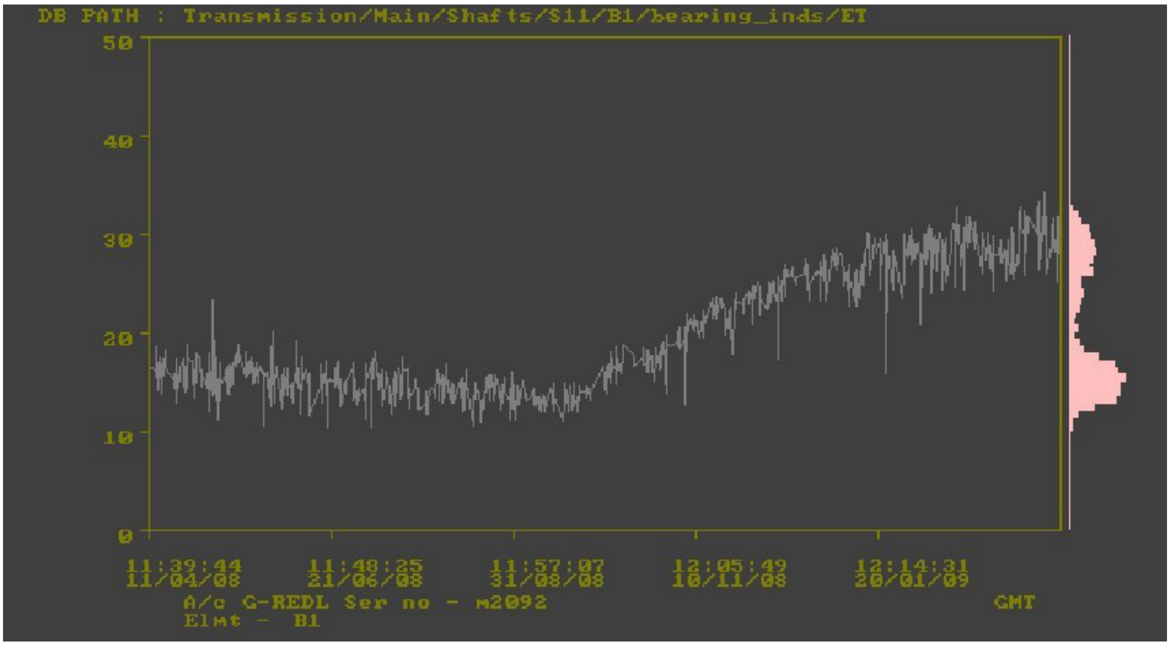

Figure G-2

G-REDL HUMS lower planetary bearings Tonal Energy

Appendix H

Eurocopter-generated HUMS CIs for G-REDL

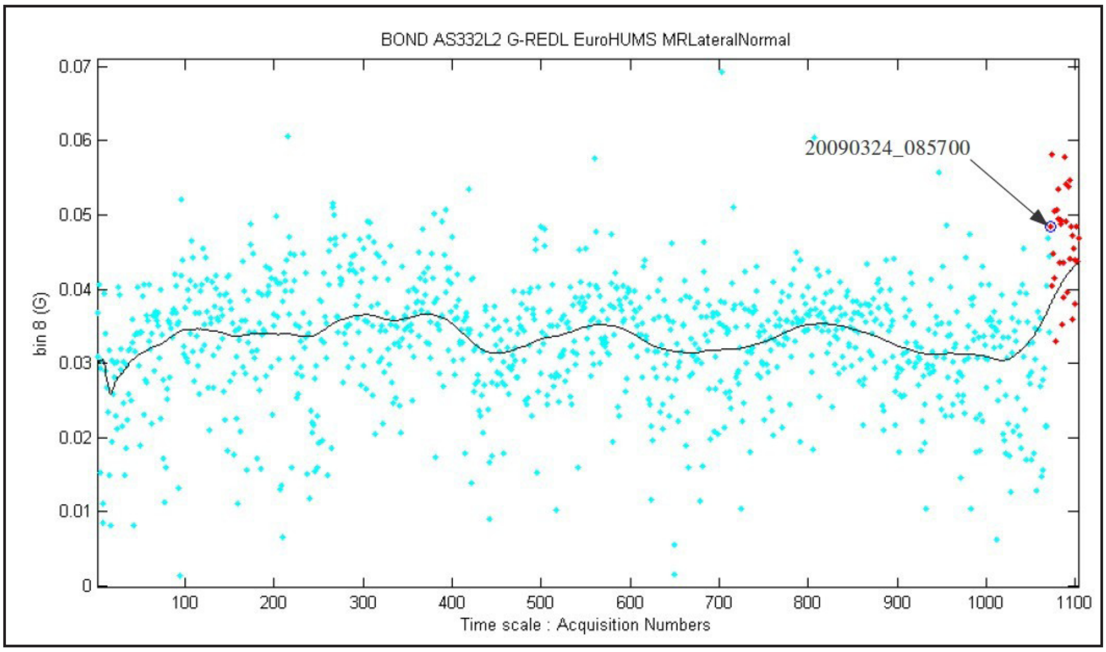

Figure H-1

Upper epicyclic ring gear eight-per-rev CI, calculated from the main rotor accelerometer Y-axis accelerometer measurements. Arrow points to operations of 24 March 09
(Source: Eurocopter)

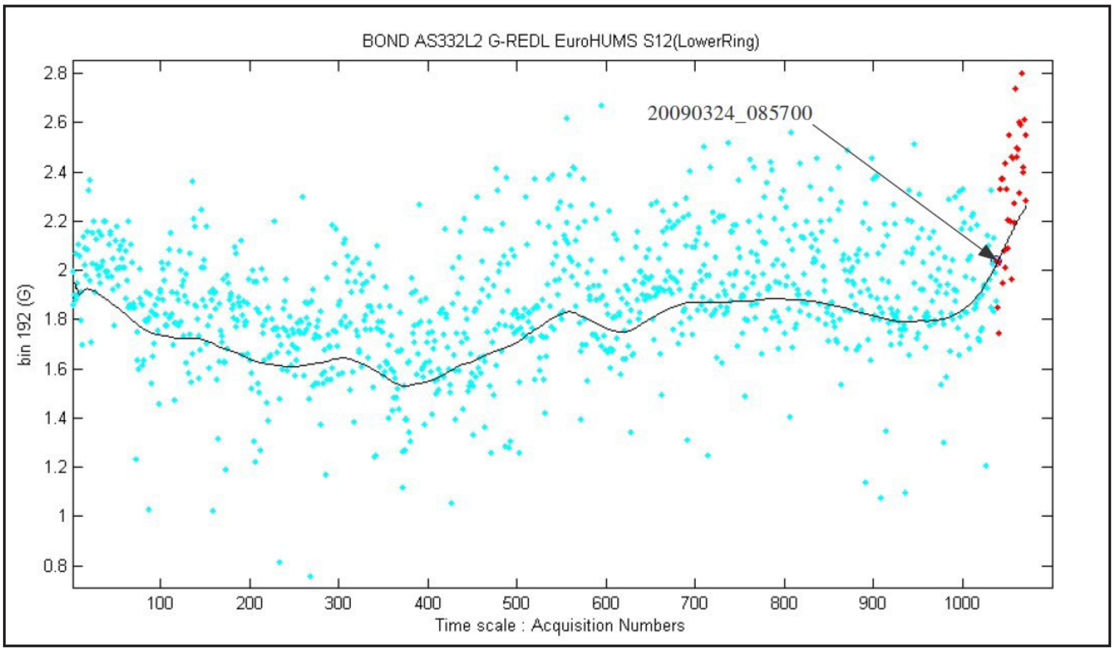

Figure H-2

Lower epicyclic ring gear, lower sideband mesh CI. Arrow points to operations of 24 March 09
(Source: Eurocopter)

Appendix I

Safety Information Notice 2075-S-63

eurocopter
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No. 2075-S-63

SAFETY INFORMATION NOTICE

SUBJECT: **MAIN ROTOR DRIVE**

Oil contamination of power transmission assemblies:
Modification to the removal criteria

For the attention of

AIRCRAFT CONCERNED	Version(s)	
	Civil	Military
EC120	B	
AS350	B, BA, BB, B1, B2, B3, D	L1
AS550		A2, C2, C3, U2
AS355	E, F, F1, F2, N, NP	
AS555		AF, AN, SN, UF, UN, MN
EC130	B4	
SA360	C	
AS365 / SA365	C, C1, C2, C3, N, N1, N2, N3	F, Fs, Fi, K
AS565		AA, MA, MB, SA, SB, UB
SA366	G1	GA
EC155	B, B1	
SA321	Ja	Ga, Gb, Gc
SA330	F, G, J	Ba, C, Ca, Ea, H, L, Jm, S1, Sm (Ver L remo)
SA341	G	B, C, D, E, F, H
SA342	J	L, L1, M, M1, Ma
ALOUETTE II	313B, 3130, 318B, 318C, 3180, 3180B, 3180C	
ALOUETTE III	316B, 316C, 3160, 319B	
LAMA	315B	
EC225	LP	
EC725		AP
AS332	C, C1, L, L1, L2	B, B1, F1, M, M1
AS532		A2, U2, AC, AL, SC, UC, UE, UL

Revision 0 2009-07-09 Page 1/2

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Appendix I (cont)

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No. 2075-S-63

In-service experience shows that despite the wide safety margins provided for the sizing of the components installed on your helicopters, some very exceptional events may lead to incipient fatigue cracks or even fracture.

Compared to possible surface degradation resulting from operation (for example: wear resulting from operation, spalling of bearing races or gear teeth seats), the growth of a fatigue type crack produces a small number of particles captured at the magnetic plugs.
In addition, it is relevant to note that fatigue crack growth develops more quickly than surface degradation.

In order to enhance detection of these possible and exceptional events at best, EUROCOPTER has decided to complete the procedures to be applied if and when particles are discovered.

These procedures, initially defined to detect any slowly worsening degradation resulting from operation and generating a great number of particles, are redefined in order to reinforce the detection of this exceptional occurrence of a fatigue crack, without considerably impairing the availability of your aircraft.

EUROCOPTER informs you that additional information has been included in:

- Aircraft Maintenance Manual (AMM) Task 20-10-00,3-20: for the EC120,
- Standard Practices (MTC) Manual Work Card 20.08.01.601: for all the other aircraft.

The next issue of these documents will contain the technical instructions as defined on the appended pages.

EUROCOPTER asks you to comply with these new procedures which are aimed at improving the flight safety of your aircraft, and to contact the EUROCOPTER Customer Support Technical Service to assist you should you experience some difficulty in interpreting the findings.

Revision 0 2009-07-09 Page 2/2

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Appendix I (cont)

STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs

20.08.01.601

Page 1

1 GENERAL

The presence of particles on filters, magnetic components and strainers is not necessarily revealing that a power transmission system assembly is damaged and needs to be replaced.

These particles may belong to different categories, depending on:

- the identification of the particles (shape, type, size and quantity),
- the nature of the occurrence (sudden, repeated),
- the history of the power transmission system assembly (operating time, previous failures, running-in time, etc.),

A decision has to be taken which is intended:

- to avoid removing a power transmission system assembly unduly,

- to avoid keeping in service a power transmission system that does not offer all the guarantees required to ensure flight safety.

Appendix I (cont)

STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs

20.08.01.601

2 IDENTIFICATION OF PARTICLES

2.1 General

Accuracy of identification depends on the methods and means available to operators:
There are:
a) Simple means and methods of analysis which can be applied quickly to determine:

- The shape of particles by visual inspection:
  - with the naked eye
  - with a tenfold magnifying glass
  - with a binocular microscope
  - with digital photos
- The quantity and size by:
  - gauging
  - sizing
  - counting
- The nature of the occurrence:
  - exceptional
  - repeated
  - progressive
- The nature of the materials by:
  - tests with a magnet (magnetic materials)
  - tests with a soldering iron (metal with low melting point)
  - chemical tests (other materials).

b) For reference, the exceptional means requiring the use of trained personnel and special equipment are rarely available to operators. These means include:

- Macrography
- Spectrographic analysis
- X-ray crystallography
- Chemical analyses

Appendix I (cont)

2.2 Description of particle shape

a) Scale

Scale results from damage to the surface of bearing races, balls, rollers and gear tooth flanks. Scale appears as very thin particles (a few hundreds of a millimeter) with a sharply cut or rounded contour. One face is always shiny with parallel marks caused either by operating conditions or machining. When examined under a binocular microscope or a powerful magnifying glass, the other face is generally granular, sparkling and grey. The source of particles which have not been forced out of shape by gearing can be determined from a number of special features.

Example: Scale from bearing races, balls and rollers. Scale of this type may be of rounded shape or cut contour and split radially and look like a “rose petal”, thickening towards the centre.

Appendix I (cont)

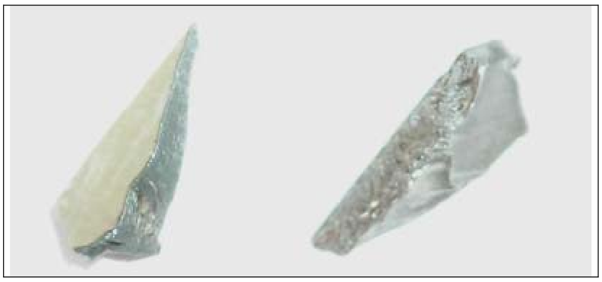
STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs

20.08.01.601

b) Metal flakes

Metal flakes can come from a broken gear tooth, bearing race, etc.
They are polyhedral in shape. There are machining marks on one or more surfaces. Other surfaces have the granular appearance characteristic of a brittle break



c) Splinters

Splinters are small metal fragments (less than 0.5 mm^3 in volume) and have a granular appearance. The machined surfaces are not easy to identify due to their small dimensions.

Appendix I (cont)

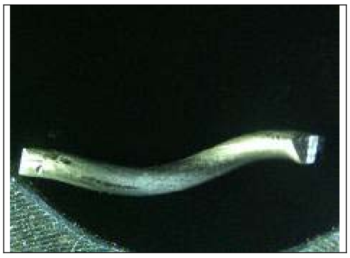
Splinters pass through the strainer and are collected by the magnetic plugs.
Normally, they are a sign of serious damage, calling for further investigation to locate, using a magnet, larger fragments in the gearbox sump.
This category also includes fragments of split pins and fragments of lockwire as identified in paragraphs d) and e) below.

d) Fragments of split pins

Fragments of split pins, of characteristic shape, when not flattened. Due to their original thickness, they can be quite large when distorted.

e) Fragments of lockwire

Fragments of lockwire (stainless steel) which is originally 0.8 mm in diameter but may be flattened and distorted by pressure.



Appendix I (cont)

STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs

20.08.01.601

f) Metal shaving

Metal shaving comes from a number of various sources and appears as a curved strip a few millimeters long when not forced out of shape by gearing. Metal shaving can be in the form of rolls or spirals. The inner surface is folded, while the smoother, outer surface has longitudinal machining marks.
Metal shaving may also be broken into small flakes (1 to 3 mm long). Metal shaving resulting from damage to a gearbox is rarely more than 0.8 mm thick, or more than 2 to 3 mm wide, so that it can be distinguished from bigger machining metal shaving (except for finishing metal shaving).

g) Particles from abrasion or wear

They are produced by wear of elements in contact or fretting wear in oily environment. They are of various origins and types and are found:

- on the magnetic plugs where they form whiskers (steel) ,
- on the filters (steel, bronze, silver, magnesium, light alloys).
- suspended in the oil (steel, bronze, silver, magnesium, light alloys) giving the oil a specific color.

Appendix I (cont)

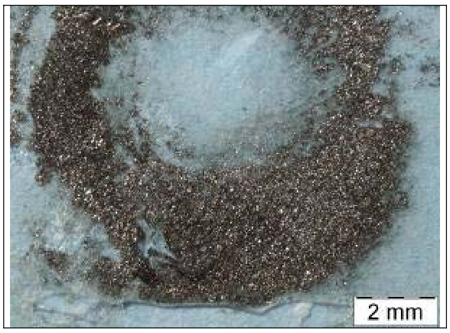
STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs

20.08.01.601

Particles from fretting wear in an oily environment may appear as a reddish "rust-colored" deposit (particles from fretting wear + oil) on the inner walls of the gearboxes, oil sights and magnetic plugs (slightly magnetic) and appear as a specific coloration of the service oil. These phenomena are usually the result of internal mechanical damage requiring analysis/identification before returning into service.

They are normally impalpable. On the magnetic plugs, they must not be confused with the splinters with which they may be mixed.



h) Miscellaneous non-metallic waste

Non-metallic waste may have got into the gearbox during assembly or maintenance operations and generally consists of paint, Loctite, sealant, varnish, wood, various fibres, etc. which do not affect performance in any way.

Appendix I (cont)

STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs	**20.08.01.601**

3) DEFINITION OF THE MEASURES TO BE TAKEN

a) General

The measures to be taken are identified by following the procedure below.
This procedure takes into consideration various parameters:

- Type of the particles collected
- Overall surface area of the particles collected
- Time since overhaul (TSO)
- Shape of the particles (surface area, length, thickness)
- Characteristic of the occurrence (frequency and quantity collected)
- Number of particles collected

Compliance with this procedure results either in:

- maintaining normal maintenance
- or checking the power transmission system assembly at shorter intervals
- or conducting a metallurgical analysis before resuming flights
- or replacing the affected module(s) for repair.

You are reminded that the procedure described below requires the whole of the particles (magnetic plugs, filters and oil filtration) to be collected, as stated in the Maintenance Manual.

NOTE:

Should it be necessary to send in the particles for metallurgical analysis, use a copy of the follow-up record sheet appended herewith.

Similarly, if a power transmission system assembly is to be returned to the works, it is requested to send it along with:

- the particles having justified the removal, and specify the location where they were found,

and/or

- the follow-up record sheet (or a copy) as well as a written proof made out by the laboratory, specifying the type of material collected.

Appendix I (cont)

STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs

20.08.01.601

CAUTION: The classification of particles into Groups/Classes/Divisions, defined in the previous revisions of this work card, has been modified.

From now on, the new classification takes into consideration the identification of particles and the check of criteria, as stated below.

- Scale, flakes and splinters:
  - According to the surface of the particles collected
    - According to the size of some of the particles
      - According to the type of material of the particles.

- Fragments of split pins and lockwires:
  - According to the operating time of the power transmission system assembly concerned.

- Shavings:
  - According to the number and conditions of occurrence (gradually – sudden).

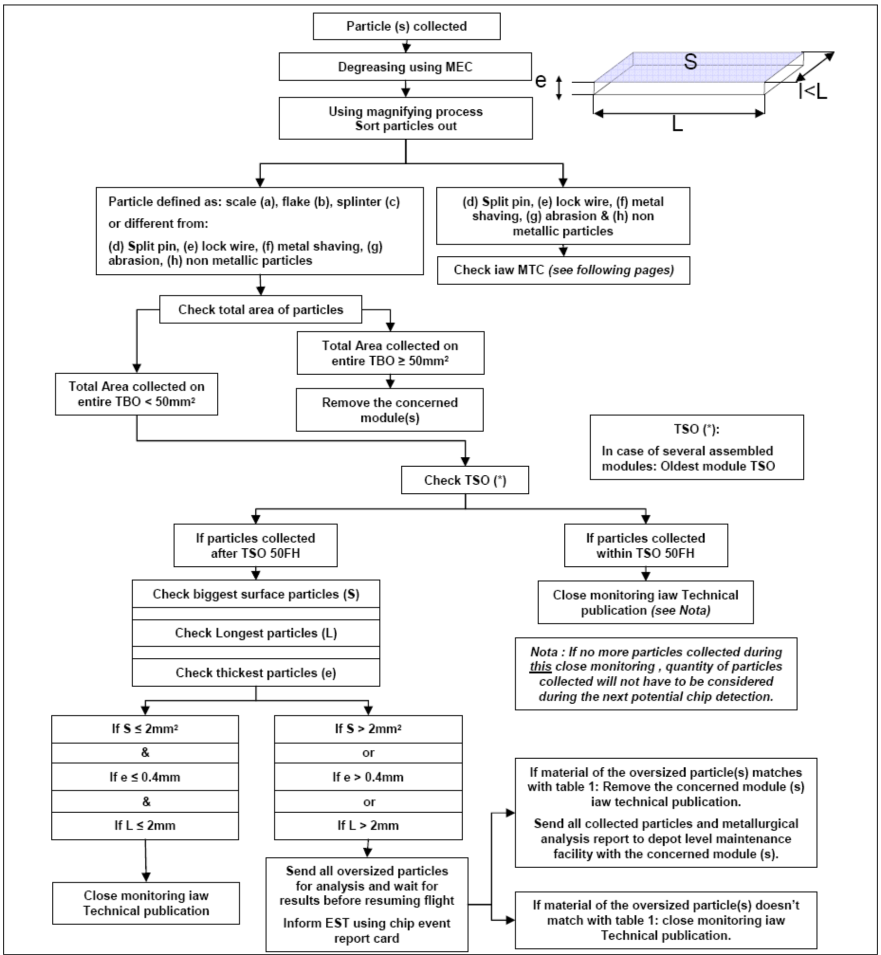
- Abrasion particles:
  - According to the conditions of occurrence (gradually –sudden).

For this reason, to know whether or not power transmission system assemblies can be kept in service, which according to the previous revision depended on the discovery of particles classed A12, B22, C2 and D2, from now on you must comply with the block diagrams below.

Appendix I (cont)

STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs	**20.08.01.601**



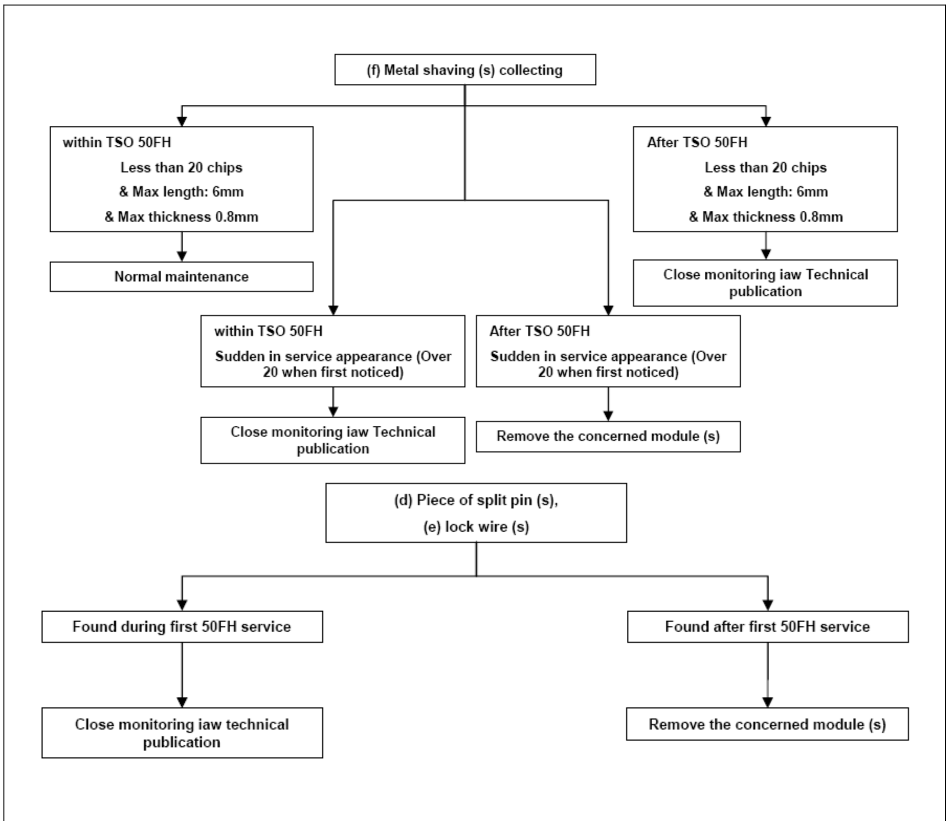
Procedure to be followed after collection of particles

Appendix I (cont)

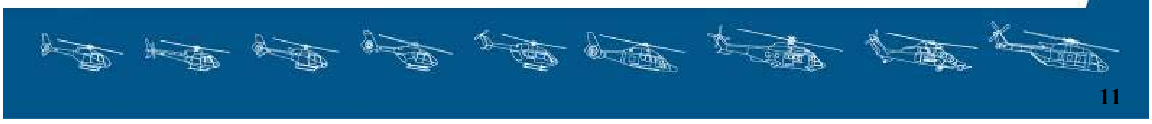
STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs

20.08.01.601



Procedure to be followed after collection of particles

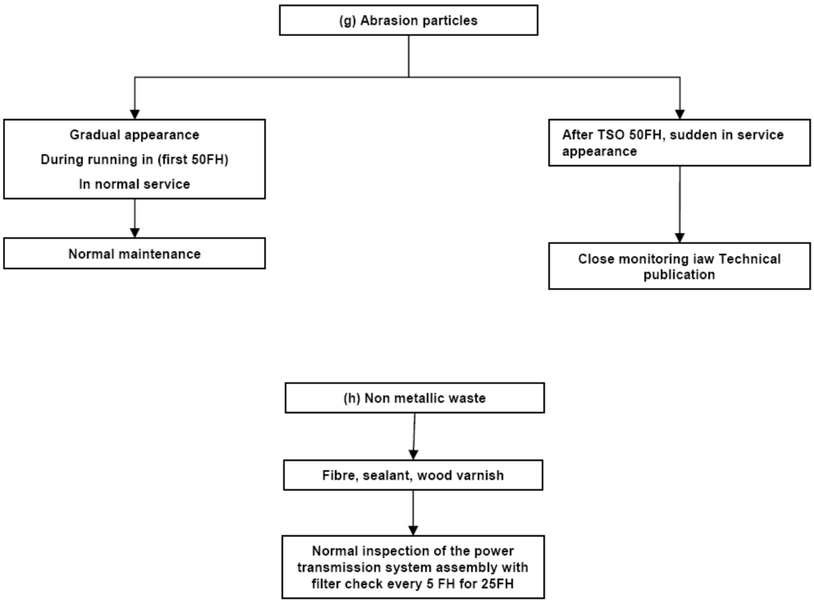


Appendix I (cont)

STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs

20.08.01.601



Procedure to be followed after collection of particles

Appendix I (cont)

STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs	20.08.01.601

A/C:	Type:	Version:	TT:	Date:
Dynamic component	MRH: ☐	MGB: ☐	IGB: ☐	TGB: ☐
Modules identity	PN:	SN:	TSN:	TSO:
	PN:	SN:	TSN:	TSO:
	PN:	SN:	TSN:	TSO:

Collecting location	Specify Magnetic plug (s) location		Fill the concerned case (s)
	Magnetic Plug		Oil filter: ☐
			Sump: ☐
			Nr sensors: ☐

Circumstance of the event	Fill and specify the concerned case (s)
Chip warning	
Scheduled maintenance	
HUMS system	

references	Customer contact	EC contact
E-mail:	…	Dyncomp.technical-support@eurocopter.com
Phone	…	*Customer Assistance (24/24 – 7/7)* *+33 (0)4.42.85.97.97*
Address	…	EUROCOPTER – Service ESTVM Bat Marseilleveyres R06 – 2nd Etage Aéroport Marseille Provence 13725 MARIGNANE Cedex FRANCE

Additional information:
All oversized particles collected require to be sent to material analysis laboratory. Specify discovery location and don't mix particles coming from different areas.

Follow-up record sheet

13

Appendix I (cont)

STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs

20.08.01.601

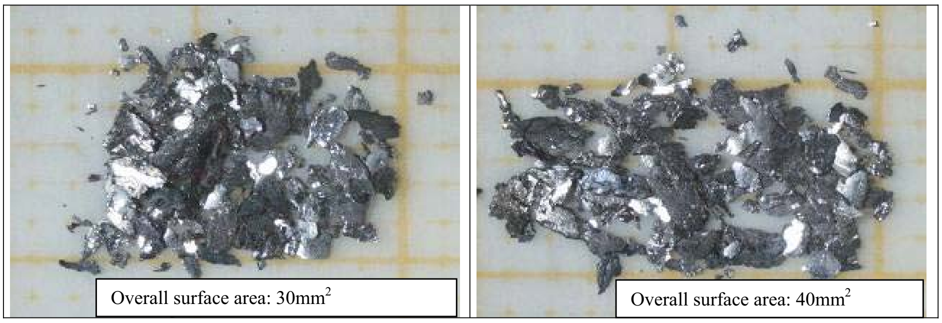
TABLE 1	
Material	**Other designation**
16NCD13	SAE 9315 MILS 7393 MILS 8690
35NCD16	-
15CN6	E15CrNi06
18NC16	-
32CDV13	897M39
40NCD7	AISI 4340
80DCV40	AMS6490 M50
15-5 PH	Z6CNUNb15-05
20NCD12	M50 NiL
100C6	SAE 52100 AMS 6443 MILS 7420
18NCD2	SAE 8720
18NCD4	SAE 4720

The power transmission system assembly concerned must be removed if particles beyond the sizing criteria (surface area-thickness-length) and coming from one of the materials listed above, are discovered.

Appendix I (cont)

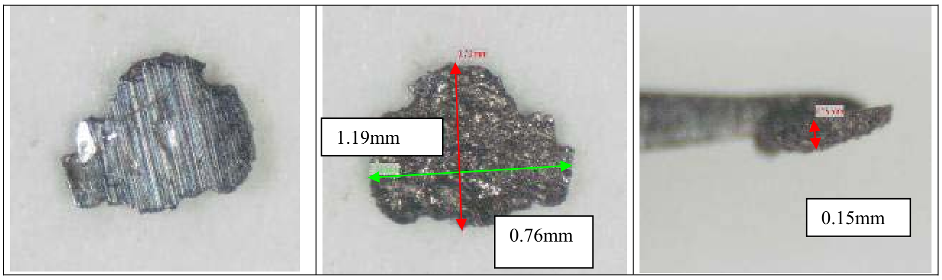
b) Decision aid

- Examples of particles (scale) collected after removal of fragments of split pins, lockwire and abrasion particles :



- Examples of particles whose geometrical features have been analyzed:

Particle No. 1: within the acceptance criteria

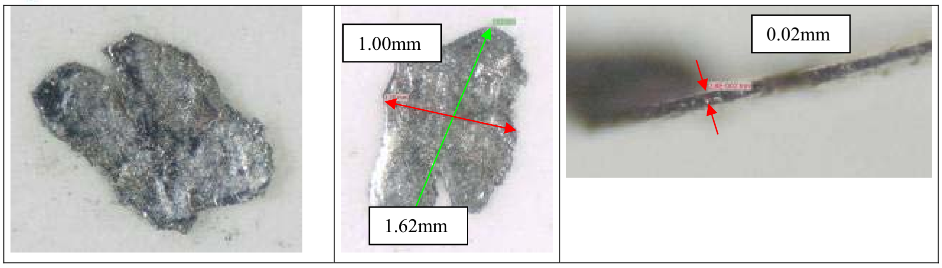


Particle No. 2: within the acceptanc criteria

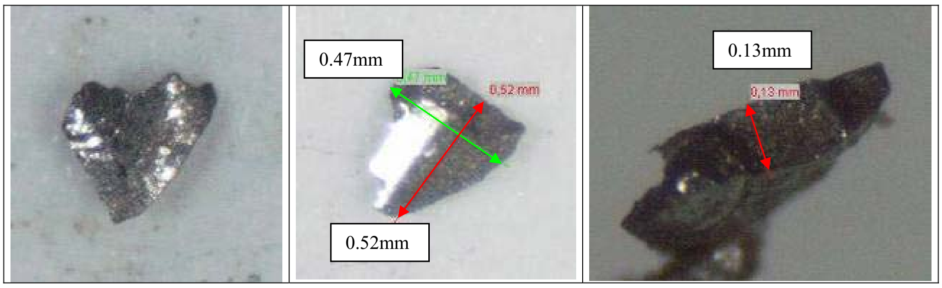
Appendix I (cont)

STANDARD PRACTICES

Oil contamination check on power transmission assemblies equipped with magnetic plugs	20.08.01.601



Particle No. 3: within the acceptance criteria



Appendix J

Emergency Alert Service Bulletin 05.00.81

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T.F.S. No. 00000522

EUROCOPTER
DIRECTION TECHNIQUE SUPPORT
13725 MARIGNANE CEDEX FRANCE

EMERGENCY

ALERT SERVICE BULLETIN

SUPER PUMA	NUMBER	VERSIONS	
AS332	**05.00.81**	Civil:	**L2**
AS532	**05.00.58**	Military:	**A2, U2**

SUBJECT: TIME LIMITS – MAINTENANCE CHECKS

Check of the magnetic plug on the main gearbox (MGB) epicyclic module
Main module chip collector modification

ATA: 63

Corresponds to MOD 0752522

REVISION No.	DATE OF APPROVAL	DATE OF ISSUE
Revision 0	On: April 10, 2009	2009.04.10
Revision 1	On: April 18, 2009	2009.04.18
Revision 2	On: April 23, 2009	2009.04.23

Approved under EASA DOA No. 21J.056

This document is available on the internet: www.eurocopter.com/techpub

Page 1/21
2009.04.23

Appendix J (cont)

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T.F.S. No. 00000522

1. PLANNING INFORMATION

1.A. EFFECTIVITY

1.A.1. Helicopters/installed equipment

On main gearboxes (MGB), all part numbers, pre and post MOD 0752522.

NOTE 1

MOD 0752522 is intended to improve the detection of metallic particles generated by possible deterioration of the epicyclic stage by removing the magnets and the flanged edge from the chip collector on the top part of the main reduction module.

1.A.2. Non-installed equipment

1) On main gearboxes (MGB), all part numbers, pre and post MOD 0752522.

2) On main reduction modules for Main Gearboxes (MGB) of all part numbers pre and post MOD 0752522.

1.B. ASSOCIATED REQUIREMENTS

Not applicable.

Approved under EASA DOA No. 21J.056

Page 2/21
2009.04.23

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T.F.S. No. 00000522

1.C. REASON

To ensure the integrity of the Epicyclic Module by:

- reducing the inspection interval of the epicyclic module magnetic plug,
- immediately removing the epicyclic module and inspecting the chip collector if detection of any particle at the magnetic plug was not followed by application of Sub-Task 60-00-00-212-001 (inspection of the non electric magnetic plug on the epicyclic module) or of Sub-Task 60-00-00-212-004 (inspection of the electric indication chip detector on the epicyclic module) of MMA Task 60.00.00.212 (inspection of a magnetic element).

Revision 0 of the present ALERT SERVICE BULLETIN resulted in issue of EASA Airworthiness Directive No. 2009-0087-E

Revision 1 of the present ALERT SERVICE BULLETIN was intended:
- to add embodiment of MOD 0752522,
- to inform operators that embodiment of MOD 0752522 renders the directives of revision 0 of the present ALERT SERVICE BULLETIN null and void.
- to inform operators that embodiment of MOD 0752522 modifies the measures to be taken in the event of particle detection at the Epicyclic Module magnetic plug.

Following embodiment of MOD 0752522, the particles collection procedure applicable following detection at the Epicyclic Module magnetic plug, no longer requires removal of the Epicyclic Module from the MGB. Only the procedure described under Task 05-53-00-218 need be applied. Moreover, considering that this modification deletes the segregation of particles between the main module and the epicyclic module, if the criteria specified in Work Card 20.08.01.601 of the Standard Practices Manual (MTC) are met, the complete MGB must be removed.

Revision 1 of the present ALERT SERVICE BULLETIN did not form the subject of an EASA Airworthiness Directive.

Revision 2 of this ALERT SERVICE BULLETIN is intended to inform operators that even after embodiment of MOD 0752522, the check of the magnetic plug of the epicyclic module during each inspection after the last flight of the day without exceeding 10 flying hours, described in paragraph 2.B.1., remains applicable,

Revision 2 of this ALERT SERVICE BULLETIN will form the subject of an EASA Airworthiness Directive.

Appendix J (cont)

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T.F.S. No. 00000522

1.D. DESCRIPTION

Revision 0

Following the accident to helicopter registration G-REDL, which occurred on 1st April 2009, the investigation is still in progress under the authority of the British AAIB, with the participation of the French BEA, EASA and EUROCOPTER.
At this stage, the cause of the accident appears to be linked to the deterioration of the epicyclic stage of the main gearbox, the reason for which has yet to be determined. In the light of this information, detection of any pollution of the main gearbox is of the very highest importance.
EUROCOPTER re-iterates and emphasises, as a precaution, the procedure which is applicable when a particle is found on the magnetic plug of the epicyclic stage.
EUROCOPTER has made immediate application of the following 2 measures mandatory:
- The inspection frequency of the said magnetic plug must be increased in accordance with the terms of the present ALERT SERVICE BULLETIN.
- If any particles were found on the said magnetic plug at the end of your previous flights, it is essential to apply the current procedure which is recalled in the present ALERT SERVICE BULLETIN.

These measures have been taken as a precaution.

Revision 1:

Since issue of revision 0 of the present ALERT SERVICE BULLETIN, the studies in progress investigating the possibility of improving the metallic particles detection system monitoring the Main Gearbox elements, have resulted in a modification to the chip collector located at the interface between the Epicyclic module and the Main module.

The detector currently fitted enables segregation of the particles generated in the possible event of deterioration of the epicyclic module and as such avoids their contaminating and damaging the main module. However in service experience has shown that this chip collection device may delay the detection of particles.

In order to improve the flow of particles towards the detection devices (gearbox sump and epicyclic module magnetic plugs), EUROCOPTER has called up:

- Removal of the magnetic elements installed on the chip collector
- Removal of the flanged edge from the chip collector.

EUROCOPTER has made the measures defined in revision 1 of the present ALERT SERVICE BULLETIN mandatory.

It must be underlined however that the cause of the reported event remains still to be determined. EUROCOPTER will inform you of any new developments.

Revision 2:

EUROCOPTER issued Revision 1 to rapidly provide the users with the technical information, enabling them to embody MOD 0752522 and EAD directives No. 2009-0095-E concurrently.
As reversion to the initial maintenance after modification 0752522 (magnetic plug check every 25 FH) is currently undergoing substantiation with EASA, check of the magnetic plug of the epicyclic module during each inspection after the last flight of the day without exceeding 10 flying hours remains applicable.
The present Revision 2 is issued to inform the operators of the EASA agreement.

Appendix J (cont)

1.E. COMPLIANCE

EUROCOPTER renders compliance with the present ALERT SERVICE BULLETIN mandatory.

1.E.1. Compliance at the works

1.E.1.a. On Helicopters

Comply with paragraph 1.E.2.a. before delivery.

1.E.1.b. On non-installed equipment

Apply paragraph 2.B.3. before installation on an aircraft.

1.E.2. Compliance in service: By the operator:

1.E.2.a. On helicopters/installed equipment

BEFORE MOD 0752522:

1) - Comply with paragraph 2.B.1. before the next flight,

   Then,

   - Comply with paragraph 2.B.1. after each last flight of the day without exceeding 10 flight hours between two inspections.

2) If, within the last 200 flight hours preceding receipt of revision 0 of the present ALERT SERVICE BULLETIN, one or more particles were detected on the magnetic plug of the epicyclic module without complete compliance with Sub-Task 60-00-00-212-001 or Sub-Task 60-00-00-212-004 of MMA Task 60-00-00-212 (epicyclic reduction gear module not removed to inspect the chip collector magnets):

   - Comply with paragraph 2.B.2. before the next flight.

3) Apply paragraph 2.B.3 of the present ALERT SERVICE BULLETIN within 150 flight hours, without exceeding 3 months following receipt of revision 1 of the present ALERT SERVICE BULLETIN, issued on April 18, 2009.

AFTER MOD 0752522:

- Comply with paragraph 2.B.1. after each last flight of the day without exceeding 10 flying hours between two inspections.

1.E.2.b. On non-installed equipment

BEFORE MOD 0752522:

1) For MGBs which had already logged some flight hours since new, or overhaul, on receipt of revision 0 of the present ALERT SERVICE BULLETIN:
   – Apply paragraph 2.B.1. before installation on the aircraft.

2) On Main Gearboxes (MGB):
   – Apply paragraph 2.B.3. before installation on the aircraft.

3) On Main Gearbox (MGB) main reduction modules:
   – Apply paragraph 2.B.3. before installation on the aircraft

AFTER MOD 0752522: Not applicable.

1.F. APPROVAL

Approval is limited to civil version helicopters subject to an Airworthiness Certificate.

The technical information contained in Revision 0 of this ALERT SERVICE BULLETIN was approved on April 10th, 2009 under the authority of EASA Design Organisation Approval No. 21J.056.

The information or instructions referring to modification MOD 0752522 Edition 2 were approved on April 22, 2009, under the authority of EASA Design Organisation Approval No. 21J.056.

The technical information provided in Revision 1 of this ALERT SERVICE BULLETIN was approved on April 18, 2009, by the EUROCOPTER Airworthiness Department, but did not form the subject of an EASA agreement.

The technical information provided in Revision 1 of the present ALERT SERVICE BULLETIN provided the possibility to embody MOD 0752522 at the same time as EAD 2009-0095-E, in order to avoid a second epicyclic module removal.

The technical information provided in Revision 2 of this ALERT SERVICE BULLETIN was approved on April 23, 2009, under the authority of EASA Design Organisation Approval No. 21J.056.

1.G. MANPOWER

1.G.1. Qualification

Mechanical technician

1.G.2. Time for the operations

10 minutes for the check, without removal of the epicyclic module.
Approximately 10 hours for the inspection in the event of removal of the epicyclic module.
Approximately 14 hours to embody MOD 0752522.

Appendix J (cont)

1.H. WEIGHT AND BALANCE

Not applicable.

1.I. EFFECT ON ELECTRICAL LOADS

Not applicable.

1.J. SOFTWARE MODIFICATION EMBODIMENT RECORD

Not applicable.

1.K. REFERENCES

Aircraft Maintenance Manual (MMA) Tasks:
- 05-53-00-218
- 60-00-00-212
- 63-20-00-021
- 63-20-00-421

Standard Practices Manual (MTC) Work Cards:
- 20.08.01.601
- 20.03.01.102
- 20.08.05.101
- 20.08.05.103

1.L. OTHER DOCUMENTS AFFECTED

Aircraft Maintenance Manual (MMA).
Maintenance Program (PRE).

1.M. TOOLING AFFECTED

Not applicable.

1.N. INTERCHANGEABILITY OR MIXABILITY OF PARTS

Not applicable.

Appendix J (cont)

2. ACCOMPLISHMENT INSTRUCTIONS

2.A. GENERAL

NOTE 1

EUROCOPTER are ready to provide you with any further information or support you may require to comply with the instructions described in the present ALERT SERVICE BULLETIN especially in case of systematic exchanges or any problem with tools in relation with paragraph 2.B.3.:
Contact the EUROCOPTER Customer Service Technical Support Department (SVTM)
On: Tel: +33 (0)4.42.85.20.51
Fax: +33 (0)4.42.85.99.66
Email: DynComp.Technical-Support@eurocopter.com
Or Customer Assistance (24/24 – 7/7)
On: Tel: +33 (0)4.42.85.97.97
Fax: +33 (0)4.42.85.99.96
Email: Customer.Assistance@eurocopter.com

2.B. OPERATIONAL PROCEDURE

2.B.1. Checking the (electric or non-electric) magnetic plug on the epicyclic module

Refer to Figure 1

- Check the magnetic plug (a) in accordance with Sub-Task 60-00-00-212-001 or Sub-Task 60-00-00-212-004 of MMA Task 60-00-00-212.

In the event of any metal particle detection at the magnetic plug of the epicyclic module remember in addition to the complete application of Sub-Task 60-00-00-212-001 of the MMA, to:

* Check pollution of the MGB in accordance with Sub-Task 05-53-00-218-001 of Task 05-53-00-218.

* Check and apply the monitoring procedure in accordance with Sub-Task 05-53-00-218-003 of Task 05-53-00-218.

NOTE 2

If, following application of the measures described above, the replacement criteria are met and if no particle has been found on the magnetic plug in the MGB sump: only the epicyclic module need be replaced.

Appendix J (cont)

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T.F.S. No. 00000522

CAUTION

After embodiment of MOD 0752522, the measures to be taken in the event of detection of one or more particles at the epicyclic module magnetic plug change:

- **Do not disconnect the epicyclic module as mentioned in Sub-Task 60-00-00-212-001 of MMA Task 60-00-00-212, but apply Sub-Task 05-53-00-218-001 of Task 05-53-00-218.**
- **If the criteria specified in Standard Practices Manual (MTC) Work Card 20.08.01.601 are met, remove the MGB.**

2.B.2. Checking the absence of particles on the chip collector

Refer to Figure 1

2.B.2.a. Procedure

- Remove the epicyclic module as per MMA Task 63-22-00-021.
- Using a magnet, collect any particles that may be found in the chip collector (b).
- Apply Sub-Task 05-53-00-218-001 of Task 05-53-00-218 in order to check the contamination of the flared housing and main gearbox (MGB) and collect all the particles contaminating the MGB and its lubrication system.
- Determine the number and type of particles, including all the particles found during the previous operations and refer to the criteria defined in the Standard Practices Manual (MTC) Work Card 20.08.01.601.

2.B.2.b. Measures to be taken

. if the replacement criteria are not met:

- Thoroughly clean the area concerned.
- Install the epicyclic module as per MMA Task 63-22-00-421.
- Return the helicopter to flight configuration.

CAUTION

The MGB must be checked and monitored in accordance with Sub-Tasks 05-53-00-218-001 and 05-53-00-218-003 of Task 05-53-00-218 even if the particles found are within the acceptable criteria.

Approved under EASA DOA No. 21J.056

Page 9/21
2009.04.23

Appendix J (cont)

. if the replacement criteria are met:

- Send the epicyclic module to an approved repair centre for investigation.
- Install an epicyclic module as per MMA Task 63-22-00-421.

NOTE 3

If, following application of the measures described above, the replacement criteria are met and if no particle has been found on the magnetic plug in the MGB sump: only the epicyclic module need be replaced.

- If one or more particles are found, contact the EUROCOPTER Technical Support department as indicated in paragraph 2.A.

2.B.3. Embodiment of MOD 0752522

2.B.3.a. Preliminary checks:

- Apply the directives defined in paragraph 2.B.2.a.

. If the replacement criteria are not met:

- Thoroughly clean the area concerned.

CAUTION

The MGB must be checked and monitored in accordance with Sub-Tasks 05-53-00-218-001 and 05-53-00-218-003 of Task 05-53-00-218 even if the particles found are within the acceptable criteria.

- If one or more particles are found, contact the EUROCOPTER Technical Support department as indicated in paragraph 2.A.

Appendix J (cont)

. **if the replacement criteria are met:**

- Send the epicyclic module to an approved repair centre for investigation.

NOTE 4

If, following application of the measures described above, the replacement criteria are met and if no particle has been found on the magnetic plug in the MGB sump: only the epicyclic module need be replaced.

- If one or more particles are found, contact the EUROCOPTER Technical Support department as indicated in paragraph 2.A.

2.B.3.b. Modification of the chip collector

1) Removal of the chip collector (b) as shown in Figure 2:

- Remove the nuts (c).
- Remove the top collector (d).
- Remove the chip collector (b) together with its magnetic elements (e).

NOTE 5

Take care not to damage the seal (f) located at the periphery of the chip collector (b).

2) Removal of the magnetic elements (e) as shown in Figure 3:

- Remove the rivets (g) attaching the magnetic elements (e) to the chip collector (b) as per MTC Work Card 20.03.01.102 paragraph 3.
- Remove the magnetic elements (e).
- Carefully deburr the bore of all the rivet holes (g).

NOTE 6

Take care not to distort and/or warp the chip collector (b) during application of this procedure.

Appendix J (cont)

3) Modification of the chip collector (b) as shown in Figure 4:

- Gradually remove the flanged edges (h) from the chip collector (b) by successive passes with a milling machine.
- Blend with a 5 mm radius.
- Carefully deburr the areas cut away.

NOTE 7

Take care not to distort and/or warp the chip collector (b) during application of this procedure.

4) Re-identify the chip collector (b) in accordance with paragraph 2.C. as per MTC Work Cards 20.08.05.101 and 20.08.05.103 and in accordance with Figure 5:

- Cross out the part number of the chip collector (b) with indelible ink.
- Mark the new part number on the chip collector (1) with indelible ink as per MTC Work Card 20.08.05.103.
- Clean the chip collector (1).

NOTE 8

Take care not to distort and/or warp the chip collector (b) during application of this procedure.

5) Installation of the chip collector (1) in accordance with Figure 2:

- Fit the seal (f) on the chip collector (1).

NOTE 9

If the seal (f) has been damaged (torn, cut etc.) during removal, replace it with a new seal (2) after adjusting its length.

- Lubricate the seal (f) with gearbox running oil.
- Install the chip collector (1) together with its seal (f) but without its magnetic elements (e).
- Install the top collector (d).
- Fit the nuts (c).
- Apply torque.
- Install the epicyclic module in accordance with MMA Sub-Task 63-22-00-021.

Appendix J (cont)

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T.F.S. No. 00000522

REMINDER

Due to the presence of the O-ring (MMA Task 63-22-00-421, item 8) inside the bevel gearwheel, high load may be required for removal or installation of the 1st stage sun gear.
Correct installation is ensured by complying with dimension L (Sub-Task 63-22-00-421-001 of MMA Task 63-22-00-421).

CAUTION

After embodiment of MOD 0752522, the measures to be taken in the event of detection of one or more particles at the epicyclic module magnetic plug change:

- **Do not disconnect the epicyclic module as mentioned in Sub-Task 60-00-00-212-001 of MMA Task 60-00-00-212, but apply Sub-Task 05-53-00-218-001 of Task 05-53-00-218.**
- **If the criteria specified in Standard Practices Manual (MTC) Work Card 20.08.01.601 are met, remove the MGB.**

Appendix J (cont)

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T.F.S. No. 00000522

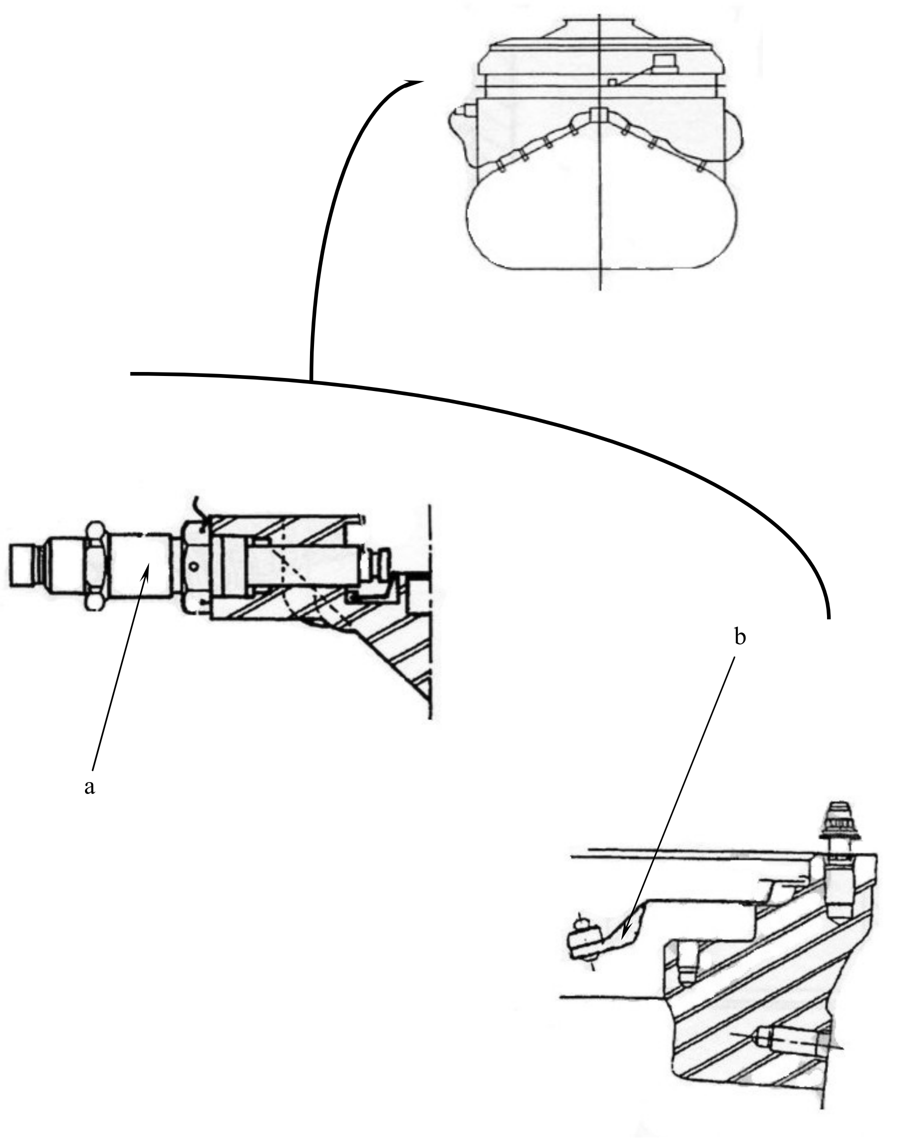
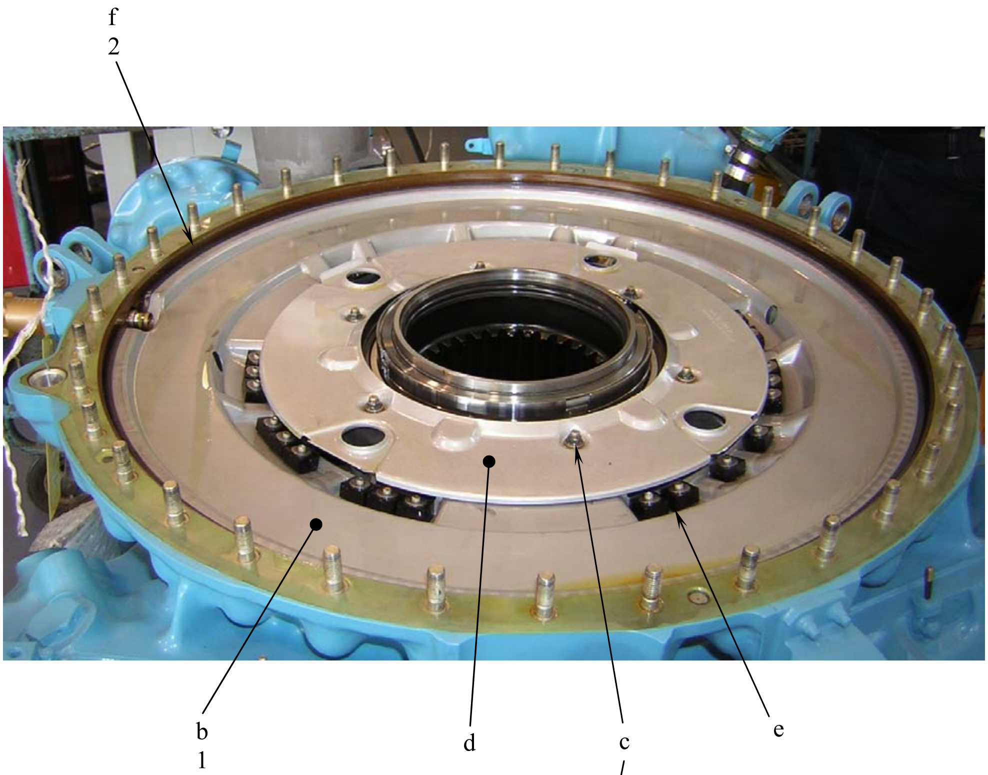


Figure 1

Approved under EASA DOA No. 21J.056

Page 14/21
2009.04.23

Appendix J (cont)



0.156
0.7 – 0.85 daN.m
62-75 lbf.in

Figure 2

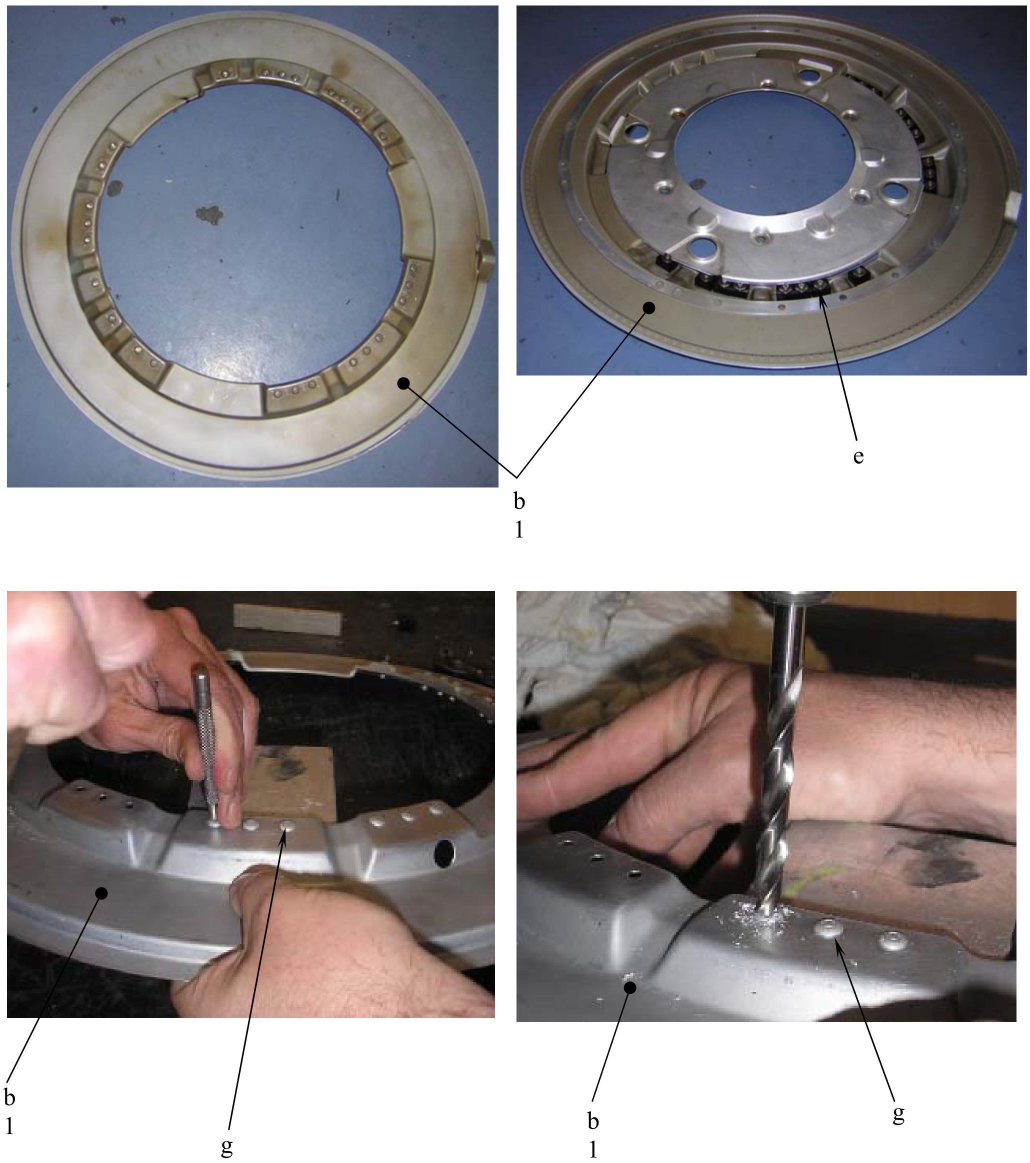


Figure 3

Appendix J (cont)

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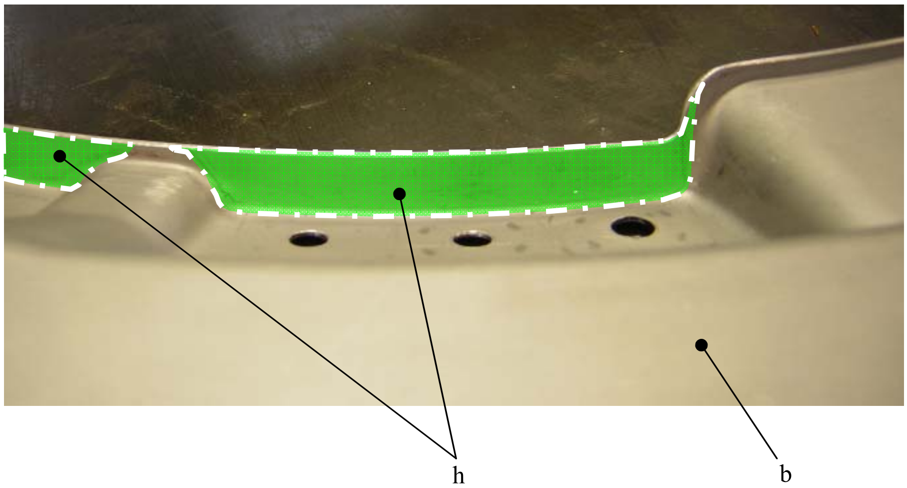
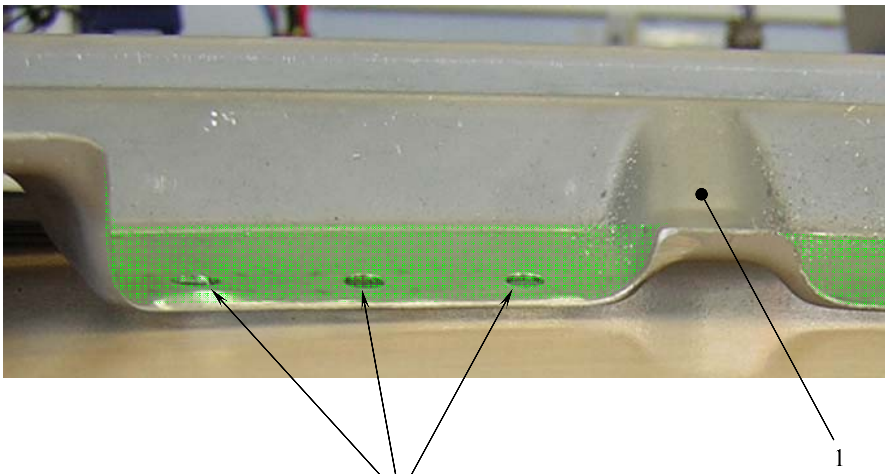
T.F.S. No. 00000522

Chip collector (b) before deletion of the flanged edges.



Chip collector (1) after deletion of the flanged edges and the magnetic elements (e)



Clearance holes for the attachment rivets (g) for the magnetic elements (e)

Figure 4

Approved under EASA DOA No. 21J.056

Page 17/21
2009.04.23

Appendix J (cont)

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T.F.S. No. 00000522

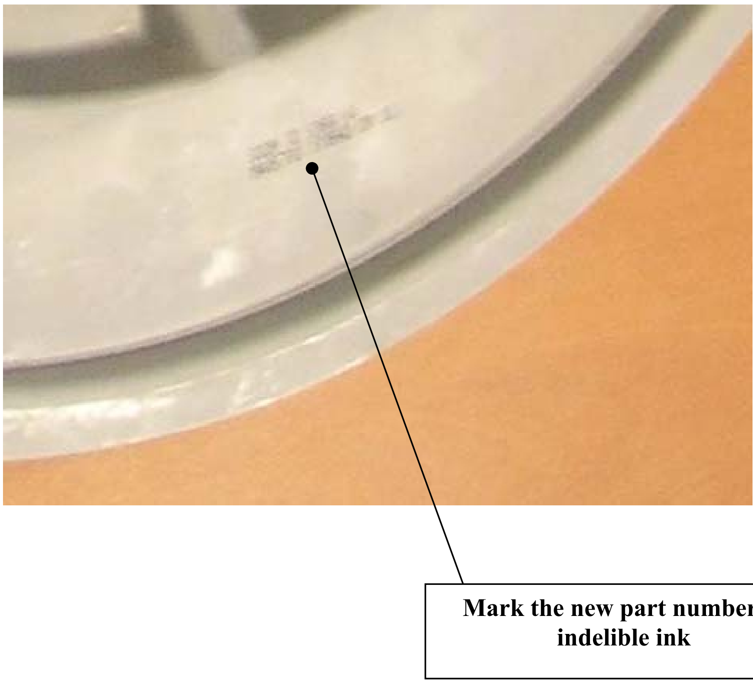

Figure 5

Appendix J (cont)

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T.F.S. No. 00000522

2.C. IDENTIFICATION

- Record first compliance with Revision 2 of this ALERT SERVICE BULLETIN on the log-card (FME) of the main gearbox (MGB) epicyclic module.

  and

- After application of paragraph 2.B.3. record embodiment of MOD 0752522 on the log-card for the MGB main reduction module.

- Re-identification of the chip collector after embodiment of MOD 0752522.

Old part number (item b)	New part number (item 1)
332A32-3229-00	**332A32-3213-21**

2.D. OPERATING AND MAINTENANCE INSTRUCTIONS

Not applicable.

Approved under EASA DOA No. 21J.056

Page 19/21
2009.04.23

Appendix J (cont)

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T.F.S. No. 00000522

3. MATERIAL INFORMATION

3.A. MATERIAL: PRICE AND AVAILABILITY

3.A.1. Cost

For any information on the kits and/or components, contact the EUROCOPTER Network Sales & Customer Relations Department.

3.A.2. Availability

The industrial delivery lead-time will be notified to the user, on request, by the Sales & Customer Relations Department.

3.B. INFORMATION CONCERNING INDUSTRIAL SUPPORT

Not applicable.

3.C. MATERIAL REQUIRED FOR EACH HELICOPTER/ENGINE/COMPONENT

3.C.1. Kits or components to be ordered for one helicopter or one assembly

Material P/N	Qty	Item	Key Word	Former P/N	Instructions
332A32-3021-01	A/R	-	Epicyclic module		
706A39-821-003	A/R	2	Seal		

3.C.2. Material to be ordered separately

Items marked with an asterisk "*" or required for compliance with the Tasks and/or Work Cards listed in paragraph 1.K. can be ordered from the INTERTURBINE company.
Website: http://www.itlogistics.de
Telephone: +49.41.91.809.300
AOG: +49.41.91.809.444

Appendix J (cont)

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T.F.S. No. 00000522

3.D. PROCUREMENT CONDITIONS

Order the required quantity (unless otherwise specified)

from

EUROCOPTER
Etablissement de Marignane
Direction Ventes et Relations Client
ECR.
13725 MARIGNANE CEDEX
FRANCE

NOTE 1

For ALERT SERVICE BULLETINS, order by:
Telex: HELICOP 410 969F.
Fax: +33 (0)4.42.85.99.96

NOTE 2

On the purchase order, please specify the mode of transport, the destination, and the serial numbers of the helicopters to be modified.

4. APPENDIX

Not applicable.

Approved under EASA DOA No. 21J.056

Page 21/21
2009.04.23