FINAL REPORT

ACCIDENT

to

(Aerospatiale) Eurocopter
AS 350B1, EI-IHL

at

Ballynacally, Co. Clare
Ireland

12 July 2007

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CONTENTS

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AAIU Formal Report No: 2009-006
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Operator:	Irish Helicopters Limited
Manufacturer:	Aerospatiale (Eurocopter)[1]
Model:	AS350B1
Nationality:	Ireland
Registration:	EI-IHL
Location:	Ballynacally, Co.Clare
Date/Time (UTC[2]):	12 July 2007 @ 11.21 hrs

SYNOPSIS

On 12 July 2007, the helicopter was undertaking a routine safety inspection of gas pipelines under contract to the National gas supplier. A crew of two were on board, a Pilot and an Observer. The inspection route took the helicopter south of Ennis and along the Shannon estuary towards Foynes. In the vicinity of Lisheen, a descent was made to facilitate closer inspection of works on the surface. A 360-degree inspection turn was carried out to the left before following the pipeline onwards. Shortly after the completion of the inspection turn, the engine stopped suddenly and without warning. The Pilot lowered the collective and attempted to enter autorotation from a low level and over difficult and undulating terrain.

The helicopter impacted into farmland to the west of Ballynacally in rising terrain. The Observer was pronounced dead at the scene. The Pilot suffered serious impact injuries and was airlifted by Coast Guard helicopter to hospital in Galway.

The Investigation determined that the engine stoppage was as a result of the 41-tooth Bevel Gear disintegrating due to fatigue. The 41-tooth Bevel Gear is a component of the engine accessory gearbox, and resulted in a loss of drive to the Fuel Control Unit (FCU) stopping the engine within seconds.

[1] **Aerospatiale**: The original manufacturer and Type Certificate holder, which became Eurocopter France on 1 January 1992 and Eurocopter on 1 June 1997.
[2] **UTC**: All times are UTC unless indicated otherwise, local time is UTC + 1 hour.

NOTIFICATION

Notification of the accident was received by the AAIU from the Station Manager at Shannon at 11.46 hrs on 12 July 2007. The Operator, through the Flight Operations Manager, also contacted the AAIU and supplied additional information. The Chief Inspector of Air Accidents, Mr. Jurgen Whyte, who happened to be in the general area at the time, responded directly to the accident site and commenced the Investigation at 13.00 hrs. In addition, two Inspectors of Air Accidents, Mr. John Hughes and Mr. Leo Murray, travelled by road from Dublin and arrived on site at 17.00 hrs.

In accordance with the provisions of S.I. 205 of 1997, the Chief Inspector of Air Accidents, on 12 July 2007, appointed Mr. Leo Murray as the Investigator-in-Charge to carry out a Formal Investigation into this Accident and prepare a Report.

1. FACTUAL INFORMATION

1.1 History of the Flight

The helicopter was engaged on a routine safety inspection of gas pipelines which were routed underground. This inspection, which was carried out under contract, required that the terrain where gas pipelines were laid had to be inspected on a two-weekly basis. This inspection was to ensure that no unauthorised activity such as digging or excavation was taking place in the vicinity of the pipelines, which would adversely effect the safety or security of the gas pipeline. Should unauthorised activity be observed, the crew had permission to set down the helicopter within a way leave area along the route to ensure the safety of the pipeline.

On the day of the accident two gas pipeline inspections were planned; the first from Gormanston to the west of the country, ending at Foynes, and a second in Northern Ireland. At the Operator's base at Trevet Airfield, near Dunshaughlin, County Meath, a total of 410 litres of Jet A1[3] was uplifted by EI-IHL, the fuel tank contents indicating 100% prior to departure. The helicopter left Trevet Airfield at 09.45 hrs with a planned elapsed flight time of 2 hours and 30 minutes. From Trevet, with the Pilot and Observer on board, the helicopter routed to the vicinity of Gormanston to begin the first gas line inspection that was scheduled that day. The Pilot occupied the front right seat, the Observer occupied the front left, with the dual cyclic and collective controls removed from that side. The inspection was carried out generally at a height of between 800 to 1,000 ft. From Gormanston the helicopter routed in a westerly direction towards Ballinasloe. The inspection then deviated briefly towards Tynagh before resuming the route west towards Craughwell. From here the inspection turned south towards Gort and Ennis. Up to this point the flight was routine. Approaching the Shannon Control Zone the Pilot called Shannon Tower on 118.7 MHz stating that he was passing Crusheen at an altitude of '*700 feet following the pipeline to Foynes*'. The flight was cleared to '*operate not above 700 feet and to maintain own terrain separation*'. This was the last regular communication received from EI-IHL.

[3] **Jet A1**: A grade of AVTUR, Aviation Turbine fuel.

In the vicinity of Lisheen the helicopter descended to a height of 400 ft and performed an inspection turn to the left, before continuing onwards towards Ballynacally (**Appendix A**). At 11.21 hrs the helicopter suffered a sudden and complete power loss. A witness, working on land nearby observed the helicopter at a low altitude and noted that it '*seemed to be weaving from side to side and up and down*' as it descended. He lost sight of it behind trees where he thought it '*appeared to be landing*'. At 11.33:14 hrs the Dublin Emergency Switchboard received a call from a member of the public stating that there had been a helicopter accident near Ballynacally. Two Ambulances were dispatched from Ennis, and arrived at the scene at 12.03 hrs. At 12.23 hrs, Limerick Fire Control advised that one person was fatally injured and that the other was in a serious condition at the accident site.

1.1.1 Pilot Interview

The Pilot was interviewed thirteen days after the accident following his release from hospital. During this interview he recalled the events of the flight and those following the engine stoppage. The flight passed to the east of Ennis at 700 ft routing then in a south-westerly direction towards Clarecastle. In the vicinity of Lisheen the Pilot descended to allow for observation of roadworks and performed a left circuit similar to a racetrack pattern to facilitate the view of the Observer. The Pilot could not recall if the engine stoppage occurred during this turn or when on-course flight was resumed. The first indication of any problem was a red light on the 'Warning-Caution-Advisory Panel'[4]. He remarked to his Observer that he had a problem, but does not recall receiving any reply from him. At the time he thought the warning may have been the Main Gearbox Temperature (Red) light. As he looked down at the panel to check the light, the Aural Warning Horn activated. The aural warning activates when the rotor speed drops below 360 RPM. He recalled then the nose of the helicopter pitching up and down slowly by 15 to 20 degrees. The Pilot lowered the collective control, halfway at first, to check if this influenced the pitching behaviour, then all the way down. The pitching tendency did not stop and led the Pilot to believe that there may have been a problem with the rotor head. As the helicopter descended the Pilot was of the opinion that there might not be sufficient control to arrest the descent. He attempted to set up an autorotation but could not recall if it was stable.

As the helicopter descended he observed that a stone wall lay in the direct flight path, so he turned '*20 degrees to the right*' to converge with a hedgerow, as it appeared to be the best option in the circumstances. He spoke to the Observer remarking '*this is not looking good – I have to go for the hedge*'. This was the Pilot's last recollection of the flight. After the impact he recalls being outside the helicopter near a ditch and saw his Observer nearby, still conscious. The Pilot asked if he was okay, but the Observer indicated that he was not. Within a minute or so, a person appeared at the scene having heard the impact. He first went to the Observer and then to the Pilot. The Pilot told him he had better go back and attend to the Observer *'as he was not looking good'*.

[4] **Warning-Caution-Advisory Panel**: Annunicator panel with red (warning) and amber (caution) lights situated on the pilots forward instrument panel.

The person told the Pilot that he had called the Emergency Services and that they were on the way. The Pilot, himself seriously injured, recalls the arrival of the Ambulance Crews and their efforts to resuscitate the Observer. Shortly afterwards an Irish Coast Guard helicopter arrived and airlifted the Pilot to hospital.

1.1.2 Witness statements

A number of individuals in the locality recounted hearing the approaching helicopter and subsequent impact. The Investigation identified one witness who observed the helicopter during its final descent. This witness, who was working on land at his father's farm at Carrowhilla, observed the helicopter at low altitude, '*about the height of a tall tree, the tail was going from side to side and up and down as it descended*.' The witness saw it descend behind trees where he thought it appeared to be landing. As he was on a tractor with its engine running at the time, he could not tell if there was any sound. He stated that he did not think any more about it until he saw the accident on the news, whereupon he contacted the Gardaí at Kilrush Garda Station. Two witnesses, who were working on a farm nearby with power tools, heard the helicopter make a '*spluttering noise, then silence, then a loud bang'*. Neither individual saw the helicopter, and were not sure at the time what had happened. A short time later they met a person who said a helicopter had crashed, they went to the field and assisted the Emergency Services in accessing the site. Another witness, in her garden near Ballynacally, heard the helicopter approaching '*making a queer noise*' and then she '*heard a bang'*. At no stage did she see the helicopter.

1.2 Injuries To Persons

Injuries	Crew	Passengers	Total in aircraft	Others
Fatal	1	0	1	0
Serious	1	0	1	0
Minor	0	0	0	0
None	0	0	0	0
TOTAL	2	0	2	0

1.3 Damage to Aircraft

The helicopter was destroyed.

1.4 Other Damage

Damage to hedgerow, wire fencing and posts.

1.5 Personnel Information

1.5.1 Commander

Personal Details:	Male, aged 55 years
Licence:	Irish Commercial Pilot's Licence (H)
Last Periodic Check:	9 May 2007
Medical Certificate:	Class I, issued 14 March 2007

Flying Experience:

The Pilot was a Type Rating Examiner on the AS350 with a total of 8,300 hrs flying time of which 1,189 hrs were on type. He flew a total of 46 hrs in the previous 90 days, 15 hrs in the previous 28 days and 5 hrs in the previous 24 hour period. The Pilot completed and passed a proficiency check a few days prior to the accident.

1.5.2 Observer

Personal Details:	Male, aged 69 years
Licence:	Not applicable

Experience:

The Observer joined the Operator in 1980 as Commercial Manager. He continued in that role until 2005 wherein he was appointed Commercial Director. In 2006, he advised the Operator that he wished to retire and at this point he was offered the position of Observer for gas pipeline patrols, as over the years he had carried out these duties when required thus gaining a great deal of experience.

1.6 <u>Aircraft Information</u>

1.6.1 Leading Particulars

Aircraft type:	AS350B1
Manufacturer:	Aerospatiale (Eurocopter)
Constructor's number:	1963
Year of manufacture:	1987
Certificate of Registration:	Issued 27 May 2004
Certificate of Airworthiness:	Issued 22 May 2007
Total airframe hours:	9,974 hours
Total cycles:	67,323 cycles
Engines:	1 x Turbomeca Arriel 1D1
Maximum authorised take-off weight:	2,200 kg
Actual Take off weight:	1,885 kg
Estimated weight at time of accident:	1,650 kg
Centre of Gravity limits (at accident weight):	3.17m to 3.49m aft of datum
Centre of gravity at time of accident:	3.32m aft of datum

1.6.2 General Information

The AS350 is a single-engine helicopter designed for light utility work equipped with a skid-type landing gear. At the time of the accident, a total of 2,572 of the type were in service, together with 635 examples of the AS355 twin-engine version. The type has achieved approximately 26 million flight hours since introduction in 1987. The configuration of EI-IHL provided seating for five occupants; two in separate forward seats (including the pilot) with provision for three passengers on a rear bench-type seat.

This helicopter, Serial No. (S/N) 1963 was first registered as N518R in 1987. It was transferred onto the UK register as G-BWFY on 31 July 1995. On 27 May 2004, the helicopter was registered in Ireland as EI-IHL to Irish Helicopters Ltd, Westpoint Hangar, Dublin Airport. At the time of the accident the Operator was based at Trevet Airfield, near Dunshaughlin, County Meath.

1.6.3 Engine General

The Turbomeca Arriel 1D is single-shaft free turbine engine. The engine consists of five separate modules, each with an identification plate identifying the Part and Serial number of that Module. The modular construction of the engine allows component modules to be repaired or replaced on an individual basis should this be necessary. The engine modules are illustrated in **Figure No. 1**.

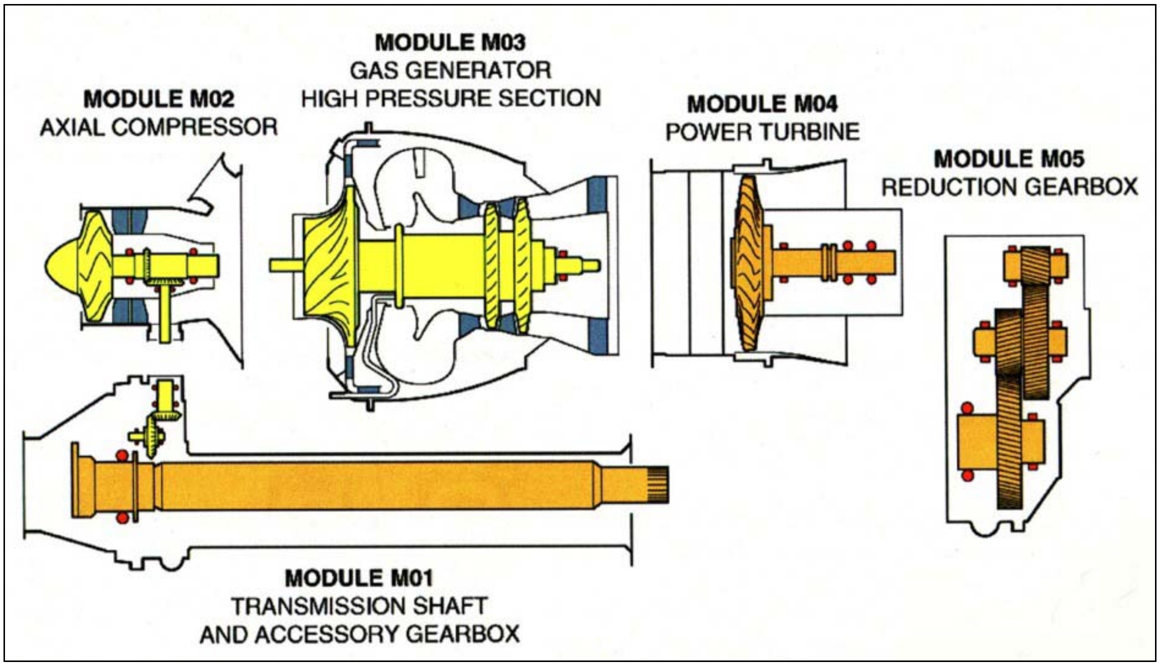

Figure No. 1: Schematic of Arriel 1 engine modules

The function of each module is as follows:

- **Output Shaft Module**, **M01**, including the transmission shaft and accessory gearbox, which transmits engine power to the main gearbox and accessory drive couplings.

- **Axial Compressor Module**, **M02**, mounted at the front of the engine, comprising a single-stage axial compressor followed by a guide vane.

- **Gas Generator Module**, **M03**, the high-pressure section of the gas generator, centrally located and comprises a centrifugal compressor, combustion chamber and two-stage generator turbine driving the compressors.

- **Free Turbine Module**, **M04**, The power turbine, situated at the aft end consisting of a free turbine wheel and shaft.

- **Reduction Gear Module, M05**, which reduces the free turbine speed from 41,586 RPM to 6,000 RPM.

The position of the 41-tooth Bevel Gear is illustrated in **Figure No. 2**. The 41-tooth and 17-tooth gears are termed 'Assembled Gears'; these gears, together with the 23-tooth Bevel gear comprise the 'Matched Gear Assembly'. The 37-tooth 'Breather Gear' meshes directly with the 17-tooth gear (**Figure No. 3**).

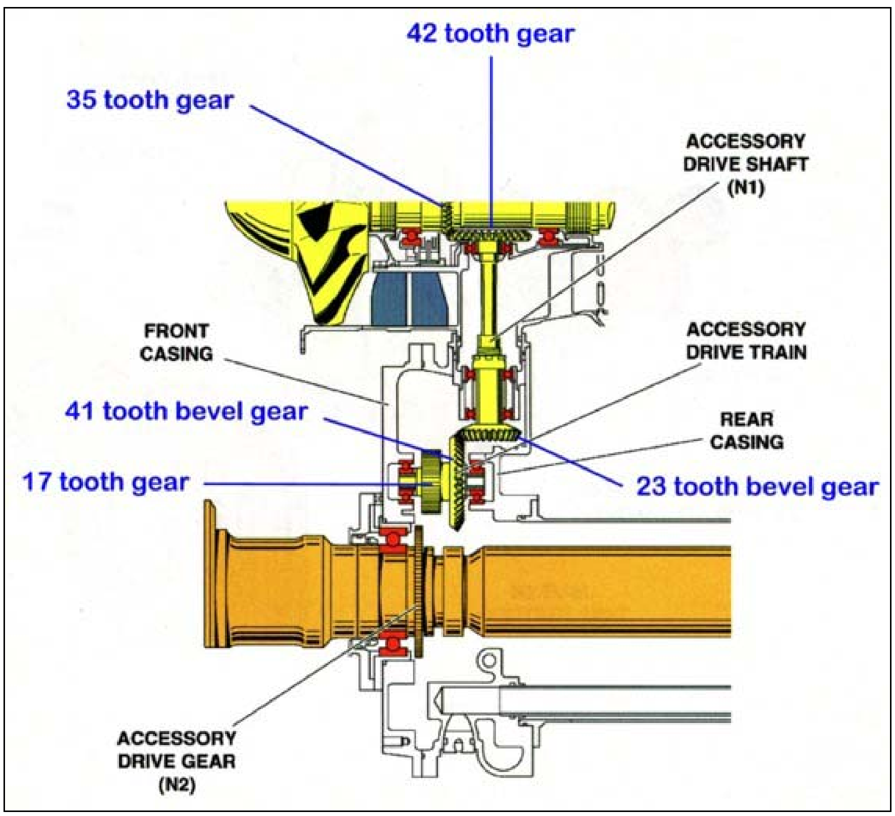

Figure No. 2: Identification of Accessory Drive gears

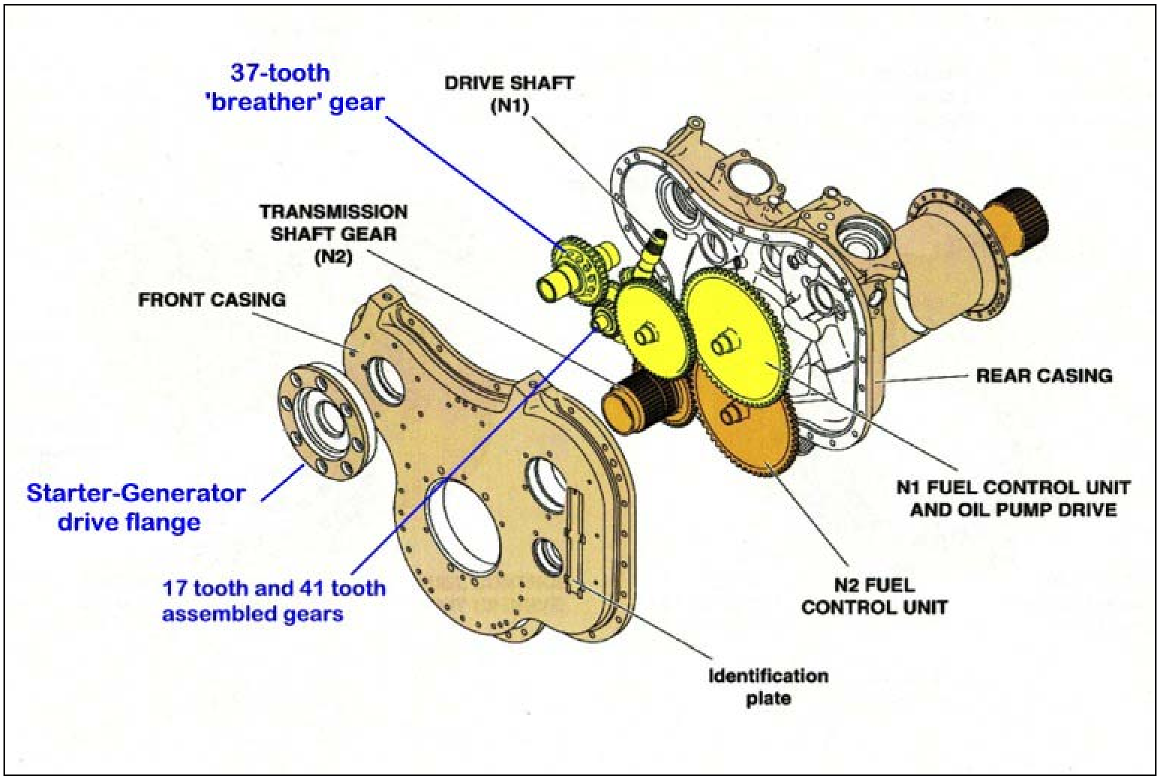

Figure No. 3: Identification of 37-tooth 'Breather Gear' and 'Assembled Gears'

The Starter-Generator is mounted by means of a flange on the front of the engine. The rotor shaft of the Starter-Generator connects directly with the 37-tooth 'Breather' Gear drive shaft.

During the engine starting sequence, the 37-tooth 'Breather' Gear directly drives the 17-tooth, and 41-tooth Gears, which in turn drive the accessory drive shaft (N1). With the engine running, the accessory drive shaft (N1) now drives the Starter-Generator through the assembled gears and 37-tooth 'Breather' gear.

1.6.4 Engine History

The engine installed in EI-IHL was an Arriel 1D Serial No. (S/N) 7035, which was built in 1987. Maintenance records indicate this engine was repaired at a maintenance facility between September 2003 and December 2003 with a TSN[5] of 7,232 hours. This work involved overhaul of Module M02 and M03 and repair of Modules M01, M04 and M05. The engine was first installed on EI-IHL on 6 October 2005. At the time of the accident the engine had accumulated 8,224 hours total time with 992 hours since repair in December 2003. On 15 October 2006, at 7,829.8 hours TSN, the igniters were replaced and an engine oil change carried out. On 1 March 2007, a 500 hour inspection was carried out at 7,987 hours TSN. The Starter-Generator brushes were replaced during this inspection.

[5] **TSN**: Time Since New (used in Engineering documentation).

1.7 Meteorological Information

1.7.1 Met Éireann, the Irish Meteorological Service, provided the following information after the accident:

Meteorological Situation:

A cold front had moved through the area during the morning and, at the time of the accident, the Ballynacally area was well to the rear of the cold front lying in a slightly unstable, moderate westerly airflow.

Meteorological conditions at the time of the accident:

Interpolation from adjacent synoptic stations (particularly Shannon Airport which would have been very representative of the situation in Ballynacally at this time), combined with archived satellite and Radar data, imply the following conditions existed at the location of the accident at 12.23 hrs on 12 July:

Wind:	Surface, 270 degrees at 12 kts Gradient Wind, 290 degrees at 20 kts
Cloud Amount:	Few/Scattered 1,500-2,000 ft, Broken 3,000-4,000 ft Risk of broken cloud 1,500-2,000 ft
Cloud Type:	Cumulus and Stratocumulus
Visibility:	Generally 20-30 km, Risk of 6-9 km
Weather:	Light rain showers were likely to develop in this area
Temperatures:	Air Temperature 17 ºC Dew Point 12 ºC
Freezing level:	Circa 10,000 ft
MSL Pressure:	1013 hectoPascals (hPa)

Additional Comment:

At the time this accident occurred, the weather in the area could be considered to be relatively benign with just light showers likely. There is no evidence to suggest the presence of Cumulonimbus cloud or any mountain or lee wave activity.

1.8 Aids to Navigation

Not applicable.

1.9 Communications

1.9.1 General

When the accident occurred the Pilot was in radio contact with Shannon Air Traffic Control (ATC) on Tower frequency 118.700 MHz. At 11.11:01 hrs the Pilot called Shannon ATC stating his altitude was '*700 feet passing Crusheen into the Shannon Zone following the pipeline to Foynes*', routing east of Ennis. Shannon ATC cleared EI-IHL to '*operate not above 700 feet and to maintain own terrain separation*'. Apart from this routine call no other regular communication was received from EI-IHL. At 11.21:08 hrs a carrier wave was heard on the frequency for a duration of 5 seconds. Shannon ATC attempted to raise EI-IHL on the frequency at 11.21:32 hrs and requested a comm's check at 11.22:29 hrs. For the next four minutes several attempts were made by Shannon ATC to contact EI-IHL. Apart from further carrier wave activity at time 11.23:06 hrs no response was received. At 11.25:46 hrs a commercial flight came on frequency and also attempted to contact EI-IHL. No response was received.

1.9.2 Radar Information

EI-IHL first appeared on Shannon Radar at 11.06 hrs at 700 ft AMSL. At 11.18:40 hrs the helicopter was recorded at an altitude of 400 ft at a speed of 96 kts. In the vicinity of Lisheen the helicopter made a 360-degree inspection turn before continuing southwest at that altitude. At 11.21:10 hrs the Radar return indicated an altitude of 200 ft descending with a speed of 92 kts, coinciding with an MSAW[6] alert on the Radar screen. Radar contact was lost at 11.21:15 hrs.

1.9.3 Global Positioning System (GPS)

The Investigation recovered a Garmin GPS unit from the helicopter at the scene. Data from the unit was used to reconstruct the probable flight path as depicted in **Appendix A**.

1.10 Aerodrome Information

Not applicable.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

Not fitted and not required to be fitted.

1.11.2 Flight Data Recorder

Not fitted and not required to be fitted.

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[6] **MSAW**: Minimum Safe Altitude Warning.

1.12 Wreckage and Impact Information

The helicopter impacted into a grass field surrounded by trees and hedgerow, with the elevation of the land 150 ft AMSL and rising on the westerly side. The helicopters flight path into this field was made over a loose stone wall, about 1.5 metres high. The approach to this area consisted of steeply rising and undulating terrain. The fields in the vicinity of the approach path were small, and bordered by tree-lined hedgerows and stone walls.

The wreckage, except for the aft tail boom structure, was concentrated in a single area. A trail of witness marks and pieces of structure revealed that the helicopter impacted heavily, at speed, on its main landing skids. The underside of the helicopter was severely damaged during the impact sequence. Sloping terrain to the right of the impact line showed evidence of two main rotor blade strikes. The helicopter continued forward with a considerable velocity and impacted into a hedgerow, which contained a line of mature trees. This impact resulted in the disintegration of the entire front cockpit of the helicopter. The wreckage pattern included the windscreen centre support, windshield transparency pieces, both main doors and panels, together with numerous charts and loose items from the cockpit. The aft section of the tail boom including the entire tail rotor assembly was sheared off. The wreckage, still with considerable momentum, was then propelled into an adjoining field where it came to rest, in an almost upright position, approximately 10 metres from the tree impact. A section of the tail rotor drive was found approximately 58 metres further on from the main wreckage (**Appendix B**).

1.13 Medical Information

Both occupants were thrown from the helicopter during the impact sequence. Attempts by the Emergency Services to resuscitate the Observer were unsuccessful and he was pronounced dead at the scene at 12.45 hrs (13.45 local time). A Post Mortem was carried out at Limerick Regional Hospital by the County Coroner on 13 July 2007 and revealed that the Observer died due to cardio-respiratory arrest and hypovolaemic shock secondary to injuries sustained in the accident.

The Pilot had no memory of the actual impact. He regained consciousness at the accident site having suffered serious impact injuries. He was treated at the scene by the Emergency Services, and was airlifted to hospital in Galway by an Irish Coast Guard helicopter.

1.14 Fire

There was no fire.

1.15 Survival Aspects

1.15.1 General

The initial impact with the surface was followed by a rapid deceleration and break up of the forward cockpit section after impact with the tree-lined hedgerow.

The main wreckage then continued into the adjoining field, the body of the helicopter rotating rapidly about its vertical axis. During this sequence the two forward seats failed under lateral shear load, near to the base of each seat. With no restraint now being provided by the harnesses, the occupants were thrown from the helicopter.

1.15.2 Seats and Harnesses

The front seats are each constructed as a single unit from composite glass fibre material. The base of each seat is anchored to two metal rails running fore-aft by means of two rows of set screws, eleven on the inboard edge and ten on the outboard edge. These rails are in turn secured to the floor of the helicopter by means of bolts held by clevis fasteners to facilitate release and removal of each seat. Pairs of cushions complete each seat arrangement.

The front occupants were secured by means of four-point harnesses. The two lap straps on each seat were anchored to the floor of the helicopter by attachment rings and were fastened across the lap by means of a multi-point buckle. In addition, two shoulder straps were fed from an inertia reel assembly attached to the lower rear of each seat. The AS350B1 was certified under the Airworthiness Requirements of FAR Part 27. The seats were tested by the manufacturer during type certification according to FAR 27.561 Amendment 10 current at the time (**Table No. 1**)

Ultimate load Factors:	**AS350B1 Manufacturer's Specification:**	**AS350B1 Certification: FAR[7] 27.561 Amend. 1-10 1 Feb 1965**	**Current Standard: EASA[8]CS-27 Amendment 2 17 Nov 2008**
Upwards	2.25 g	1.5 g	4 g
Downwards	6 g	4 g	20 g
Laterally	3 g	2 g	8 g
Forwards	6 g	4 g	16 g
Rearwards	-	-	1.5 g
Harnesses and attachments	10 g forwards	-	-

Table No. 1: Ultimate load factors, forward seats

The Certification tests were successfully completed, failure of the seat test specimen occurred at a loading of 820 dekaNewton (daN), which is equivalent to a 10.65g forward load. The forward seats in the AS350 were tested during the certification process to be in excess of FAR 27.561 (Amendment 10) then in place, and complied with complementary and special conditions defined in DGAC[9] letters 6518 and 6437.

[7] **FAR 27.561**: Federal Aviation Regulation, (Part 27 Subpart 561, Airworthiness Standards, Normal Category Rotorcraft, as issued 1 February 1965).
[8] **EASA**: European Aviation Safety Agency, (CS-27 Small Rotorcraft, Subpart 561)
[9] **DGAC**: Direction Générale de L'Aviation Civile, (the Aviation Regulator in France).

The manufacturer has worked on improvements to the seat installation since introduction of the type, and has issued recommended modifications regarding these seats. One such modification, Service Bulletin 25.00.24 was incorporated on the left (Observers) seat in 1997. The purpose of this modification was to avoid the possible formation of cracks between the backrest and seat pan, and to improve the seat attachment points.

In 1999, the manufacturer offered further seat modifications as a recommended modification. These modifications were outlined to operators in a Service Letter dated 24 November 1999 (Ref 1424-25-99). One option was the installation of 'new generation' high-energy-absorbing seats to provide better protection to the occupants of these seats. The installation of these seats requires nine structural components to be replaced under the cockpit floor. These components can only be accessed after removing the flight controls and electrical harnesses in the area. This procedure involves a work schedule for two persons for approximately three weeks and must be performed by qualified personnel, trained beforehand by the helicopter manufacturer, (Service Bulletin SB 25.00.57 refers). The second option outlined in the Service Letter involves re-enforcement of existing bucket-type seats. In this case some sub-floor reinforcements must be modified and relocated for attachment of a new type of seat rail. The static strength of the seat/floor attachment is thus significantly improved by reinforcement of the seat with glass fabric plies and additional screws for the rail/seat interface. This modification, which does not require removal of the flight controls or electrical harnesses, must be carried out by a mechanic who is specialized in structures, and takes approximately three days, (Service Bulletin SB25.00.63 refers). Neither of these optional modifications were made to EI-IHL.

1.16 Tests and Research

1.16.1 Fuel Tests

A sample of fuel from EI-IHL was sent to an independent laboratory for analysis together with a fuel sample from the bowser at Trevet Airfield. The report stated that both fuel samples were: *'Consistent with the Defence Standard Specification 91-91/5 requirements as tested, apart from the appearances. The samples were mainly consistent with an AVTUR reference, however FTIR*[10] *indicated the presence of some contamination. It was not possible to identify the contaminant(s), however the spectrum suggests that water or an alcohol could be present. The appearance of both samples was pale straw colour, bright with a small quantity of sediment'*.

1.16.2 Flight controls

The flight controls were checked for continuity. The right seat cyclic control was found to have continuity to the rotor swash plate. Right-seat cyclic control movement was restricted due to impact damage. The left-seat cyclic and collective controls were not installed at the time.

[10] **FTIR**: Fourier Transform Infrared Spectroscopy.

The right anti-torque pedals runs were checked and were found continuous to the aft fuselage bulkhead where the tail boom was severed in the impact sequence. Inspection of the tail-rotor pitch-change mechanism revealed no pre-accident defects. The tail rotor drive shaft failed due to a single event overload during impact. The primary flight controls and rotor head revealed no evidence of pre-accident defects.

1.16.3 Engine A-frame fracture

Initial inspection of the wreckage revealed the right-forward engine support fractured and separated. The separated sections were later subjected to analysis by an independent laboratory. This analysis confirmed that the component had collapsed locally with marked bending either side of the fracture point. The fractures were indicative of single event overload failure, with no indication of any pre-existing fracture or defect in the component.

1.16.4 Engine Inspection

1.16.4.1 General

The wreckage was removed on the evening of the accident, and held secure overnight in the local area. The following morning the wreckage was escorted to the AAIU facility at Gormanston in County Meath for further technical examination. An initial engine inspection was carried out, which revealed the presence of metallic particles on the Magnetic, and General Indicating Plugs, positioned below the engine. This indicated that internal damage had occurred to the engine or its ancillary components. The engine was then removed from the helicopter and placed on a stand to facilitate further inspection. Under the supervision of an AAIU Inspector, a representative of the engine manufacturer inspected the engine and found that the accessory drive (driving the Fuel Control Unit and Starter-Generator) was not being driven when the Gas generator was rotated by hand, indicating a failure in the accessory drive shaft or drive train.

Following the initial inspection, the engine was transported by sealed crate to the engine manufacturer's facility at Tarnos, France for dismantling. This dismantling was made using the expertise and tooling of the manufacturer, which were made available to the Investigation. At the Tarnos facility the engine was disassembled under the supervision of two AAIU Inspectors of Accidents and one Inspector of the Bureau d'Enquêtes et d'Analyses (BEA), the Accident Investigation Bureau of France.

The external condition of the engine was good, with impact damage only apparent on the engine tailpipe. All ancillary pipework and connectors were correctly fitted. The Gas generator, Free turbine and Free-wheel were able to rotate. Boroscopic inspection of compressor blades and combustion chamber revealed no damage. The control harness was removed and tested satisfactory. The Magnetic and General Indicating Plugs were checked for proper continuity and insulation. Module M05 was removed and a check of the drive gear/spline nut position marks carried out; the alignment was found correct.

Modules M02, M03 and M05 were then removed. This allowed Module M01 to be disassembled, which revealed that the 41-tooth Bevel Gear had disintegrated (**Photo No. 1**). The fragments were photographed and loose metallic fragments preserved for examination.

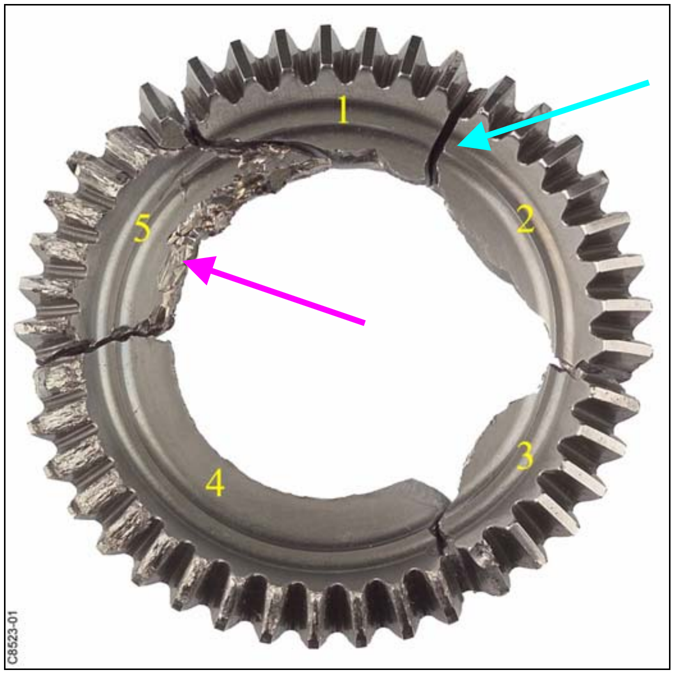

Photo No. 1: Bevel Gear fragments recovered from Module M01

1.16.4.2 Laboratory examination of accessory drive components

The manufacturer undertook to perform a check of all clearances of the gear assembly together with a laboratory investigation of the disintegrated Bevel Gear components. Bearing axial play, adjusting washers and their support shoulders on the shaft were found within tolerance. This examination included testing of the material characteristics (hardness and surface treatment), fracture surface analysis by means of binocular and microscopic inspection. These tests were made under the supervision of the BEA. Three types of damage on the 41-tooth Bevel Gear were observed: a fracture on tooth space bottom land that initiated on the small-diameter side of the web and initiation of cracks on almost all the tooth space bottom lands, indications of alternate bending stress on the web, and heavy peening on the tooth tips as gear meshing was lost (**Appendix C**).

1.16.4.3 Hardness test of 41-tooth gear

A micrographic section was taken close to the tooth space bottom lands (using Nital 5% chemical etching). The observation reveals a fine martensitic microstructure, typical of a carburised zone, and a coarser martensitic structure that comply with the material specifications. Measurements were taken on a polished section. The **Macrographic core hardness** (HV_{30}) was measured on average at 432 HV.

This value was slightly above the original specification drawings but within the Turbomeca specification defined in Specification document ST02603 issued on 18 September 2006. The observation of the micrographic sections of the gear teeth were made on the sound part of the teeth. The **carburising depth** was slightly greater than the depth specified on the drawing (the 41-tooth Bevel-Gear design drawing indicates a carburising depth between 0.25 and 0.40 mm). Specification ST02603 authorises an additional carburised layer of 0.15 mm for machining reserve. The caburizing depth corresponding to a Hardness filitation ($HV_{0.5}$) 550 $HV_{0.5}$ on the tooth flanks was 0.08 greater than the value specified after machining. Laboratory examination showed the absence of notable wear on the tooth flanks.

1.16.4.4 Testing of Engine Accessories

1.16.4.4.1 Harness and chip detectors

A continuity check was performed on the complete harness equipped with the two chip detectors and was found satisfactory. A magnetic pull test was then carried out on the chip detectors and was also found satisfactory.

1.16.4.4.2 Tachometer transmitter

A visual inspection of the component did not reveal any anomalies. All tests performed on the tachometer transmitter showed that it was in compliance with the manufacturer's specifications.

1.16.4.4.3 Fuel Control Unit (FCU)

A visual inspection confirmed installation of locking wires and warranty seals. During tests the start and acceleration curves were found to be in accordance with specifications. Static droop curves were found out of tolerance; the curves revealed a drift of approximately + 20 RPM. Response time was 1.4 seconds, within the manufacturer's specification of less than 3.5 seconds. At zero fuel flow, the pump pressure was found out of tolerance at 3,000 kiloPascals (kPa), with manufacturer specification of 3,350 kPa (+100/-0). The Investigation is of the opinion that the non-conformities observed on the FCU did not play a role in the disintegration of the 41-tooth Bevel Gear or the engine failure.

1.16.4.4.4 Oil Pump

A visual inspection of the Oil Pump did not reveal any anomalies. The Oil Pump was not tested on an accessory test rig due to the presence of metallic particles on the magnetic plugs. Before disassembly, it was possible to rotate the pump by hand, but some rough points were detected. Inspection of the Pressure Pump revealed the presence of normal operating score marks on the gears and body. Inspection of the Rear Bearing Scavenge Pump revealed the presence of scores, which was indicative of the passage of metallic particles on the body. The presence of these particles was noted on the intermediate plate.

Inspection of the Accessory Gearbox Scavenge Pump revealed scores on the body and bottom of the pump also indicating the passage of metallic particles, again evidence of particles was found. The two lip seals, which separate the Pressure Pump from the Scavenge Pumps were very rigid. One was found ruptured. The other components of the Oil Pump were inspected and did not reveal any anomalies.

1.16.4.4.5 Starter-Generator

The Starter-Generator is fitted directly to the front of the engine by means of an adapter flange. The component has a dual function in that its acts as a starter motor for the engine operating through the 41-tooth Bevel Gear during the start cycle, and then as a DC generator once the engine is at operating speed. The Starter-Generator fitted to EI-IHL had a current rating of 150A. In starter-mode it produces an output of 2.8 kW (3.8 HP) at 1,000 RPM; in generating-mode it has an output of 4.5 kW and a speed range of 8,100 to 12,500 RPM. The Starter-Generator design incorporates a damping system. This comprises a pair of damper plates either side of a friction disc at one end of the rotor shaft. At the other (cooling fan) end of the shaft, a retainer spring, a set of Belleville Springs and a drive shaft nut are fitted.

With the drive shaft nut correctly tightened, appropriate pressure is applied to the damper plates and friction disc. The procedure for the overhaul of the unit is outlined in the APC Starter-Generator Overhaul Instructions (TM 101 revision 12). **Figure No. 4** illustrates the arrangement:

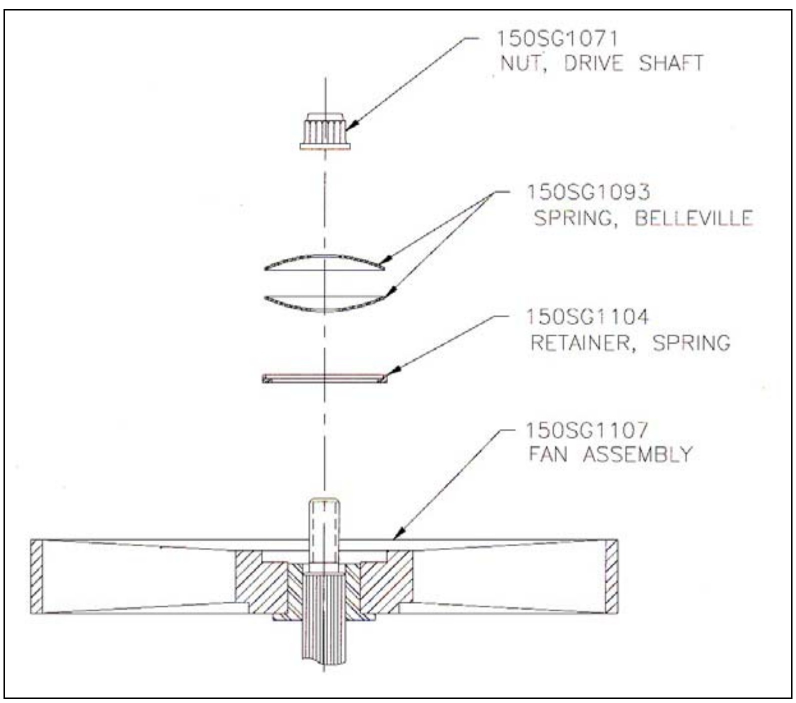

Figure No. 4: Belleville Spring Installation Arrangement

1.16.4.4.6 Visual Inspection of the Starter-Generator

A visual inspection of the Starter-Generator revealed the friction disc of the damping system to be off-centre. To ascertain the extent of the offset, a series of cut-views using Tomography were carried out using equipment from TomoAdour Cie. This testing did not require any dismantling of the Starter-Generator. The source detector set was moved in 0.6 mm steps over a distance of 12 mm length parallel to the rotor shaft axis. Images were extracted in the range 5.40 mm to 6.60 mm and made available to the Investigation. The image in **Photo No. 2** shows a cross-cut of the Starter-Generator, with the rotor shaft at the centre appearing as a white disc. Surrounding the rotor shaft, in grey, is the friction disc. Note the damage to the centre of the disc and the displacement from its normal position, indicated by the red circle. The damping plate was found to be approximately 7.2 mm off-centre.

The Investigation then undertook a series of tests on the Starter-Generator. The Starter-Generator was coupled to a test engine to examine if the damping adjustment and off-centre friction disc were causing undue stress or vibration to the accessory drive components. This investigation was only possible with the expertise and assistance of the engine, airframe, and component manufacturers. The tests took place at the engine manufacturers facilities at Tarnos and Bordes and the airframe manufacturers facility at Marignane, in France. All testing was supervised by Inspectors of Air Accidents of the AAIU or the BEA.

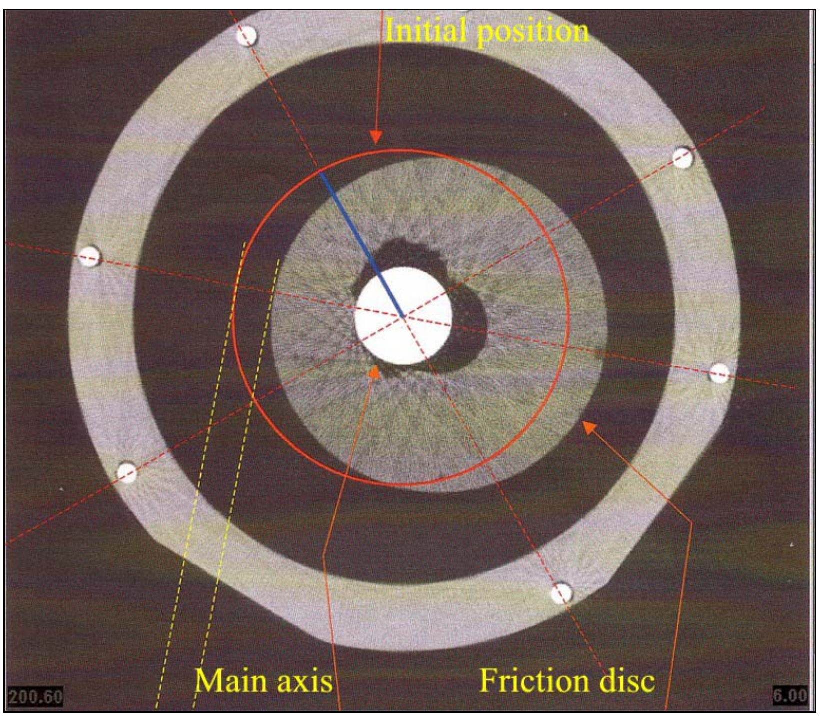

Photo No. 2: Image of damaged Starter-Generator friction disc

1.16.4.4.7 Starter-Generator history

At the time of the accident, EI-IHL was fitted with Starter-Generator P/N APC 150 SG122Q, S/N 5085. This unit was built by Aircraft Parts Company (APC) in July 1987. Inspection of the identification plate shows the unit was built with P/N APC 150SG117Q, the '117' was later over stamped with the '122' designation. APC Starter-Generator casings are built with an anodised protective finish. At some point, the outer casing of the unit was sprayed with black paint. The paint was applied in such a manner that some of the over spray had penetrated inside the component covering the fan and commutator head assembly. Although the painting of this component was unapproved and non-standard, the painting was not a factor in the accident. The painting of the outer casing of this unit was not carried out by the Operator or its parent company in the UK. Components such as the Starter-Generator may be exchanged between different helicopters, or placed in the component supply chain. Starter-Generator S/N 5085 was last completely overhauled on 18 August 2004 at an independent repair facility. It was installed on a UK-registered helicopter on 24 January 2005. On 17 June 2005, it was removed for repair of a burnt brush spring, and following repair was released for service on 26 July 2005 (at 369.1 hrs since O/H[11]). On 21 October 2005, it was installed on EI-IHL but removed (as a serviceable unit) shortly afterwards on 25 October 2005 (at 371.7 hrs since O/H) and placed in storage. Following the overhaul of the Starter-Generator in 2004, none of the subsequent work required removal or adjustment of the damping system, nor did the helicopters maintenance records indicate any such adjustment was made.

On 14 June 2006, the unit was again installed on EI-IHL and remained fitted until the accident. Since that date the following entries were made in the aircraft documentation:

24.9.06	'Gene intermittent goes off line'- 'Tag found loose re-secured IAW[12] 70-41-00' [Ref Tech Log, Page No.0448]
1.3.07	'Gene light flickers' - 'brushes very worn-replaced' [Ref Worksheet IHL/PDG/01/07, 500 hour inspection]
2.5.07	'Generator brush checks MET 300-80-001' [Ref Workpack Ref: IHL 03/07]
11.7.07	[date of the last entry in the airframe logbook]

1.16.4.4.8 Direct Current Generating Unit

The Direct Current Generating Unit (DCGU) was manufactured by ECE, a French Company, in April 1986 (S/N 112). The DCGU controls and protects components of the electrical system.

[11] **O/H**: Overhaul (used in Engineering documentation).
[12] **IAW**: In Accordance With (used in Engineering documentation).

This includes the connection of ground power, the battery, the energising and regulation of the generator, closing and cut-out of the generator, protection against generator over voltage, control of the starting winding of the generator and de-energisation of the generator if the starter motor function is active. The DCGU is contained in a moulded plastic box unit protected by a duralumin attachment cradle under the floor of the hold area. It contains a power-block assembly, a relay block assembly, and a printed circuit card (Z1) with electronic components, which form the 'regulation-closing and amplifier' system. The version fitted to EI-IHL, Part No. (P/N) 374GC01Y, also has a printed circuit card (Z2) with electronic components, which form the 'generator over voltage protection' system.

The excitation of the Generator field winding is not 28V DC but a 'pulse width modulation' (PWM). The excitation signal is not a square signal but a saw-tooth waveform due to a characteristic of the excitation winding that does not allow instantaneous voltage variation. Note that the frequency of the PWM is not constant. The power supply for the excitation is provided through a fuse (F4) through the excitation relay (K1 REX) and arrives at a transistor (Q1), back through the relay and to the Generator field winding. The printed circuit card (Z1) controls the Transistor and the excitation in the following manner. If the Generator voltage is less than the reference Voltage, Transistor Q1 is closed, excitation is at a maximum and the Generator voltage increases. When the Generator voltage becomes greater than the reference voltage, Transistor Q1 opens, and there is no excitation (**Appendix D**).

1.16.4.4.9 Battery

The helicopter was equipped with a 24-Volt, 16 Amp-hour (Ah) battery (P/N 18624, S/N 49292). It was manufactured in March 1990. A capacity check was carried out on 6 June 2007 and was satisfactory.

1.16.5 Incident in Canada

In November 2007, an AS350 helicopter in Canada, similar to EI-IHL, suffered an in-flight engine shutdown. This helicopter was an AS350B3 variant, powered by an Arriel 2B engine. The Arriel 2 differs from the Arriel 1 primarily in having a single-stage turbine section compared to a two-stage turbine on the Arriel 1. On 25 January 2008, the Transportation Safety Board of Canada (TSB) issued an Aviation Safety Advisory[13] concerning the incident.

Preliminary investigations carried out by the TSB revealed that the 41-tooth Bevel Gear of the Accessory Drive had '*fractured due to high cycle fatigue cracking. Preliminary examination of the Bevel Gear revealed numerous fatigue cracks radiating from the roots of many of the gear teeth. Circumferential fatigue cracks were also observed in the rim of the gear'*.

[13] **Aviation Safety Advisory No**. A07O0314-D1-A1.

Due to the similarities with the two events, it was considered beneficial to test the Starter-Generators from both helicopters to a comprehensive test schedule proposed by the manufacturer (Ref ESTS 2008/255).

1.16.6 Bench Testing involving Starter-Generator from EI-IHL

Of importance to the Investigation was the background of experience the engine manufacturer had with Auxilec Starter-Generators. At entry into service, in 1977, Arriel engines were fitted with these Starter-Generators. Due to oscillations induced by the DCGU some failures occurred in components of the accessory drive (not the 41-tooth Bevel Gear). After investigation of these events, Starter-Generators of this type were modified with a spring-type damping system, resulting in no further failures. The Auxilec has a coiled-spring type damper and is significantly different to the Belleville-spring type used in APC units.

The first series of tests were carried out at the engine manufacturers facility at Bordes using an Arriel 1C1 engine (S/N 18). These tests measured vibration and gear stress using speed and position sensors with the APC Starter-Generator of the accident helicopter being compared with a representative APC Starter-Generator under various load and speed configurations. The measured results did not reveal any specific anomalies between either Starter-Generator. However it should be noted that the sensors and instrumentation used in these tests were somewhat limited and no definitive conclusions could be drawn.

The Starter-Generator from EI-IHL and the Canadian incident were both manufactured by APC in the USA. This company was acquired by Unison Industries LLC in 2005. A representative of this company was present during testing at Marignane, France and assisted the Investigation during the testing schedule. Both the Irish 150A and Canadian 200A Starter-Generator units were equipped with a damping system. Although the details of the damping system between the two models differ in detail, the general principle of operation remains the same. It should be noted that over tightening the drive shaft nut during overhaul assembly will flatten the domed Belleville Springs, resulting in no damping of the Starter-Generator in either start or generation modes. A sample test of the overhaul procedure on the 150A APC type Starter-Generator revealed the damping system could be easily over-tightened when following the procedure. External inspection of both Starter-Generator units revealed that the drive shaft nut in both the Irish and Canadian cases were over-tightened.

In accordance with the ESTS 2008/255 test schedule, the 200A unit was test-run, followed by the 150A unit from the Irish accident. Following the completion of the test schedule the 150A unit was disassembled for inspection. This revealed the over-tightening of the nut had caused the outermost Belleville spring to flatten and become slightly concave in appearance. The damping system was fully tight with no possibility of displacing the internal shaft. As previously mentioned the friction disc was found broken as indicated by Tomographic Inspection. No visible circular traces of fretting could be seen on the disc, consistent with an over-tight damping system.

The opportunity was then taken to replace the Belleville tension springs and drive shaft nut and re-assemble the Starter-Generator according to the APC Overhaul Instructions. The unit was then re-tested according to the ESTS 2008/255 schedule in order for comparisons to be made. On completion of this series of tests the 150A unit was tamper sealed by the AAIU.

During the testing, the Investigation noted that the 150A Starter-Generator was fully functional in both starter and generator modes, and it also functioned within specification according to the APC 'Acceptance Test Procedure'. The Investigation also noted that no performance specifications exist for the damping system.

1.16.7 Tests on DCGU and APC 150A Starter-Generator

The engine manufacturer performed a final series of tests at their Bordes facility using more complete instrumentation than in the tests performed at Bordes in August 2007. The test was scheduled to examine the vibration and the displacement behaviour of the 41-tooth gear in operational configuration and to characterize its response with different Starter-Generators. The testing was performed on two Starter-Generators with 150A and 200A Ratings. In each case the Starter-Generator tested with the damper system correctly adjusted and then with the damping system rendered ineffective (with the drive shaft nut over tightened). The Starter-Generator units for testing were interfaced with an Arriel 1C1 engine test-bed, incorporating the DCGU from EI-IHL and a 15Ah Aircraft Battery (P/N 151CH-1). The test measured energising tension and current, generating voltage and current, and starting voltage and current.

The test measurement equipment comprised of three (Kaman) eddy-current sensors on the 41-tooth gear, one (Airpax) speed and position sensor on the Starter-Generator gear, one torque meter device on the Starter-Generator drive shaft, one 3-axis accelerometer on the Starter-Generator and vibration sensors at front and rear positions on the test engine. Suitable control and recording apparatus completed the test equipment. The test procedure measured vibration with starts using the Battery. N1 speed information was recorded with and without power extraction and application of power at stabilized speed.

Different configurations were used during the tests. The most relevant results were achieved in the configuration using an APC Starter-Generator with an over tightened damping system, representative of the accident helicopter. The test program measured the following data: in generation mode acceleration from N1 65% to N1 102% in 40 sec, deceleration from N1 102% to N1 65% in 40 sec. This acceleration/deceleration was carried out for Generator with Battery charging, a load of 80A, and a load of 160A. In generation mode for N1 ratings of 65%, 81%, 92.5%, 100% and Max N1, the engine speed rating was stabilised and the following cycle was carried out: ±30A, increase generator current to ±130A, then decrease to ±30A. For each N1 rating, measurements were made for the following loads: 17A, 34A, 85A, 150A, 85A, 34A, and 17A. Finally the Starter-Generator was run in starting mode. These start cycles were made under various conditions, with power from the test bench power circuit, from the aircraft Battery, and from a Ground Power Unit.

In electrical generation mode with excitation of the Starter-Generator by the DCGU, the tests revealed torsional oscillations when the damping system was over tightened. This test is representative of the state of the damping of the Starter-Generator in EI-IHL. The torsional oscillations were driven by the field voltage frequency of the Starter-Generator delivered by the DCGU. The torsional oscillations were at a maximum when the excitation frequency of the Starter-Generator was ranging from 50Hz and 65Hz on the 150A Starter-Generator unit from EI-IHL.

The oscillations systematically appeared for an N1 engine rating close to ground idle, N1 between 65% and 70%, and a current load of less than 40A. With high speed ratings and generator loads, above 85% N1 and greater than 2 kW, there were oscillations with an effect on the vibrations of the 41-tooth gear. When the damping system was properly adjusted, on the APC or Auxilec type Starter-Generators, these torsional oscillations were well damped. The oscillations caused, in certain cases, the disappearance of the vibration signature of the 41-tooth gear meshing order. This indicates that, during this time, the gear no longer meshes at its typical teeth passage frequency but at the frequency of the sidebands. This behaviour is termed gear flapping (**Appendix E**). With excitation of the Starter-Generator by means of the test bench equipment only, no torsional oscillation was observed, irrespective of how the damping was adjusted. Neither N1 speed rating nor tightening of the damping system produced oscillations. It should be noted that the field voltage frequency generated by the test bench (approximately 380Hz) was much higher than that delivered by the DCGU of the accident helicopter (less than 100Hz). By comparison, control units produced by APC produce PWM in the 900Hz range.

1.16.8 Additional testing

The AAIU received the results of additional testing carried out by the engine manufacturer in December 2008. In these tests, the test engine was equipped with speed and position sensors in the vicinity of the 41-tooth Bevel Gear as well as on the driving gear of the Starter-Generator. Axial deformation of the 41-tooth Bevel Gear could be measured as well as the tangential deformation of the plane driving gear. The engine was equipped with an APC-type Starter-Generator (150A and then 200A) with different damper settings. It was possible to reproduce during these tests the severe torque fluctuations observed during the earlier tests. The conditions for obtaining such torque fluctuations were unchanged, low battery load, low additional electrical load and N1 speed around 70%. With these conditions, torque fluctuations were observable and induced a dynamic deformation of the 41-tooth Bevel Gear at a frequency equal to the excitation frequency of the DCGU (electrical master box).

In the particular case where the damping device was over-tightened, the vibratory level increased significantly. The vibratory signature at order 41, which is the result of the teeth meshing, disappears. This is consistent with the abnormal teeth meshing observed during earlier testing. The observed axial deformation (between 20 and 40 µm) was at a frequency twice the excitation frequency of the DCGU. Again this is consistent with the loss of contact during teeth meshing.

In parallel, a 3D analysis model of the 41-tooth Bevel Gear was used by the engine manufacturer to evaluate the stress in the part under resonance conditions and also in the quasi-static conditions corresponding to the rotation and the teeth meshing under torque. This model was used to translate the displacement measurements obtained on the engine Bevel Gear into stress values. The Goodman diagram in **Appendix F** illustrates these values.

1.17 Organizational and Management Information

1.17.1 General

The Operator's base at the time of the accident was Trevet Airfield in County Meath. The Company was purchased by another helicopter operator based in the UK in 2002, but retained its existing operational identity and Air Operators Certificate (AOC).

The Operator was issued with AOC No. IRL 06/94 in order to conduct Commercial Air Transport Operations, having satisfied the certification requirements as prescribed in JAR-OPS and authorised under the Irish Aviation Authority (Air Operator Certificates) Order, 1999 (S.I. 420 of 1999). Under this document, the Aerospatiale AS350B was authorised for both Passenger and Cargo operations under Visual Flight Rules (VFR) by day only, with Special Approval for carriage of Dangerous Goods.

The Operator was granted an Aerial Work Permit for operation of flights for the purposes of Aerial Work Operations. This includes the raising of articles and dropping of articles, aerial application operations and training for any such purposes.

Due to the nature of operations, a Low Flying Permit was granted under the Irish Aviation Authority (Rules of the Air) Order, 2004 (S.I. 72 of 2004) (**Appendix G**). This document permitted the operation of aircraft on flights over non-congested areas for the purpose of Aerial Work operations; including the inspection of power lines, under-slung operations, aerial application for the purpose of raising and dropping of articles for forest fire fighting and for training for any such purposes. The inspection of Gas Pipelines is not specifically referred to in this document as these inspections should be carried out at such height as to ensure compliance with S.I. 72 of 2004 (Rules of the Air) Order. The minimum height for such operations is 500 ft AGL when not over congested areas. At the time of the accident, Aerial Work operations were covered in the Company's Operations Manual, Part B, Supplement 6 (Issue 5) and dated January 2006.

1.17.2 Operations Manual Part A

Part A, Section 8, of the Company's Operations Manual provides guidance concerning Minimum and Maximum Flight Altitudes:

'In accordance with JAR-OPS 3.1060, when required, the operational flight plan shall indicate safe altitudes and minimum heights, at which the flight can be conducted safely.

The minimum heights that can be flown are detailed in the relevant state's AIP (see Part A[14] Section 12 Rules of the Air para 12.2.1). The need to maintain a safe height margin above any significant terrain or obstacle en route should be considered. The minimum height flown on any operation will also to take into account the nuisance/noise level and its effect on residential areas, and in rural areas the same applies to farms and livestock, particularly stud farms and the disturbance an over-flying helicopter can have on horses.'

1.17.3 Safety Management System

In December 2007, the Operator introduced a Safety Management System. This system is designed to monitor and improve the procedures and work practices of all aspects of the company operations to ensure safety. Under this system Aerial Work operations and procedures were examined and resulted in the issue of a Flying Staff Instruction (FSI). This FSI was issued for procedural clarification of such inspections, and provide specific instructions regarding gas pipeline Inspections. Patrol speeds and heights were revised to provide increased safety margins during these operations:

'Patrols will be flown at a speed of 60-120 knots. The minimum operating heights over non congested areas shall be 700 to 1,000 feet above ground level (AGL) and over congested areas 1,500 feet AGL or 1,000 feet above the highest obstacle within a radius of 600 m from the aircraft, whichever height is the greatest.'

This FSI is now incorporated into an Aerial Work Manual, which is currently in draft form and will be introduced when approved by the IAA.

1.18 Additional Information

1.18.1 Helicopter Maintenance

The helicopter was maintained in accordance with an Approved Maintenance Programme, Ref. IAA MS 273, under approval from the Irish Aviation Authority (IAA). All Airworthiness Directives and Mandatory Modifications were carried out on the engine and airframe and entered in the appropriate technical records. All records concerning the accident helicopter were made available to the Investigation together with any additional material requested. Maintenance and related records were accurately kept by the Operator and up to date. The overhaul of components such as the Starter-Generator were carried out by an independent Overhaul facility approved for such work.

1.18.2 Normal Flight Procedures: Avoidance Zone

Section 5.1 of the AS350B1 Flight Manual (Regulatory Performance Data) provides guidance to operators regarding the Airspeed-Height Avoidance Zone (Z). Operation in the shaded areas are to be avoided (**Appendix H**).

[14] **Part A**: Reference to the Operations Manual Part A, which is issued by the Operator and approved by the IAA.

1.18.3 Emergency Flight Procedures

Section 2 of the (Operators) Operations Manual, Part B, deals with Emergency Procedures and drills relating to the AS350. An engine failure in forward flight is identified by the following indications: a yaw to the right, loss of engine noise, Ng (gas generator rotation speed) and Nr (rotor speed) decrease, the low rotor speed horn sounds. The Generator (GEN) and Engine Oil Pressure (ENG P) lights illuminate on the warning-caution-advisory panel. The Aural warning horn sounds when rotor speed is between 250 and 360 RPM. An autorotation following an engine failure is carried out as follows:

- Initially set low collective pitch, monitor and control the rotor RPM
- Establish approximately 65 kts (120 km/hr) airspeed
- Move the fuel control to the shutdown position
- According to the cause of the loss of the engine, attempt a re-light; otherwise, close the fuel shut-off valve
- Switch off: the booster pump, the generator (or alternator if installed) and the electrical power master switch (if there is a smell of burning)
- Manoeuvre to head the helicopter into the wind in final approach, at a height of 20-25 feet (6-8 metres) and at a constant attitude
- Gradually apply collective pitch to reduce the sink rate
- Resume level attitude before touchdown, and cancel any sideslip tendency, and
- Gently reduce collective pitch after touchdown

1.18.4 41-tooth Bevel Gear disintegration

1.18.4.1 General

From entry into service to the end of 2007 Arriel 1 and 2 engines worldwide had accumulated a total of approximately 26 million flight hours. During this time a total of nine failures of the 41-tooth Bevel Gear resulting in an unscheduled in-flight shutdown, or failed starting, have been reported by the engine manufacturer. Note that Arriel engines are fitted to a wide range of single and twin-engine helicopters.

1.18.4.2 Failures due to assembly discrepancies

A total of five events were attributed to assembly discrepancies of the Accessory Drive Gearbox. These events occurred between November 1997 and December 2003. In all these cases the failure occurred with a relatively short operating period after manufacture or overhaul. New procedures and revised practices were put in place by the engine manufacturer to prevent a re-occurrence of these incidents.

November 1997:
Incident to Arriel 1B (S/N 750) resulting in an in-flight shutdown. The engine had accumulated 1,760 hrs since new, and **51 hrs since last overhaul**. Investigation revealed rework during overhaul, which modified in error the depth of a case housing.

October 1998:
Incident to Arriel 1D1 (S/N 9201) resulting in an in-flight shutdown. The engine had accumulated 2,777 hrs since new, and **30 hrs since last overhaul**. Investigation revealed an error with the reading of a value engraved on a part.

January 1999:
Incident to Arriel 1C2 (S/N 12286) where the component failed during starting. The engine had accumulated **38 hrs since new**. Investigation revealed a measurement error during assembly.

January 2001:
Incident to Arriel 1M (S/N 6052) resulting in an in-flight shutdown on a twin-engine SA365N Dauphin helicopter. The engine had accumulated 2,956 hrs since new, and **19 hrs since repair**. Investigation revealed incorrect washer sizes installed during repair, the assembly clearance was in conformity with specifications.

December 2003:
Incident to Arriel 2 (S/N 20572) resulting in an in-flight shutdown. The engine had 2,186 hrs since new, and **123 hrs since last overhaul** on Module M01. Investigation revealed washers were inverted during overhaul assembly.

1.18.4.3 Failures due to fatigue or under investigation

Of the remaining four failures, two were attributed to fatigue of the 41-tooth Bevel Gear. The two further instances are this accident to EI-IHL, and the subsequent incident in Canada, which is currently under separate investigation.

March 2001:
Incident to Arriel 1D1 (S/N 9600) resulting in an in-flight shutdown. The engine had accumulated **1,023 hrs since new**. Investigation revealed disintegration of the 41-tooth Bevel Gear due to vibratory fatigue. Assembly and tolerances of the Accessory Drive components were correct.

October 2005:
Incident to Arriel 2S1 (S/N 20542) resulting in an in-flight shutdown on a twin-engine Sikorsky S76 helicopter. The engine had accumulated **2,393 hrs since new, and 79 hrs since repair**. Investigation revealed disintegration of the 41-tooth Bevel Gear due to vibratory fatigue. Assembly and tolerances of the Accessory Drive components were correct.

July 2007:
Accident to Arriel 1D (S/N 7035) resulting in an in-flight shutdown. The engine had accumulated **6,224 hrs since new, and 992 hrs since repair**. This is the Accident to EI-IHL, and the subject of this Investigation. Assembly and tolerances of the Accessory Drive components were correct.

November 2007:
Incident to Arriel 2B1 (S/N 22360) resulting in an in-flight shutdown. Engine had accumulated **1,644 hrs since new**. This incident is under separate investigation by TSB Canada.

Examination of these four events reveals that all engines were equipped with APC type Starter-Generators. The Investigation notes that in the March 2001 incident the Starter-Generator damping was misadjusted by being too loose. Regarding the October 2005 incident, it was not possible to determine the serviceability of the Starter-Generator unit as it was removed post incident, overhauled, and returned to service. In the remaining two events, July and November 2007, the Starter-Generator damping was misadjusted by being over tightened, locking up the friction plate. Note that in three of the above cases the Starter-Generator units were not providing proper damping.

1.18.5 Overhaul of APC Starter-Generators

The servicing of APC Starter-Generators was undertaken by various service centres prior to the takeover of that company in 2005. Since that time, only two Authorised Service Centres exist, one at Holtsville in the USA, and the other in Italy. The overhaul procedure for APC type Starter-Generators has been observed to result in inadvertent over-tightening of the damping system. During overhaul of a Starter-Generator all worn or damaged parts are replaced, except where a repair procedure is given. All brushes must be replaced at each overhaul and must be run-in for proper seating. The ball-bearings, damper springs friction plate and drive shaft nut must also be replaced at overhaul.

The overhaul procedure describes the method of assembling and adjusting the damper system: *'Position the fan and spring retainer on back end of the drive shaft. Install two each new Bellville tension springs* (**Figure No. 4**). *With a suitable holding tool, hold drive shaft and install drive shaft nut, and gently tighten until the drive shaft nut and springs bottom gently against fan. Then, back off the drive shaft nut, 3/4 of a turn. Drive shaft should be tight against the damper plate*.'

A Service Letter #134 was issued by APC with regard to drive shaft alignment on 14 April 1999 and revised on 20 September 2004. It states: '*The drive shaft must stay aligned with and concentric to the armature. The drive shaft may be pushed off centre and out of position due to mishandling during shipping or during installation. If the starter-generator is allowed to be installed with the drive shaft out of position, excessive vibration and damage may develop during operation.*'

The document makes clear that before installation of the starter-generator on an engine, the drive shaft and damper plate must be inspected. '*Should the plate be out of position, the letter advises to lightly tap on the drive shaft spline, using a plastic mallet to move it back into full concentric position. The starter-generator should be installed or removed in accordance with procedures as outlined in Service Bulletin SB150SG114'*.

1.18.6 Modification of the 41-tooth Bevel Gear

In July 2008, the engine manufacturer issued Service Bulletin No. 292 72 0325 concerning Module M01 of the Arriel 1. The subject of this bulletin was to incorporate modification TU 325 which consists of the replacement of the 41-tooth Bevel Gear by a modified part. The modified part has a thickened gear web by 1mm (from 2.5 mm to 3.5 mm) to make the gear more resistant to dynamic stresses caused by high levels of power on the generator. The rim thickness is increased very slightly by 0.25mm (from 4 mm to 4.25 mm). Blending radiuses change from 2 mm to 3 or 3.5 mm. The technical information contained in the Service Bulletin was approved under the EASA design organisation Approval No. EASA.21J.070. A separate Service Bulletin (No. 292 72 2090) was issued to cover modification of the Arriel 2 by incorporation of TU 90. Reference should be made to the above Service Bulletin's for application conditions. At the current time the engine manufacturer can only confirm, '*that the new design is at least as robust as the current design relative to abnormal vibrations solicitation*.'

The engine manufacturer has also issued Service Letters No. 2666/08/ARRIEL1/100 and 2699/ARRIEL2/32 dated 18 December 2008. These Service Letters concern the in-flight shutdowns experienced as a result of the failure of the 41-tooth Bevel Gear in the accessory gearbox. The letter comments that the analysis of various tests conducted reveal that where the '*starter-generator dampening system is completely ineffective, the fatigue damage limit of the 41-tooth (bevel) gear can be reached in certain conditions of use on the AS350 helicopter'*. It points out that a '*minimum exposure time in these use conditions is required in order to provoke damage likely to result in the rupture of the 41-tooth gear.'*

1.19 Useful or Effective Investigation Techniques

The use of Tomography was utilised in the non-destructive examination of the Starter-Generator damping system.

A 3D analysis model of the 41-tooth Bevel Gear was used by the engine manufacturer to evaluate the stress in the part. This model was used to translate the displacement measurements obtained on the engine Bevel Gear into stress values.

2. ANALYSIS

2.1 General

The helicopter was engaged on a routine safety inspection of gas pipelines which are routed underground. This inspection, which is carried out under contract, requires the terrain where gas pipelines are laid, to be inspected on a two-weekly basis. This is to ensure that no unauthorised activity such as digging or excavation is taking place in the vicinity of the pipelines, which would adversely affect the safety or security of the gas pipeline.

Authorised activity such as work by the Gas Supplier is made obvious to the aerial inspection crew by means of markings visible from the air. The inspections are carried out by the Operator using a single-engine helicopter with a two-person crew, a pilot occupying the right seat and an observer occupying the left seat. As the gas network covers the entire country, a series of pre-planned routes are flown each day in order to complete the network coverage in a specified period.

Inspections are usually carried out between 800 and 1,000 feet AGL as the crew are simply observing surface activity over the pipeline route. Should unauthorised activity be observed, the crew have permission to set down the helicopter within a way leave area along the route to ensure the safety of the pipeline. This immediate landing is necessary as the gas line is generally close to the surface and any inappropriate activity observed requires prompt action by the crew. In the vicinity of Lisheen the crew descended to inspect earthworks along the main road, which were in close proximity to the gas pipeline.

2.2 Descent at Lisheen

A descent was made in the vicinity of Lisheen to a height of 400 ft AMSL. It is probable the crew identified activity taking place on the surface that required closer inspection. However, no landing was required and radar returns show the helicopter completing the inspection turn and following the pipeline onwards in the direction of Ballynacally maintaining an altitude of 400 ft.

2.3 Engine Failure

The engine failure occurred as the helicopter was approaching the village of Ballynacally from the northeast. Radar returns confirm that the helicopter was at 400 ft AMSL and cruising at 96 kts ground speed enroute to the Ballynacally area. The final recorded radar return indicates an altitude of 200 ft descending, with a ground speed of 92 kts. It is likely therefore, that the engine failure occurred in the cruise at 400 ft AMSL and at a groundspeed of 96 kts.

Where an engine suffers an uncontained failure[15] it is normally accompanied by a very loud bang, often with smoke entering the cockpit area, through the heating system ducts. However, the engine failure suffered by EI-IHL was contained, and in simplistic terms by fuel not being supplied to the engine as the FCU was no longer being driven. Therefore the nature of the engine failure was such that it would have been very sudden and without any pre-warning whatsoever. The Pilot reported that his first indication of any problem was an observation of a red warning light on the 'Warning-Caution-Advisory Panel'. This was followed by the activation of the low rotor RPM Aural Warning Horn, indicating that rotor RPM was decaying from its normal operating speed of 390 RPM and was decreasing through 360 RPM.

[15] **Uncontained engine failure**: Failure is such that internal components of the engine are expelled out through the tailpipe or the engine casing itself.

As the Pilot reduced collective, he reported experiencing a significant pitching moment (**Section 2.5**) and felt that he may have had a controllability problem with the helicopter. The Pilot reduced the collective fully and attempted to carry out an into-wind autorotation into a field. As the helicopter descended, the flight path led into rising ground (150 AMSL), containing obstacles such as stone walls, tree-lined hedgerows, fence-posts and undulating terrain.

During the final stage of the descent the Pilot was confronted with a stone wall in his immediate flight path. The Pilot stated that he made a turn of approximately '*20 degrees to the right*' in order to avoid the wall. In any event the helicopter impacted heavily, skids level, into the middle of a small field with gentle rising ground and had sufficient momentum to continue towards and through the tree-lined hedgerow and out into the adjacent field. The energy of the impact sequence was such to expel both occupants from their seats in the cockpit. The Observer was pronounced dead at the scene and the pilot suffered serious impact injuries (**Section 2.7**).

2.4 41-tooth Bevel Gear

Early experience with un-damped Starter-Generators (not the type installed in EI-IHL) resulted in some failures of an accessory drive component (not the 41-tooth Bevel Gear). It is noteworthy that when these Starter-Generator units were adequately damped no more instances of failure were evident.

Tests confirm the accessory drive gears, bearings and accessory drive casings on EI-IHL were assembled according to specifications. No metallurgical abnormalities were apparent in the accessory drive gears. The Macrographic core hardness (HV_{30}) was measured on average at 432 HV. The 41-tooth Bevel gear was manufactured in 2002. Since that date, the 16NCD13 material specification has evolved and the maximum mechanical strength has changed from 1380 MPa to 1430 MPa. Thus the specification ST02603 (Carburizing depth and Hardness) has been amended accordingly and is used for present parts production. This Macrographic core hardness value of 432 corresponds to a mechanical strength of about 1407 Mpa, which is within the current specification.

The carburising depth is slightly greater than the depth specified on the drawing (the 41-tooth Bevel-Gear design drawing indicates a carburising depth between 0.25 and 0.40 mm). The specification allows an additional 0.15 mm for machining reserve, so the maximum carburizing depth becomes 0.55 mm. Considering this, the Microhardness of the carburised layer, (Hardness filitation: $HV_{0.5}$) 550 $HV_{0.5,}$ as measured on the bottom land, is within the specification. The carburizing depth on the tooth flanks however is 0.08 greater than the value specified, while slightly higher than the specification, this was not significant as the crack was shown to have initiated in the tooth bottom land.

Laboratory examination revealed the primary fracture in the 41-tooth Bevel Gear to be fatigue in nature and was propagated during the start cycles of the engine. A series of failures of the 41-tooth gear between 1997 and 2003 were investigated at the time.

These Investigations attributed the failures to incorrect assembly of various components either during manufacture or during scheduled overhaul of the engine module. New procedures and revised practices were put in place by the engine manufacturer to prevent a re-occurrence of these incidents.

2.4.1 Starter-Generator

Examination of the Starter-Generator of EI-IHL by means of Tomography revealed the friction disc to be substantially offset and damaged. This offset was as a result of the disintegration of the friction disc centre probably due to incorrect assembly during overhaul. It was also noted that the drive shaft nut of the damping system was over-tightened, resulting in no effective damping of the Starter-Generator unit during operation. The Overhaul Manual describes a procedure of tightening the drive shaft nut that is difficult to achieve in practice. The instructions require the drive shaft nut to be tightened until the Belleville springs bottom against the fan, then the drive shaft nut must be released by 3/4 of a turn. As it is only possible to see the outermost Belleville spring end-on, this adjustment of the Belleville springs is somewhat imprecise and could lead to mis-adjustment during overhaul. At the current time, only two service centres are approved to carry out this overhaul procedure. These service centres guarantee correct adjustment of the drive shaft nut and according to the overhaul specification.

Prior to the original manufacturer being taken over, APC generators were overhauled at many service centres, some of which were not approved by the manufacturer. Restricting overhaul approval to only two service centres improves the quality assurance of the overhaul and safety in subsequent operation. There is however the problem of checking the serviceability of those units in the field; whether installed in helicopters or held in the component supply chain. The Investigation is of the opinion that the airframe manufacturer should take appropriate action to ensure that APC-type Starter-Generators in service, or intended for service, on AS350 series helicopters have been correctly overhauled.

Laboratory tests indicate the 41-tooth Bevel Gear failed due to vibratory fatigue. In electrical generation mode, with excitation of the Starter-Generator by the DCGU, the tests revealed torsional oscillations were evident when the damping system was over-tightened. The tests were representative of the state of the damping of the Starter-Generator in EI-IHL. The torsional oscillations were driven by the field voltage frequency of the Starter-Generator delivered by the DCGU. The torsional oscillations were at a maximum when the excitation frequency of the Starter-Generator was ranging from 50Hz and 65Hz on the 150A Starter-Generator unit from EI-IHL. The oscillations systematically appeared for an N1 engine rating close to ground idle (N1 between 65% and 70%) and a current load of less than 40A. With high speed ratings and generator loads (above 85% N1 and greater than 2 kW) there were oscillations, which effected the vibration of the 41-tooth gear. Where the damping system was properly adjusted, with APC or Auxilec type Starter-Generators, these oscillations were well damped.

The fatigue failures of the 41-tooth Bevel Gear have a strong parallel with the early accessory drive failure experiences with un-damped Auxilec-type Starter-Generators. Although the early Starter-Generators were of a different type, and the failed component was not the 41-tooth Bevel Gear, it is evident that inadequate damping is of significance. Testing indicates that inadequate damping by the Starter-Generator has a detrimental effect on the fatigue life of components of the accessory drive, when considering the oscillations of the DCGU observed under test.

The frequency which the DCGU operates is of some significance. Control units manufactured by APC produce PWM in the 900 Hz range. The ECE unit that was fitted in EI-IHL produced less than 100 Hz. The torsional oscillations were observed at a maximum when the field was excited near 60 Hz, and were not evident during testing when using the Bench test equipment which operates at 380 Hz. The testing and suitability of equipment not fitted to the accident helicopter is outside the scope of the investigation. The suitability of the installed equipment is a matter to be considered by the manufacturer.

2.4.2 Modification of the 41-tooth Bevel Gear

In July 2008, the engine manufacturer issued Service Bulletins No. 292 72 0325 and 292 72 2090 concerning modification to the Arriel 1 and 2 engines respectively. This modification incorporates a thickening of the web of the 41-tooth Bevel Gear in Module M01. The modification is designed to make the gear more resistant to dynamic stresses caused by high levels of power on the generator. According to the engine manufacturer, this modification does not provide a corrective solution to the last two occurrences of the 41-tooth Bevel Gear failure. At this stage, the engine manufacturer can only confirm that the new design is at least as robust as the current design relative to abnormal vibration solitations.

Tests reveal the DCGU fitted to EI-IHL, when electrically coupled with a Starter-Generator with an over tightened damping system, produced torsional oscillations corresponding to the excitation voltage of the DCGU when connected to a test engine and operated at speeds of N1 65-70%.

2.5 Observed Pitching Moment

After activation of the Aural Warning Horn, the Pilot reported the helicopter pitching slowly by 15-20 degrees. The right-forward engine support beam was found fractured and separated. The two sections of the component were subjected to analysis by an independent laboratory. The fractures were indicative of single overload failure, with no indication of any pre-existing fracture or defect in the component. Consequently, the A-frame fracture occurred during the impact sequence and could not have contributed to the pitching moment described by the Pilot. Activation of the Aural Warning Horn occurs when the rotor RPM drops below 360 RPM from its normal operating speed of 390 RPM[16].

[16] **Aural Warning Horn**: as well as low RPM, activation of the Aural Warning Horn can also occur on the AS350 should the hydraulic pressure drop below 30 bars.

As the rotor RPM decays, their will be a loss of lift. As the rotor RPM continues to decay, the rotor blade disc will progressively lose its rigidity, with the possibility of the blades striking the helicopter structure. It is not practical or safe for pilots to operate a helicopter at any time in this flight regime. However, the experience of test pilots has shown that, with low rotor RPM, oscillations can build up in the rotor head and reduce the effectiveness of the cyclic control in the longitudinal axis. Lowering the collective control decreases the pitch of the main rotor blades and increases the rotor speed.

The behaviour of a helicopter following an actual engine failure can be quite different to that experienced by a Pilot during planned engine-on autorotation training. The energy and speed of the rotor will decay much more quickly, therefore a pilot's required reaction to an actual engine failure, of lowering the collective to zero in order to stop rotor speed decay, must be virtually instantaneous. In this case, as the lowering of the collective was not carried out instantaneously on the failure of the engine, it is probable that the rotor RPM began to decay such that the effectiveness of the cyclic control was reduced, as indicated by the pitching moment experienced by the Pilot.

2.6 Fuel Tests

Trace amounts of water and/or sediment can be present in fuel and will not have an appreciable effect on the operation of the engine. The small quantity of contamination found by independent analysis did not have any bearing on the engine failure.

2.7 Survivability

2.7.1 General

On balance, the accident would be considered to have a low probability of survival. The helicopter first impacted the surface in a level attitude with significant forward velocity. This was followed by rapid deceleration and break up of the forward cockpit section after impact with the tree-lined hedgerow. The main wreckage continued into the adjoining field under significant rotational force. At this point the two forward seats failed under lateral shear load (in excess of the design limit of 3g) resulting in the occupants being thrown from the helicopter. Failure of the seat bases rendered the harness restraint system ineffective. Survivability must therefore be considered from two aspects; the operating height of the helicopter at the time of the failure, and the failure of the seating during the impact sequence.

2.7.2 Operating Altitude/Height

The helicopter was identified on radar entering the general Shannon area at an operating height of 700 ft AMSL. It was then observed descending down to 400 ft in the Lisheen area, it completed a 360-degree ground inspection turn and then continued onwards (south-south west) along the pipeline maintaining 400 ft. As the helicopter flew towards Ballynacally, the terrain height increased, in general, from sea level to 150 ft AMSL.

At an operating altitude of 400 ft, the helicopter height above the ground would have varied from 400 to 250 ft. In the general area of Ballynacally, where the engine failure occurred, the available height above ground would have been in the region of 250 to 300 ft. The ground speed of 96 kts at time of failure puts the helicopter outside of the Airspeed-Height Avoidance Zone. However, the height at which the helicopter was operating just prior to the engine failure resulted in minimal time being available for the Pilot to plan and execute a successful stable autorotation.

The nature of the engine failure was such that the Pilot had no warning of the impending failure, and with limited ground clearance (height) available, had little time to react to a serious situation. It is noteworthy that the helicopter was recorded on Radar descending through 200 ft at 102 kts IAS. This indicates that the helicopter had not decelerated to the recognised autorotation speed of 65 kts IAS. In addition, examination of the accident site reveals that the helicopter impacted skids level, with a significant forward airspeed. The Investigation is therefore of the opinion that the combination of a sudden engine failure without warning, the operating height of the helicopter at time of failure, and the difficult terrain in which the helicopter was flying over, all contributed to a very difficult scenario and would have resulted in the Pilot having very little time to assess the failure and enter into a stable autorotation.

2.7.3 Seating

The front occupants were secured by means of a four-point harness. Two lap straps were anchored to the floor of the helicopter by attachment rings and were fastened across the lap by means of a multi-point buckle. In addition, two shoulder straps were fed from an inertia reel assembly attached to the lower rear of each seat. The attachment of the inertia reel to the rear base of each seat may have contributed to the seat failure by virtue of the lateral loading being applied directly to the seat structure itself.

The manufacturer has worked on improvements to the seat installation since introduction of the type, and has issued recommended modifications regarding these seats. One such modification, Service Bulletin 25.00.24 was incorporated on the left (Observers) seat in 1997. The purpose of this modification was to avoid the possible formation of cracks between the backrest and seat pan, and to improve the seat attachment points. While this modification strengthened the basic seat structure, it was not sufficient to prevent failure considering the lateral forces experienced during the impact sequence. Additional modification options outlined in the Manufacturer’s Service Letter dated 24 November 1999 were not installed on EI-IHL. The Investigation is of the opinion that modification of the basic seats in accordance with this Service Letter should be Mandatory for Operators to provide a greater level of protection of the occupants. Although the seats were in conformity with FAR 27.561 (Amendment 10) at the time of the accident, there is no obligation for the AS350 series of helicopters to meet the more stringent current requirements as set out in the EASA specification CS-27 (Amendment 2) 17 November 2008.

2.8 Aerial Work Operations

The Operator is also engaged in the inspection of electrical power-lines. These type of inspections can involve the crew flying much lower than on gas pipeline inspections and require the Operator to possess a Low Flying Permit under the Rules of the Air Order, 2004.

Under this Permit, the helicopter may descend to specified minimum heights (measured above ground level), the height depending on the power rating of the lines being inspected. Flights under the Low Flight Permit may be conducted to heights as low as 50 ft for inspection of 38kV Power Lines and the fighting of Forest Fires over the area of operation. Paragraph 2 of the Low Flight Permit stipulates that '*Flights made pursuant to this Permission must be conducted over non-congested areas and in the event of a power unit failure at any time, the aircraft can alight without hazard to persons or property on the surface.*'

Low-level Aerial Work operations can by their very nature, be considered hazardous during specific phases of flight. With little height/time available to establish an autorotation and conduct a safe landing, the operation must be conducted, where possible, with regard to the Airspeed-Height Avoidance Zone. This requires the helicopter to be operated in excess of 500 ft AGL, or if below this height, at such a speed to allow entry into autorotation or alight without hazard. It is not always possible to remain outside of the Airspeed-Height Avoidance Zone in a single-engine helicopter. This is particularly so during take-off or landing phase and as such careful planning is required to ensure that, if a failure does occur at a critical time, that there is sufficient clear space to carry out a forced landing. Exposure to risks increases when prolonged low-level aerial work is conducted using single-engine helicopters. This exposure can be virtually negated by the use of twin-engine helicopters.

While the IAA accepts that single-engine helicopters can be used for low-level electrical power-line inspections the Investigation found that other National Aviation Authorities require the use of two-engine helicopters for such work.

The Safety Management System introduced by the Operator in December 2007 examined procedures relating to Aerial Work operations. It was felt that some clarification was required in this area, and to improve the procedures an Aerial Work Manual was drafted and submitted to the IAA in April 2008 for approval. Until that approval was sought a Flying Staff Instruction was issued in January 2008 regarding these operations. At the time of the accident some aerial work operations were carried out under a low-flying permit. Because the Gas Pipe Inspections are best carried out at approximately 800 feet, they were not stipulated on the low flying permit. Minimum heights for the Gas Line patrols were therefore governed by the Rules of the Air (500 ft AGL over non congested areas). The revised procedure provides an additional safety margin by restricting minimum height to 700 feet (over non congested areas), together with a speed range to cater for the operational avoidance zone.

3. CONCLUSIONS

(a) Findings

1. The Pilot was properly licensed.

2. The aircraft was properly registered in the State.

3. The helicopter had a valid Certificate of Airworthiness at the time of the accident.

4. The helicopter was properly maintained in accordance with an Approved Maintenance Programme.

5. The helicopter was engaged in a routine inspection of Gas Pipelines under contract.

6. The helicopter descended from its normal operating altitude to a height of 400 ft for a closer inspection of roadworks in the vicinity of the gas pipeline.

7. Radar returns indicate that, following this inspection the helicopter continued along the pipeline route to the southwest at an altitude of 400 ft AMSL.

8. As the helicopter flew towards rising terrain in the Ballynacally area (at approximately 250 ft AGL) the Pilot experienced a sudden and complete loss of engine power.

9. The height at which the helicopter was operating at the time of the engine failure was not sufficient to establish and enter a stable autorotation.

10. Following an attempted autorotation, the helicopter initially impacted heavily into an open field, then continued forward through a tree-lined hedgerow before finally coming to rest in an adjacent field.

11. The helicopter's forward cockpit area disintegrated as a result of impact with trees, with both occupants being thrown from the helicopter during the impact sequence. The Observer was fatally injured and was pronounced dead at the scene. The Pilot suffered serious impact injuries.

12. Examination of the engine accessory drive revealed that the 41-tooth Bevel Gear disintegrated as a result of fatigue.

13. Disintegration of the 41-tooth Bevel Gear resulted in the failure of the drive to the Fuel Control Unit, resulting in a loss of the fuel supply to the engine.

14. The Matched Gear Assembly (which comprises the 17-tooth and 41-tooth Assembled gears) and the 23-tooth gear were correctly assembled within the tolerance specified by the manufacturer.

15. The Macrographic core hardness of the 41-tooth gear (HV_{30}) was measured on average at 432 HV. This corresponds to a mechanical strength of about 1407 MPa which is within the current specification ST02603.

16. The Microhardness of the carburised layer, (Hardness filitation: $HV_{0.5}$) 550 $HV_{0.5,}$ as measured on the 41-tooth gear bottom land, was within Specification ST02603. The carburizing depth on the tooth flanks was however 0.08 greater than the value specified, and while slightly higher than the specification, was not significant as the crack was shown to have initiated in the tooth bottom land.

17. The Starter-Generator installed on EI-IHL was found to have a significant offset and internal damage to its friction plate. In addition, the drive shaft nut was found to be over-tightened resulting in no effective damping of the Starter-Generator unit during operation.

18. In electrical generation mode with excitation of the Starter-Generator by the DCGU, tests revealed the presence of torsional oscillations at the DCGU frequency. With the damping system over-tightened, and operating at N1 speed around 70% with low Battery and low additional electrical load, a severe torque was found oscillating with change of sign, leading to alternate shocks and loss of contact between the tooth flanks of the 41-tooth Bevel Gear.

19. The Starter-Generator installed on EI-IHL had no effective damping. Tests indicate that when the drive shaft nut of the Starter-Generator was tightened correctly, the oscillations produced by the DCGU were well damped.

20. These oscillations, observed under test conditions, probably account for the fatigue failure of the 41-tooth Bevel Gear.

21. The engine manufacturer has issued Service Bulletins No. 292 72 0325 and 292 72 2090 concerning modification to the Arriel 1 and 2 engines respectively. This modification incorporates a thickening of the web of the 41-tooth Bevel Gear in Module M01. The modification is designed to make the gear more resistant to dynamic stresses caused by high levels of power on the generator.

22. The engine manufacturer has also issued Service Letters No. 2666/08/ARRIEL1/100 and 2699/ARRIEL2/32 dated 18 December 2008. These Service Letters concern the in-flight shutdowns experienced as a result of the failure of the 41-tooth Bevel Gear in the accessory gearbox.

23. The overhaul procedure for APC type Starter-Generators is not sufficiently definitive, and could, in some instances, have resulted in over-tightening of the damping system during overhaul or maintenance.

24. Up to 2006, APC type Starter-Generators were overhauled at a number of service centres, some of which were not approved by the manufacturer. It is possible that some of these Starter-Generators were incorrectly adjusted during overhaul and are currently in service or in the component supply chain.

25. The occupied crew seats were subject to lateral forces exceeding their ultimate load factor during the impact.

26. A recommended modification (Service Bulletin SB 25.00.24) was carried out on the left forward crew seat on airframe S/N 1963 during 1997.

27. The AS350 was certified in accordance with the Airworthiness Requirements of FAR Part 27, Amendments 1-10.

28. Operation below those heights specified in the Rules of the Air are permitted by means of a Low Flight Permit held by the Operator, but this permit did not specify gas pipeline inspections under the Schedule of Operations covered.

29. The nature of Gas and Power Line inspections can involve single-engine helicopters, from time to time, being operated over terrain and obstacles at heights not conducive to establishing a stable autorotation in the event of an engine failure.

30. The pitching moment observed by the Pilot was probably due to decaying rotor RPM. Under these conditions, oscillations can build up in the rotor head and reduce the effectiveness of the cyclic control in the longitudinal axis.

(b) Probable Cause

The engine failure was caused by a loss of fuel supply from the FCU. The drive to the FCU ceased as a result of the disintegration of the 41-tooth Bevel Gear in the accessory drive due to fatigue. This fatigue was probably caused by inadequate damping (by the Starter-Generator) of oscillations produced by the DCGU.

(c) Contributory Factors

1. The height at which the helicopter was operating was not sufficient to establish a stable autorotation when the engine failure was recognised.

2. The nature of the terrain in the area.

4. SAFETY RECOMMENDATIONS

It is recommended that:

1. EASA and Eurocopter take appropriate action to verify that APC-type Starter-Generators used on the Arriel 1 and 2 engines, installed in AS350 series helicopters, and also those in the component supply chain, have been correctly overhauled. **(SR 03 of 2009)**

   In response to this Safety Recommendation:

   Eurocopter has issued an Alert Service Bulletin No. 80.00.08 Rev. 0 dated 19 December 2008, applicable to AS350 series helicopters equipped with APC 150SG and 200SGL type Starter-Generators.

   Eurocopter has issued an Alert Service Bulletin No. 80A003 Rev. 0 dated 19 December 2008, applicable to EC130 series helicopters equipped with APC 150SG and 200SGL type Starter-Generators.

   EASA has issued Airworthiness Directive No. 2009-0004 dated 12 January 2009. This AD is applicable to all AS350 and EC 130 series helicopters if equipped with APC 150SG and 200SGL type Starter-Generators.

2. EASA issue an Airworthiness Directive to all operators of AS350 series helicopters for a mandatory modification of original seats as described in Service Bulletin SB25.00.63 (or optionally SB25.00.57) as outlined in the Manufacturer's Service Letter 1424-25-99 dated 24 November 1999. **(SR 04 of 2009)**

3. The Federal Aviation Administration (FAA) request Unison Industries LLC to revise the overhaul procedures of APC designed and manufactured Starter-Generators to ensure that the drive shaft nut is correctly adjusted and adequate damping consistently achieved. **(SR 05 of 2009)**

4. EASA review the suitability of single-engine helicopters engaged in Low Level Aerial Work operations. **(SR 06 of 2009)**

   (Note: Interim Safety Recommendation **SR 13 of 2007,** which was directed to the IAA, has been withdrawn).

Appendix A

Flight path and gas pipeline route

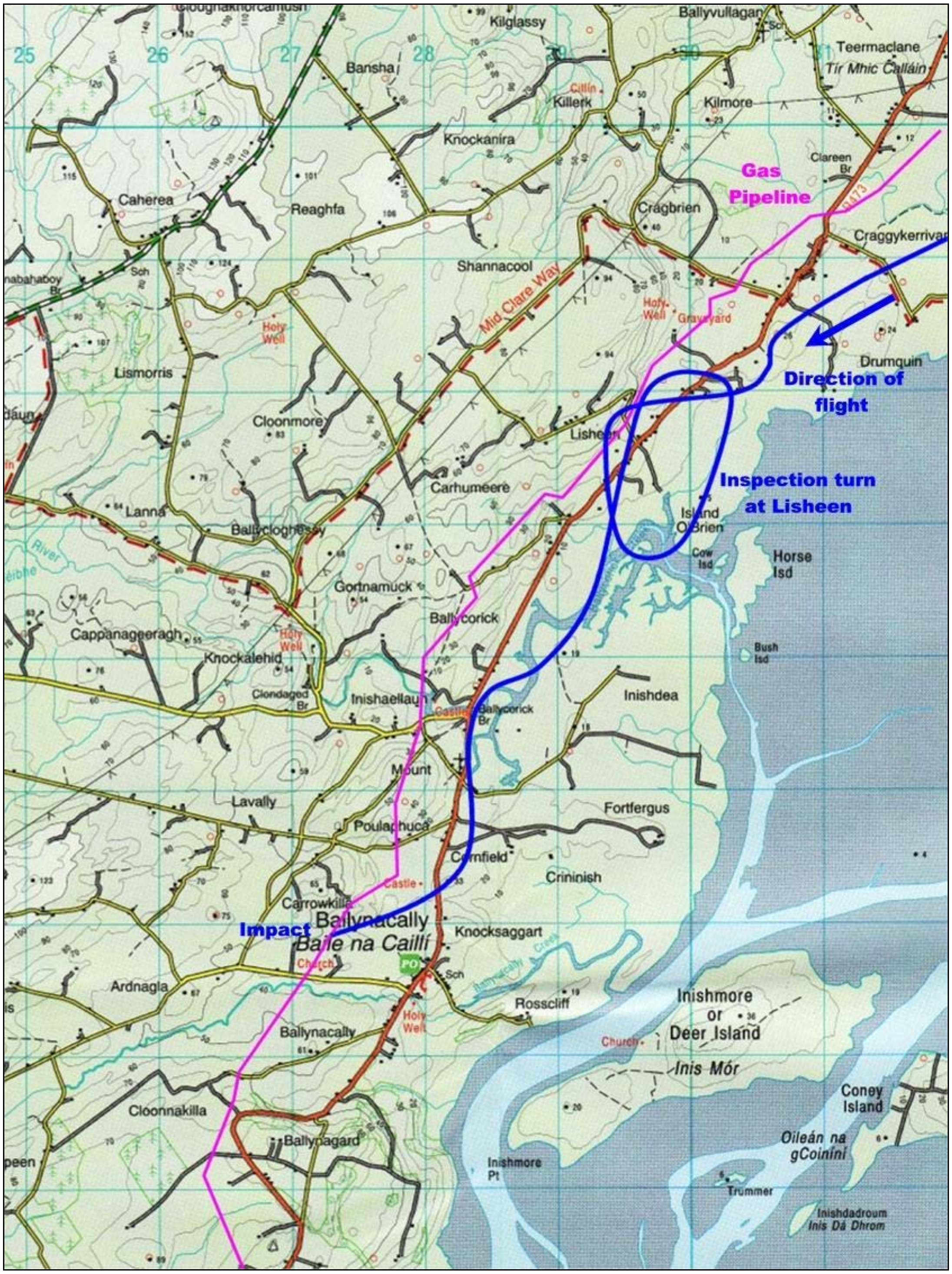

Figure A5: Flight Path and gas pipeline route
(based on *Ordnance Survey of Ireland 1:50 000*)

Appendix B

Impact sequence and wreckage

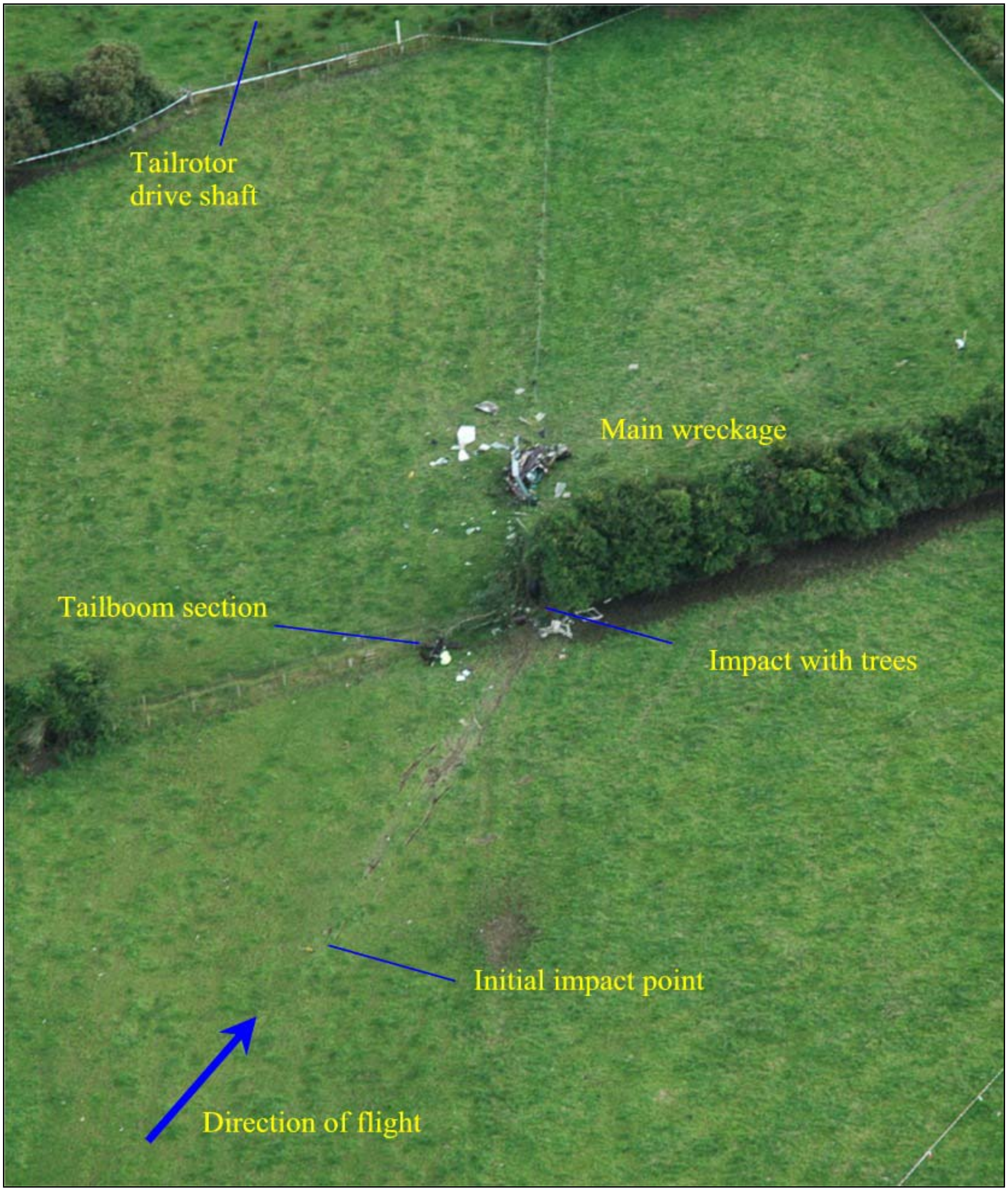

Photo B3: Aerial view of impact point and wreckage (*GASU Photo*)

Appendix C

Laboratory examination of accessory drive components

Parts:	**Matched gear assembly** (0 292 10 795 0)		
P/N:	**Assembled gears:** **41-tooth gear** (bevel teeth) 0 292 10 276 0	**17-tooth gear** (straight teeth) 0 292 10 195 0	**23-tooth gear** (bevel teeth) 0 292 10 275 0
Engine S/N:	7035		
Operation hours:	992		
Markings:	0 292 10 276 0 09/F9009 M/N442B N=35.90 H6264	8/H2121	0 292 10 275 35/F9951 M/N442B M=35.06 JF=0.05
Material:	Carburized 16NiCrMo13 Steel		

Table C2: Identification of matched gear assembly components

Components from Module M01 comprising the 41-tooth Bevel Gear fragments, hub, together with setting washers and bearings were sent for detailed laboratory analysis. Examination of the parts evidenced that the fracture of the 41-tooth gear toothed ring was caused by fatigue cracking initiated in two distinct origin areas: (1) a crack initiated on the tooth space bottom land, small-diameter side, and propagated radially outwards through the rim, and (2) a crack initiated in the fillet radius between the hub and the web and propagated through the web thickness initially and then circumferentially. No metallurgical nonconformity was found on the 41-tooth Bevel Gear components. The condition of the surfaces shows satisfactory tribological behaviour, satisfactory bearing surface on the tooth flanks and the absence of notable wear. The root cause of the fracture and the order in which the two cracks appeared could not be clearly determined at this stage. Crack No.1 propagated in the same direction as the starting loads and crack No.2 is typical of a vibratory fatigue phenomenon on the web.

Examination of parts

Module M01

41-tooth Bevel Gear (P/N 0 292 10 276 0):
Three types of damage were observed, a fracture on tooth space bottom land that initiated on the small-diameter side of the web. Initiation of cracks on almost all the tooth space bottom lands, again on the small-diameter side. There was also heavy peening of several tooth tips (over a sector of about 180º) probably due to the final overlapping of the teeth on each other after gear meshing was lost.

17-tooth straight gear (P/N 0 292 10 195 0):
The absence of significant wear was noted on the tooth flanks.

23-tooth Bevel Gear (P/N 0 292 10 275 0):
Heavy peening was noted on all the tooth tips, probably due to final overlapping of the teeth on each other.

37-tooth 'Breather' drive gear (P/N 0 292 10 835 0):
Impact marks were noted on the web and the tooth flank edges resulting from the destruction of the 41-tooth Bevel Gear, (impact marks located on the 41-tooth Bevel Gear side).

Bearings (P/N 960 649 050 1):
The bearings installed on 37-tooth 'Breather ' gear were serviceable with no defects.

Starter-Generator adapter (P/N 0 292 10 201 0):
The Starter-Generator adapter was according to specification.

<u>Module M02</u>

42-tooth 'accessory drive shaft' gear (P/N 0 292 15 232 0):
The absence of significant wear was noted on the tooth flanks.

35-tooth gear (P/N 0 292 15 226 0):
The absence of significant wear was noted on the tooth flanks.

41-tooth Bevel Gear (P/N 0 292 10 276 0):
The micrographic observation showed a uniform martensitic structure.

Inspection of Bevel Gear pair assembly

The Bevel Gear pair setting dimensions were measured at Tarnos during the Module disassembly and showed no assembly anomalies with respect to the assembly after repair. **Table C3** and **Figure C7** (page 47) show the comparison of the results for the different settings of the Bevel Gear pair for new, after replacement, and after the accident:

Dimensions in **mm**	**R.02100**	**R.02200**	**R.02400**
New:	2.07	1.49	1.96
After replacement:	2.16	1.43	2.00
After accident:	2.16	1.48	1.94

Table C3: Dimensional settings of matched gear assembly

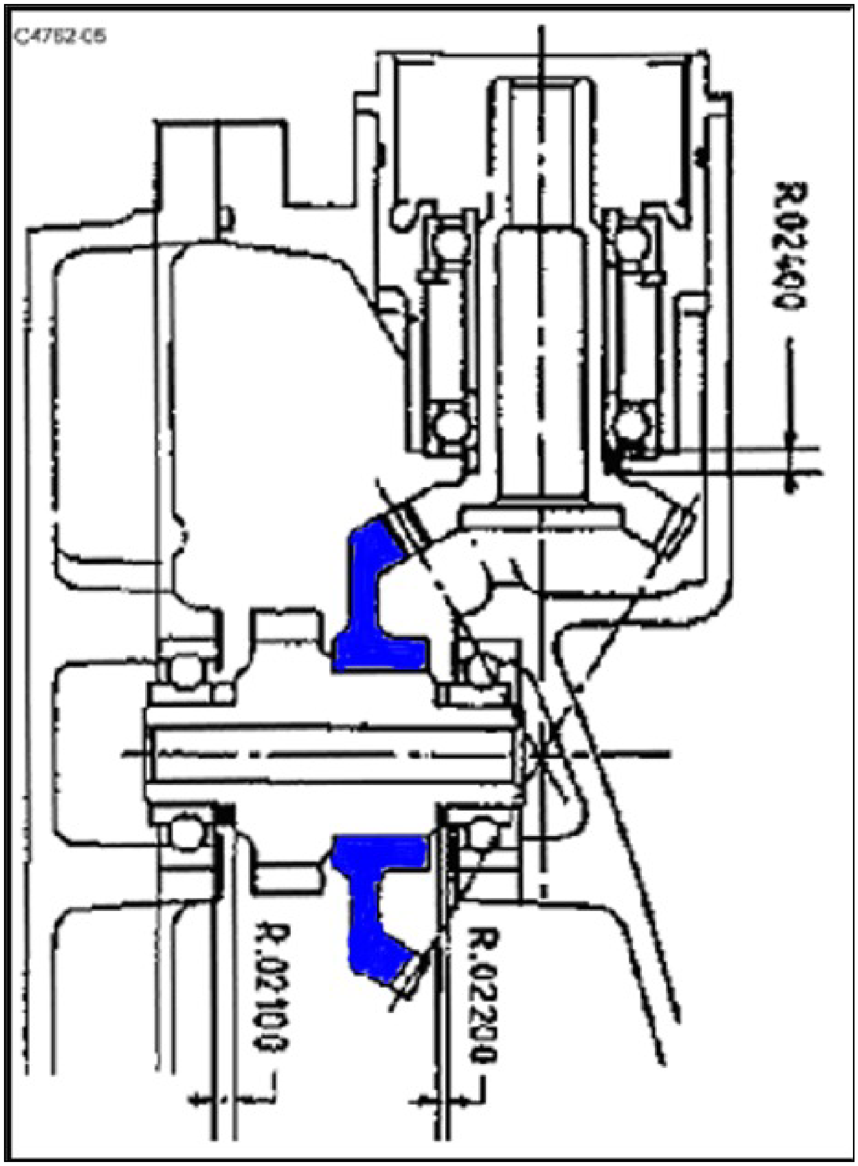

Diagram C2: Sectional view of 41-tooth Bevel gear (shaded area)

Hardness test of 41-tooth gear

The hardness values measured on the 41-tooth Bevel Gear are higher than the values specified on the drawing. Measurements were taken on a polished section.

The **Macrographic core hardness** (HV_{30}) was measured on average at 432 HV. This value is above the specification of 355 HV minimum to 415 HV maximum. (This value is slightly above the original specification drawings but within the Turbomeca specification defined in Specification document ST02603 issued on 18 September 2006). The observation of the micrographic sections of the gear teeth were made on the sound part of the teeth.

The **carburising depth** is slightly greater than the depth specified on the drawing (the 41-tooth Bevel-Gear design drawing indicates a carburising depth between 0.25 and 0.40 mm). Specification ST02603 authorises an additional carburised layer of 0.15 mm for machining reserve. The carburizing depth corresponding to a Hardness filitation ($HV_{0.5}$) 550 $HV_{0.5}$ on the tooth flanks is 0.08 greater than the value specified after machining. Laboratory examination shows the absence of notable wear on the tooth flanks.

Visual examination of the matched gear assembly (Bevel Gears)

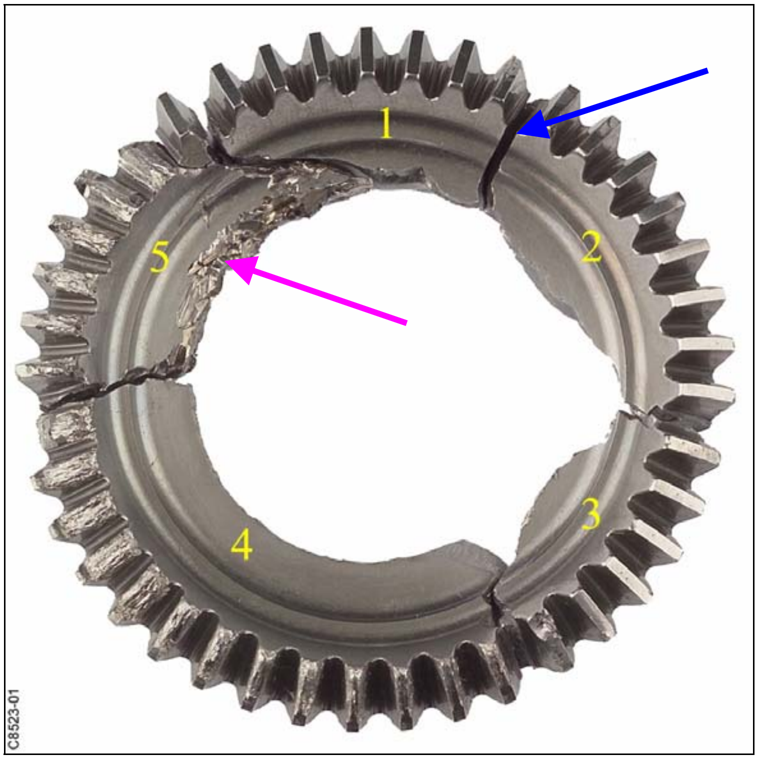

Photo C4: Identification of Bevel Gear sectors

initial fracture on tooth space bottom land (blue arrow) and area of web showing indications of alternate bending (magenta arrow)

The assembled gears are mated by mechanically fitting the 41-tooth Bevel Gear onto the 17-tooth straight gear.

The mechanical fit is from 0.065 mm minimum to 0.091 mm maximum, as specified on the manufacturers drawing.

Visual examination of the 41-tooth Bevel Gear

The observation of the 41-tooth Bevel Gear shows that the web fractured in five sectors. The fracture path between the web occurs mainly in the web fillet radius (see **Photo C4**).

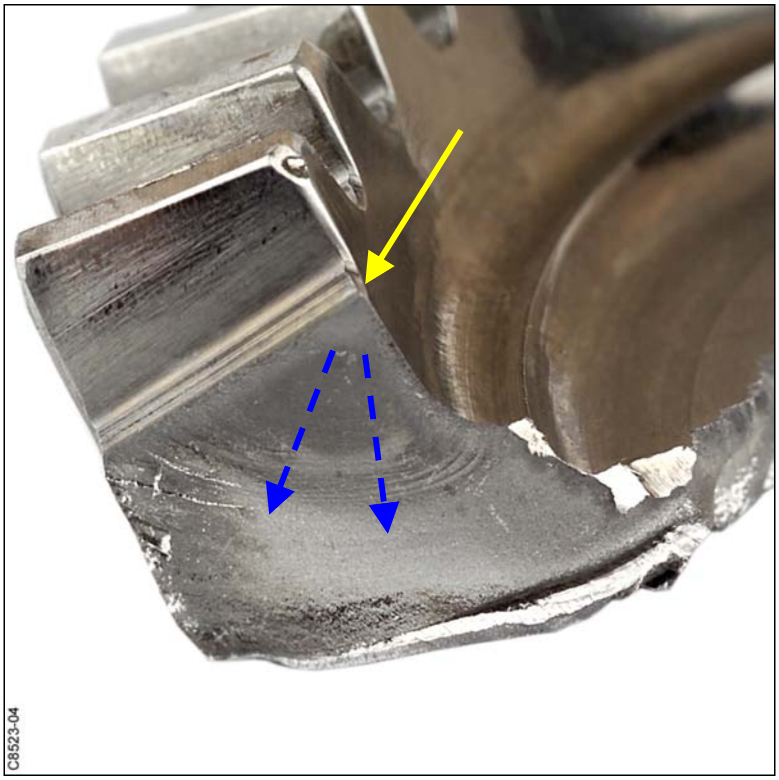

Photo C5: Macrographic observation of Sector 2
The crack origin region is indicated in yellow, the direction of propagation is indicated in blue.

Photo C6: Crack initiation between Sectors 1 and 2
consistent with maximum stress on starting

The absence of notable wear on the tooth flanks, after 992 hours of operation, rules out the hypotheses of a poor adjustment of the gear pair backlash, a material non-conformity or a surface hardening treatment (carburising) non-conformity.

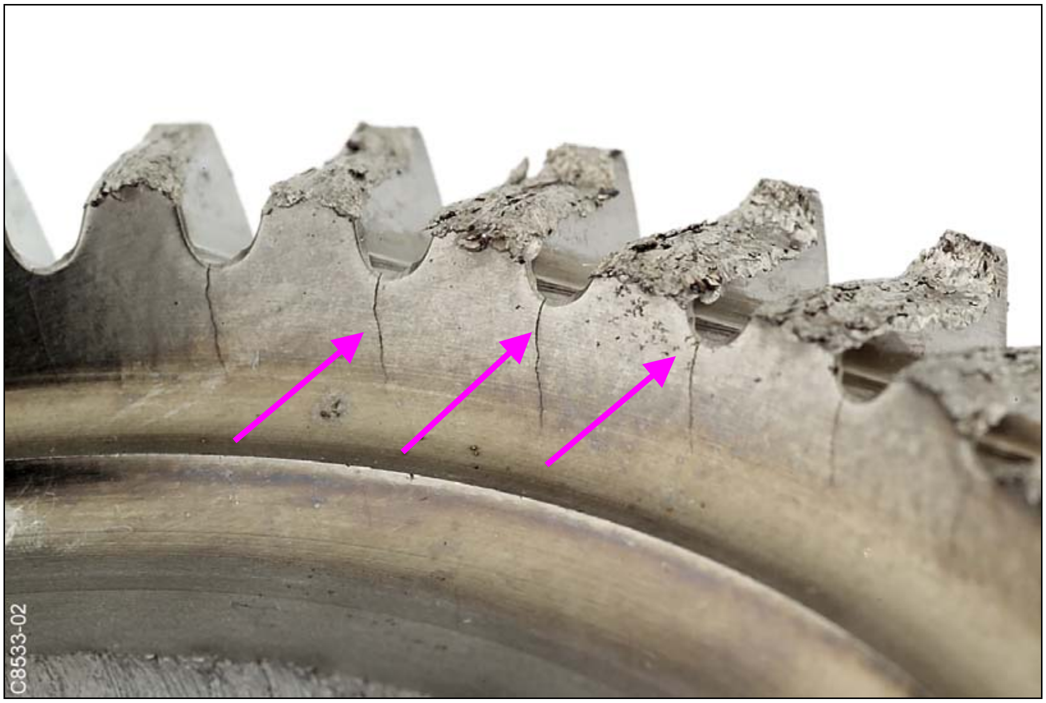

Photo C7: Macrographic observation of Sector 5

Note the presence of secondary cracks on almost all the tooth space bottom lands.

The crack origin region is in the bottom land fillet radius, slightly offset on the starting flanking side. Heavy damage of the tooth tips resulting from the overlapping of the teeth with those of the 23-tooth gear after gear meshing was lost. The direction of the primary crack indicates that this was propagated during the starting cycle.

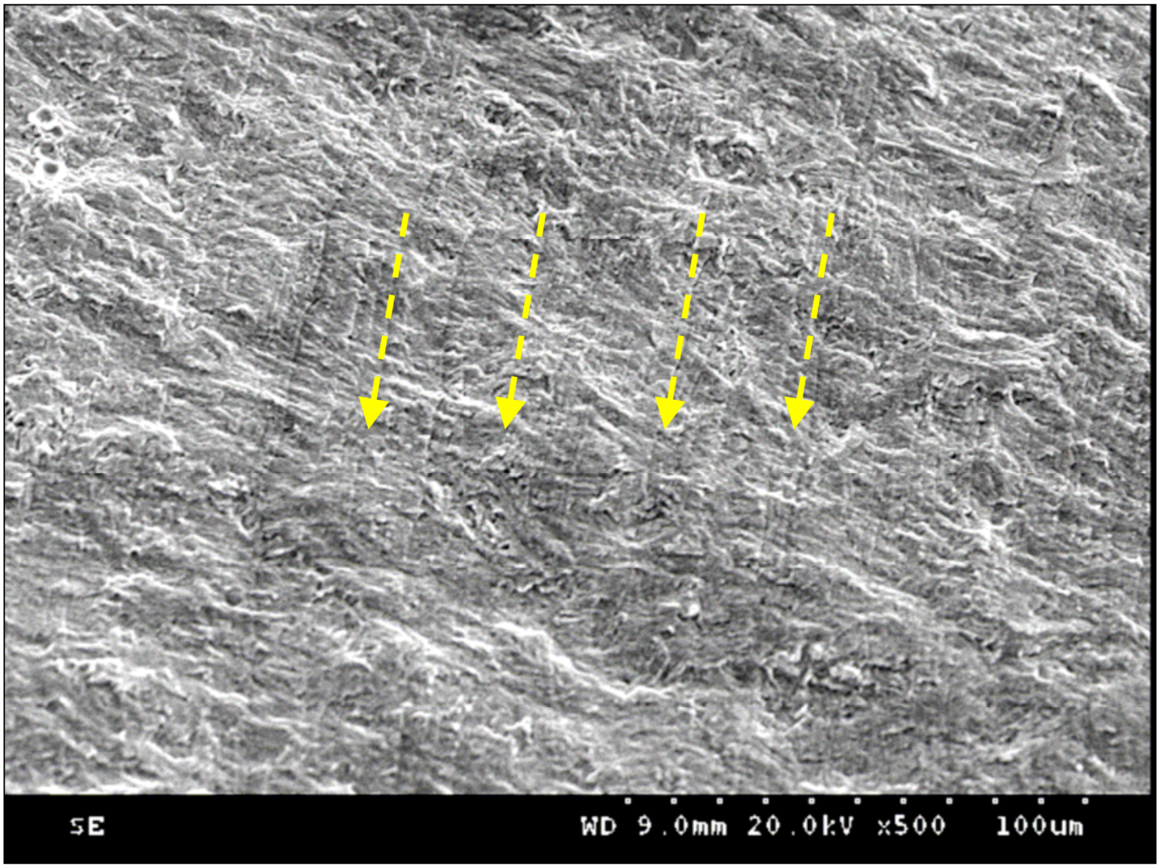

Photo C8: Fractographic examination of Sector 2,
indicating presence of fatigue striations

The fractographic observation under the Scanning Electron Microscope (SEM) of the fracture surface in sector 2 shows a fatigue propagation pattern.

The crack origin region is located on the tooth space bottom land, on the small diameter side. No metallurgical anomaly was observed in the crack origin regions. The crack propagated owing to high cycle fatigue until it met the fillet radius between the web and the rim. Striation spacing varies significantly and randomly with respect to the propagation direction.

Macrographic observation of the fracture surface on the web

The observation of the fracture surface shows two opposite lunulae that are typical of exposure to alternate bending stresses and of a progressive cracking process.

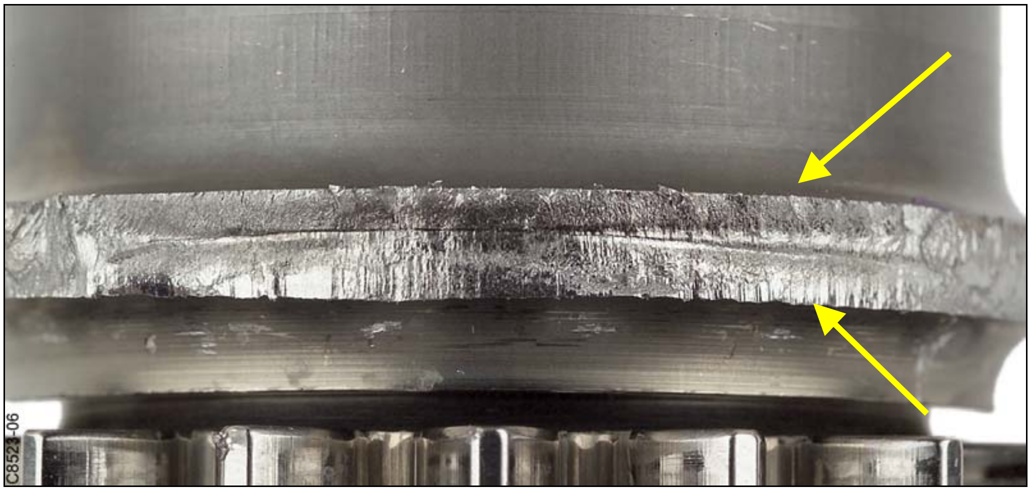

Photo C9: Fractographic examination of the fracture surface on Sector 5, indicating the crack origin regions at the end of the fillet radii.

The fractographic examination of the fracture surface on sector 5 located on the rim confirms the fracture under alternate bending stress. The crack origin regions are located at the end of the fillet radii between the hub and the web. No metallurgical anomaly was observed in the crack origin regions.

Micrographic examination of the 41-toot Bevel Gear

The micrographic section was taken close to the tooth space bottom lands (Nital 5% chemical etching). The observation reveals a fine martensitic microstructure, typical of a carburised zone, and a coarser martensitic structure that comply with the material specifications.

Carburising treatment on the 41-tooth Bevel Gear

The **Macrographic core hardness** (HV_{30}) was measured on average at 432 HV. This value was slightly above the original specification drawings but within the Turbomeca specification defined in Specification document ST02603 issued on 18 September 2006. The observation of the micrographic sections of the gear teeth were made on the sound part of the teeth.

Carburising treatment

The **carburising depth** was slightly greater than the depth specified on the drawing (the 41-tooth Bevel-Gear design drawing indicates a carburising depth between 0.25 and 0.40 mm). Specification ST02603 authorises an additional carburised layer of 0.15 mm for machining reserve. The caburizing depth corresponding to a Hardness filitation ($HV_{0.5}$) 550 $HV_{0.5}$ on the tooth flanks was 0.08 greater than the value specified after machining. Laboratory examination showed the absence of notable wear on the tooth flanks.

Fractographic examination of a secondary crack on sector 5

The fractographic examination carried out on one cracked tooth shows a fatigue propagation pattern. The crack origin region is located on the tooth space bottom land, on the small diameter side. No metallurgical anomaly was observed in the crack origin region.

Micrographic observation of a secondary crack on sector 5

37-tooth Breather Gear: Presence of slight impact marks on the web and on the tooth flank edges, rear side, resulting from the fracture of the 41-tooth Bevel Gear.

Bearings

Inspection of the Bearings revealed no abnormalities.

Visual examination of the drive shaft assembly

The observation of the drive shaft assembly (Modules 01 and 02) shows that the 23-tooth and 42-tooth gears are correctly meshed with each other. The condition of the bearing surfaces on the tooth flanks satisfactory. The observation of the 42-tooth and 35-tooth gears shows that the surface condition satisfactory and that tooth flank bearing correct.

Module M03

The aim of the investigation of Module M03 was to check if there was any evidence of possible resistive torque in the Gas Generator assembly, which could have contributed to the Bevel Gear rupture. The balancing check of the Gas Generator rotating assembly was carried out and found satisfactory. The Gas Generator was dismantled and revealed: A slight rubbing of the centrifugal compressor on its cover was considered not significant. No rubbing marks were evident on the turbine blade tips or on any other rotating part. No trace of carbon building was found on the injection wheel manifold labyrinths. Nothing in this Module indicates an abnormal resistive torque.

Appendix D

DCGU Field winding excitation

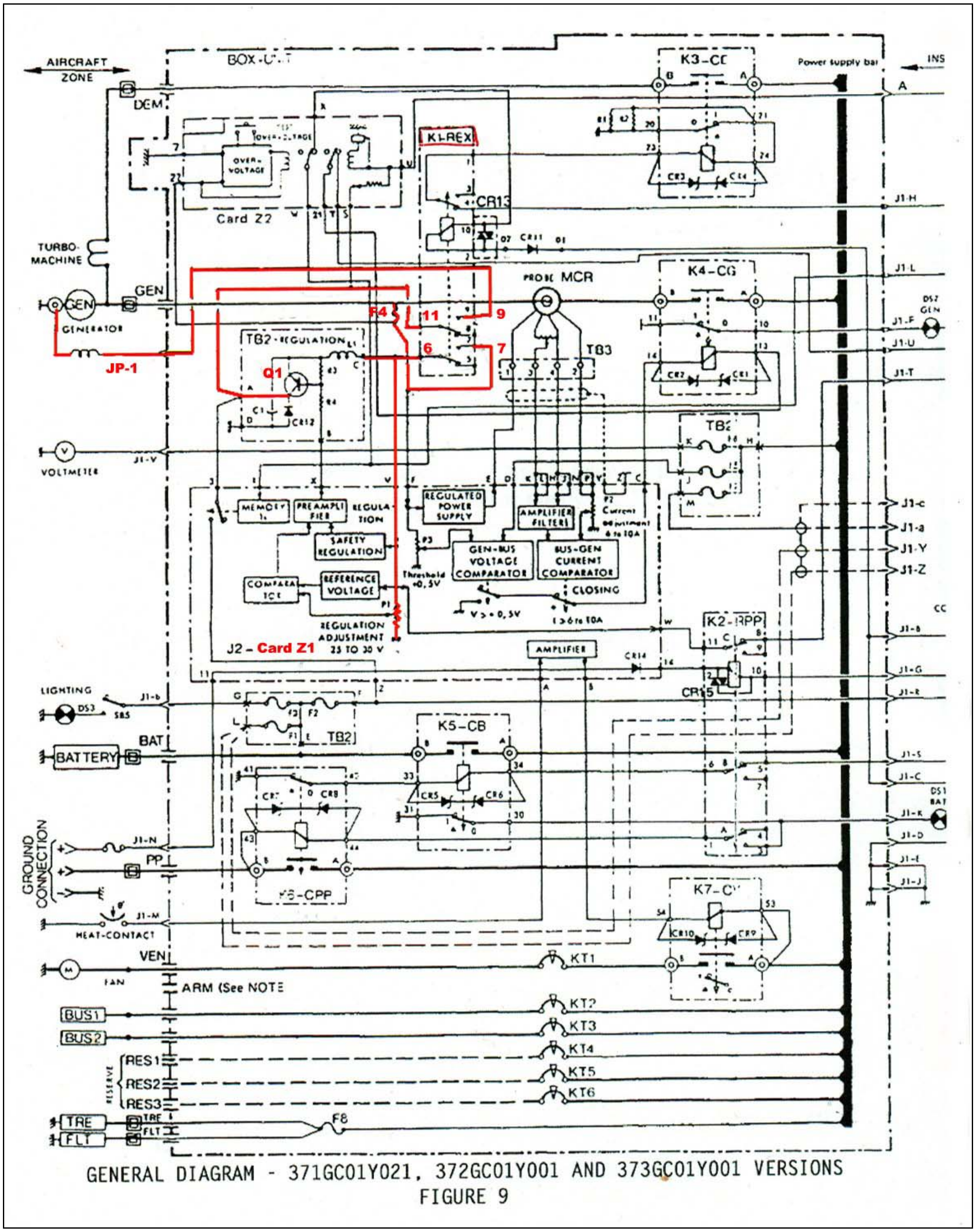

Figure D6: Extract from DCGU General Wiring diagram

Appendix E

Tests on the DCGU and APC 150A Starter-Generator

The following diagrams illustrate the vibration behaviour of the 41-tooth Bevel Gear during a starter-generator test in helicopter configuration. The Campbell diagram (**Figure E8**) shows that, using the APC 150A Starter-Generator with a tightened damping system, side bands appear around the signature of the 37-tooth ‘Breather’ gear (Order 37) when the frequency corresponding to the excitation voltage is below 65 Hz (indicated by black arrows).

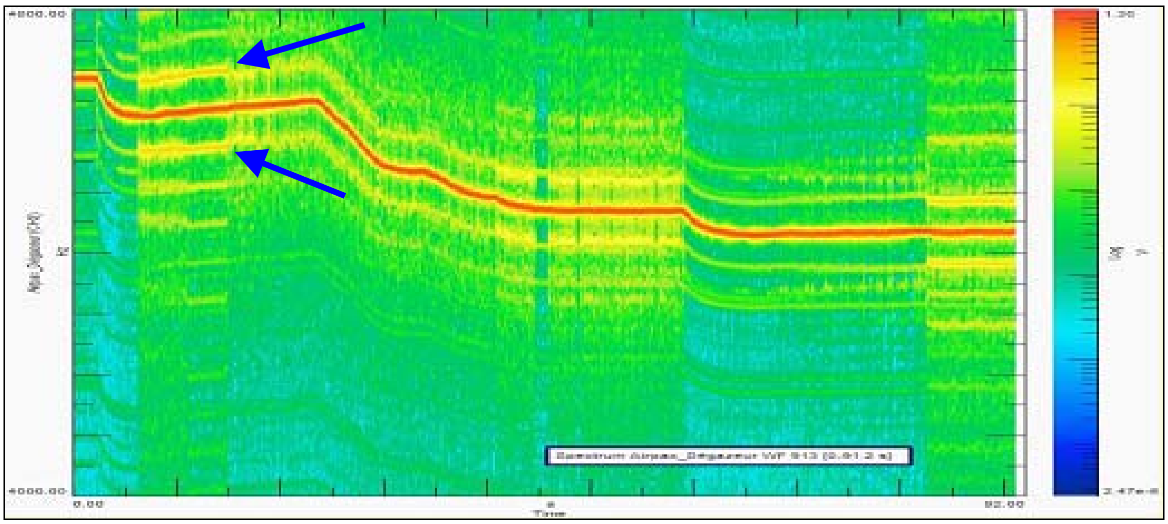

Figure E7: Order 37 frequency, with sidebands (indicated), measured at the ‘Breather Gear’ speed and position sensor (for an N1 variation between 68.4% and 64.6%)

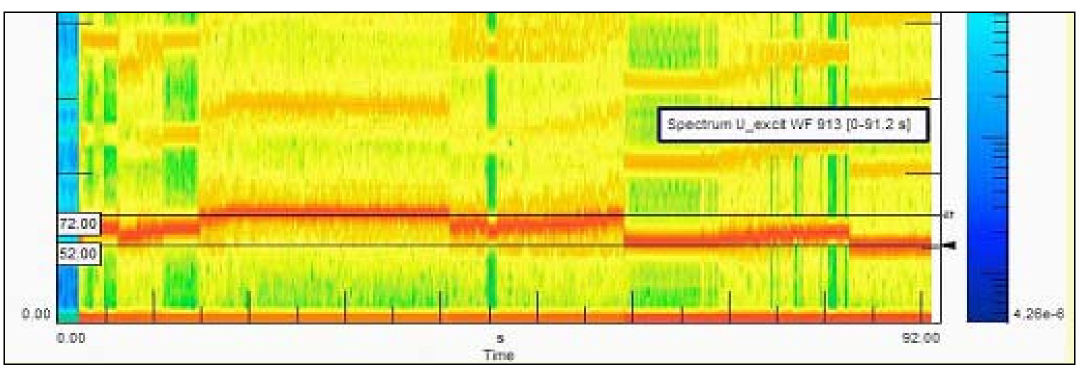

Figure E8: Frequency (Hz) corresponding to Excitation Voltage

On the 41-tooth gear similar sidebands appear around order 41 with a particularly remarkable phenomenon; the attenuation of order 41 signature (**Figure E8** and **Figure E9**) or even, in certain cases, the disappearance (in **Phase 1**) of order 41 signature and replacement by sidebands (see **Figure E10** and **Figure E11**). This means that during this phase, the gear no longer meshes at its typical teeth passage frequency but at the frequency of the sidebands, which indicates gear flapping.

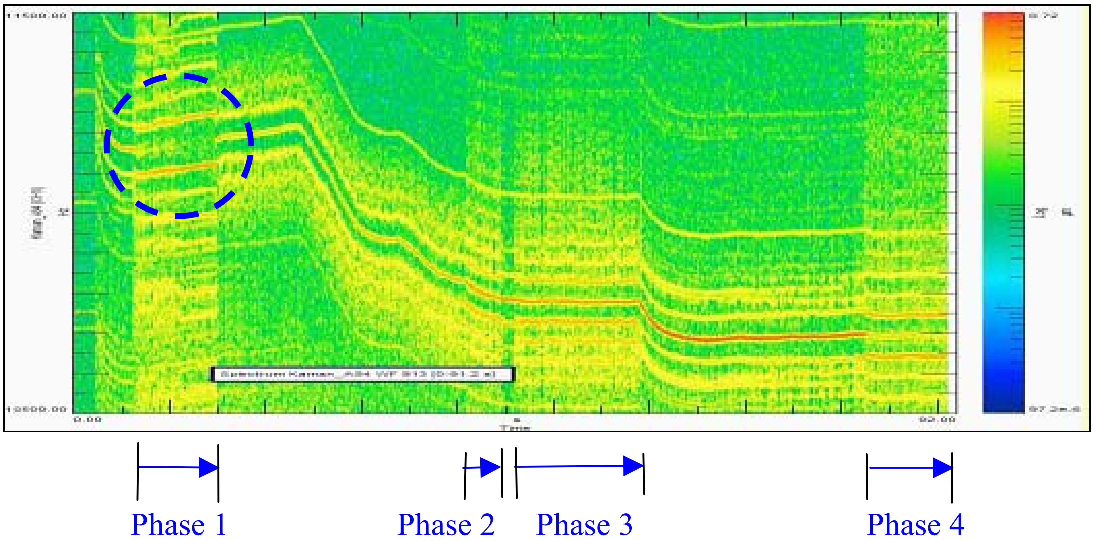

Figure E9: Order 41 frequency (+ sidebands) measured at the A94/Gear Z41 speed and position sensor (for an N1 variation between 68.4% and 64.6%)

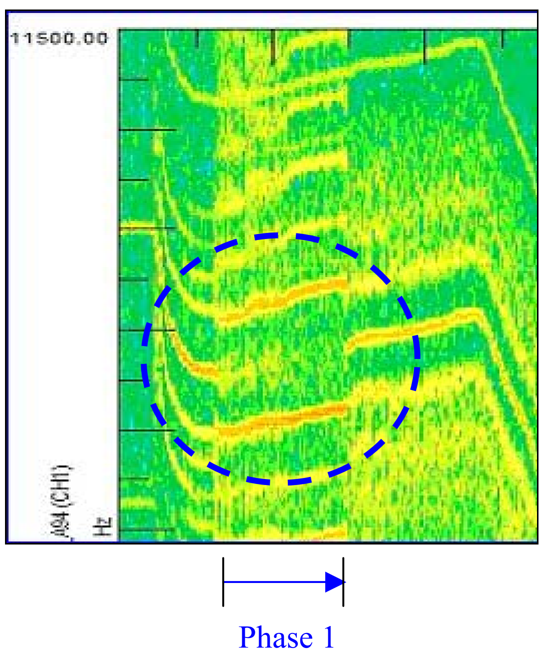

Figure E10: Periodic loss of Order 41 response in Phase 1
(Indicates Gear flapping and meshing anomaly)

In addition, on the 41-tooth gear, at low frequency, the sensors detect a higher-amplitude signature on order 2 of the modulation frequency observed on order 41.

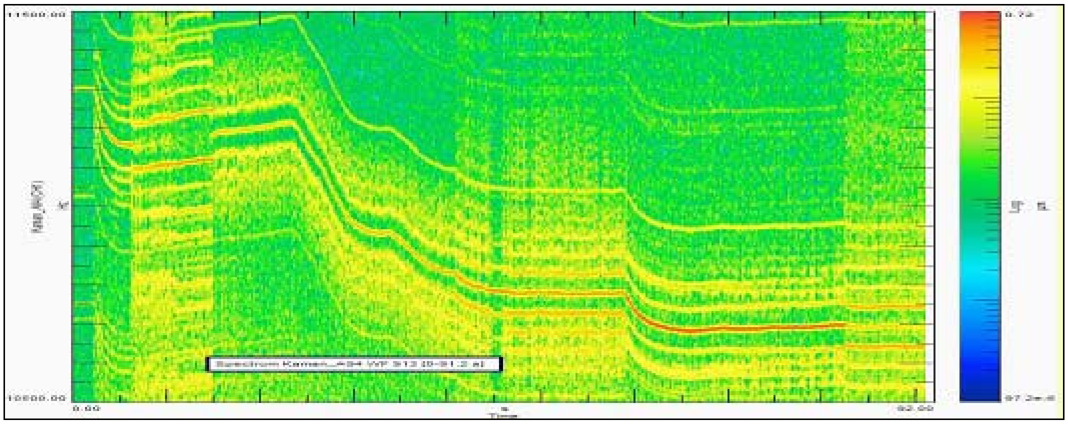

Figure E11: Order 41 frequency (+ sidebands) measured at the A94/Gear Z41 speed and position sensor (for an N1 variation between 68.4% and 64.6%)

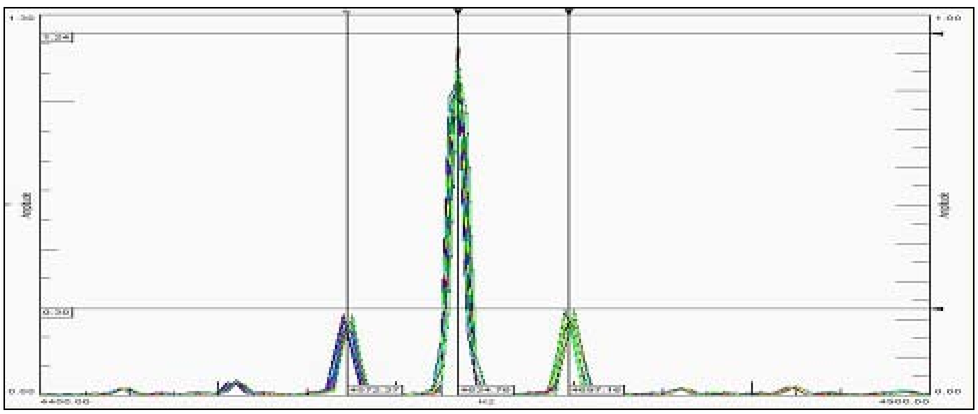

Figure E12: Order 37 frequency (+ sidebands)
(Measured at Breather Gear sensor for 3 seconds at N1 of 67.4%)

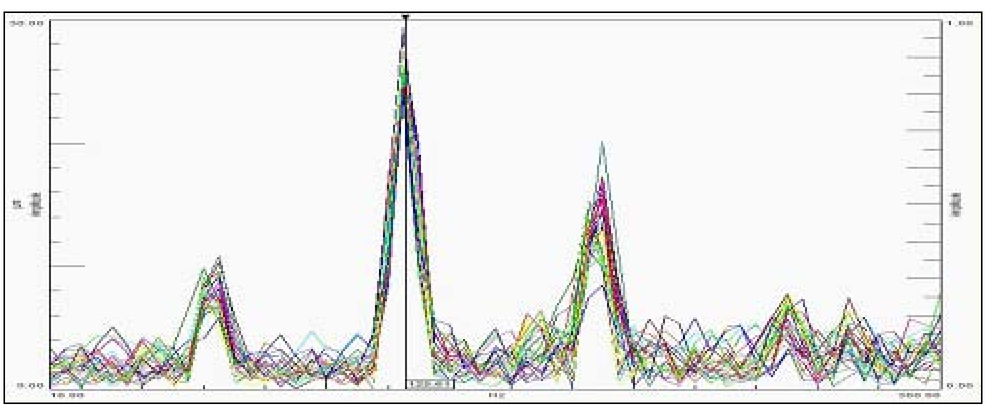

Figure E13: Maximum oscillations on Order 2
(Measured at A94/GearZ41 speed and position sensor, 125 Hz)

The frequency sections presented below show the Starter-Generator dampening effect on the Breather Gear:

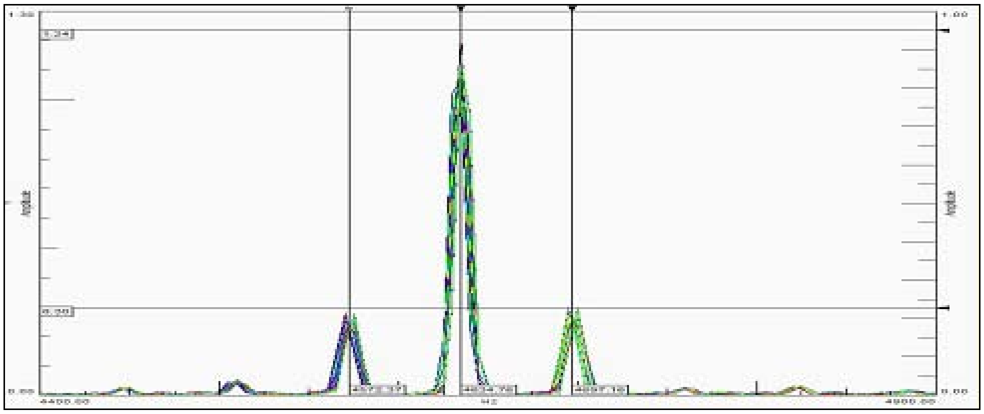

Figure E14: Damping system locked (over tightened)
(Frequency of Order 37 + sidebands,
and measured at Breather Gear sensor at an N1 speed of 67.7%)

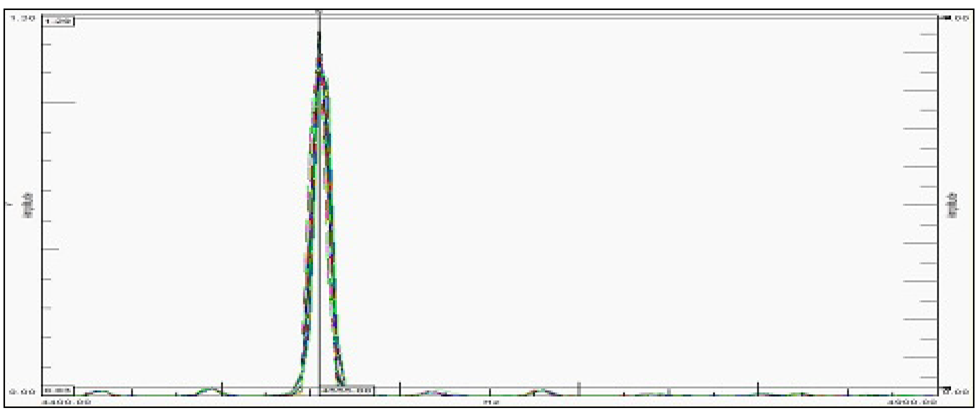

Figure E15: Damping system with correct adjustment
(Frequency of Order 37 + sidebands,
and measured at Breather Gear sensor at an N1 speed of 66.4%)

With a correctly adjusted damper, the amplitude of the side bands is significantly reduced: it represents only 2.3% of the amplitude of Order 37. However, with a blocked (over tight) dampening system, the amplitude of the sidebands is up to 25% of the amplitude of Order 37.

Appendix F

Stress values of 41-tooth Bevel Gear relative to endurance limit

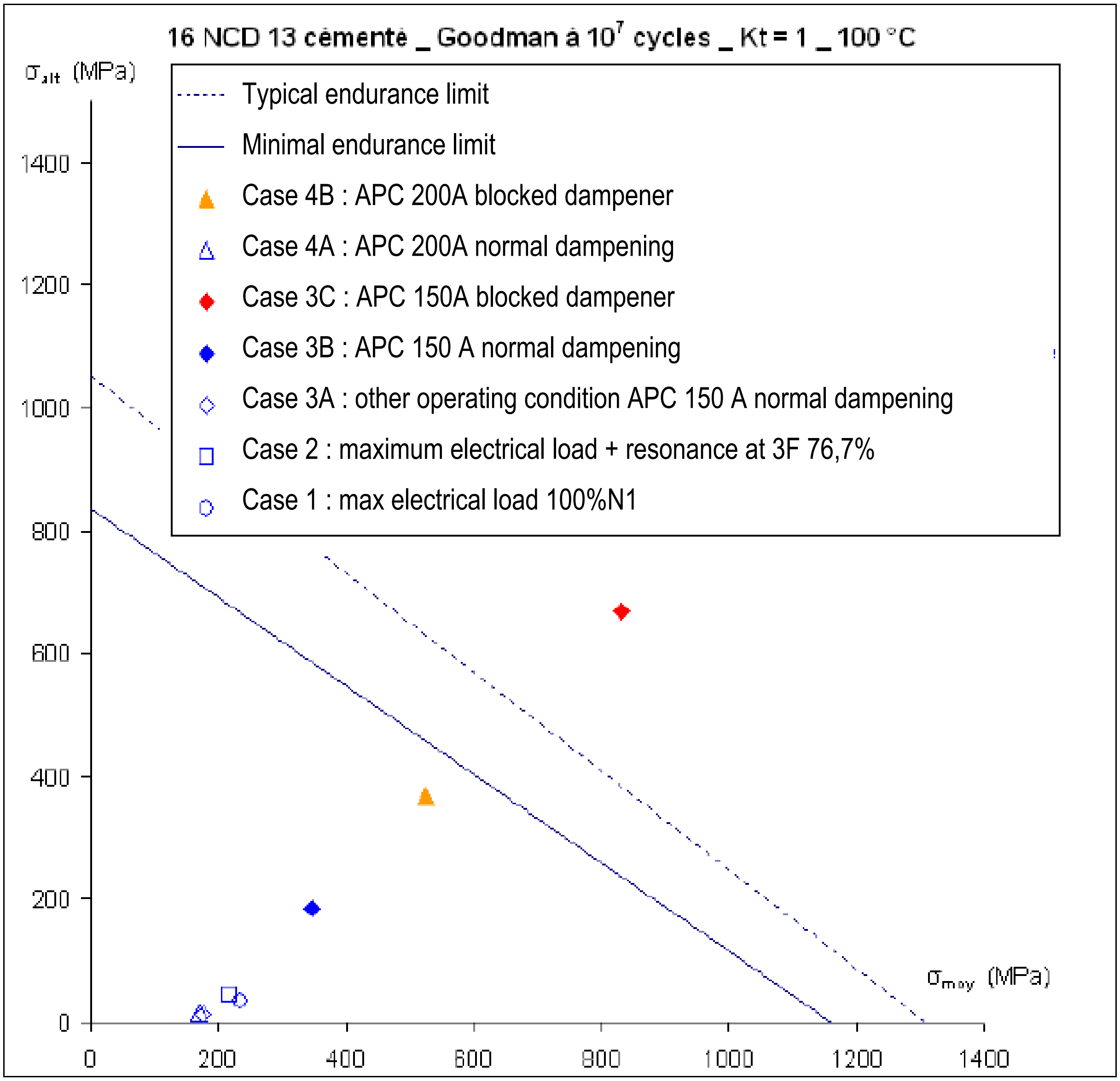

Figure F16: Plot of Stress values

The above Goodman diagram represents the stress values calculated by using a 3D analysis model, which translates the displacement measurements obtained under test conditions into stress values.

Appendix G

Low Flight Permit

LOW FLYING PERMISSION

SCHEDULE 2 - CONDITIONS

1. This Permission shall be conducted in accordance with the applicable Irish Aviation Authority Regulations and the provisions of the Irish Helicopters Ltd. aerial work/operations/maintenance manuals.

2. Flights made pursuant to this Permission must be conducted over non-congested areas and in the event of a power unit failure at any time, the aircraft can alight without hazard to persons or property on the surface.

3. Flights made pursuant to this Permission shall be conducted not below the following heights, 400 KV[17] Power lines 150 feet, 220 KV Power lines 100 feet, 110 KV Power lines 75 feet, and not below 50 feet for 38 KV Power lines, and 300 feet for general Under slung Operations and 50 feet for Forest Fire Fighting above the area of operation, over a non-congested area.

4. A flight plan shall be filed with the local AIS Unit[18] at least one hour before commencement of the low flying operation, and for operations inside a control Zone and/or a Military Restricted Area flights are subject to an operational brief with the ATS Manager. Flights shall be visual contact flights and shall not be undertaken in a flight visibility of less then 3 km or with a cloud ceiling lower than 600 ft above the operating area. The Operator shall ensure that there remains in place during all Aerial Work Operations a means of communication with SAR Services[19].

5. It is the responsibility of the pilot-in-command to become acquainted with noise sensitive areas within the operational areas and to ensure that advance contact is established with associated parties, to forewarn them of intended low-level operations and to obtain their consent for intended operations.

6. Notwithstanding any consent given under paragraph 5 above, the pilot-in-command shall, where possible, avoid repetitive or prolonged flight of more than five minutes durations over or in the vicinity of sensitive areas.

7. The pilot-in-command shall maintain a record of each flight sector operated pursuant to this Permission and shall make such records, or any details of such records, available to an Authorised Officer of the Irish Aviation Authority, on demand.

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[17] **400 KV**: Power lines with a potential of 400,000 Volts
[18] **AIS Unit**: Aeronautical Information Services Unit
[19] **SAR Services**: Search and Rescue Services

8. By accepting this Low Flying Permission, Irish Helicopters Limited, accepts full financial and legal liability for any loss of life, injuries or damage to persons or animals or damage to property or any other liability resulting either directly or as a consequence of any flight operated pursuant to this Permission.

9. For flights made pursuant to this Permission, Irish Helicopters Limited must notify, in advance all relevant interested parties to ensure each are made fully aware of the location, timings and duration of intended low flying operations.

10. Where the Operator, Irish Helicopters Ltd, is made aware of any third party complaints arising from low flying operations conducted pursuant to this Permission, such complaints shall be notified, in writing to the Authority.

11. Operational control, safety planning and oversight of all low flying operations made pursuant to this Permission shall be the responsibility of the Flight Operations Manager.

12. Flight crew rostered for flights pursuant to this Permission shall receive role training and a line check prior to conducting operational flights.

13. A copy of this Permission shall be included in the operations manual and carried on board the helicopter.

14. Unless exempted by the Authority only the flight crew of the aircraft or persons essential to the conduct of the aerial work activity may be carried on any flight pursuant to this Permission.

15. Flights pursuant to this Permission, which involve operations over water will require flight crew to wear life saving equipment.

16. Flights under this Permission shall be to of from or within the territories of the State.

17. This Permission may be cancelled, suspended, varied or revoked at any time by the Irish Aviation Authority.

Appendix H

Airspeed-Height Avoidance Zone

(Extracted from AS350B1 Flight Manual)

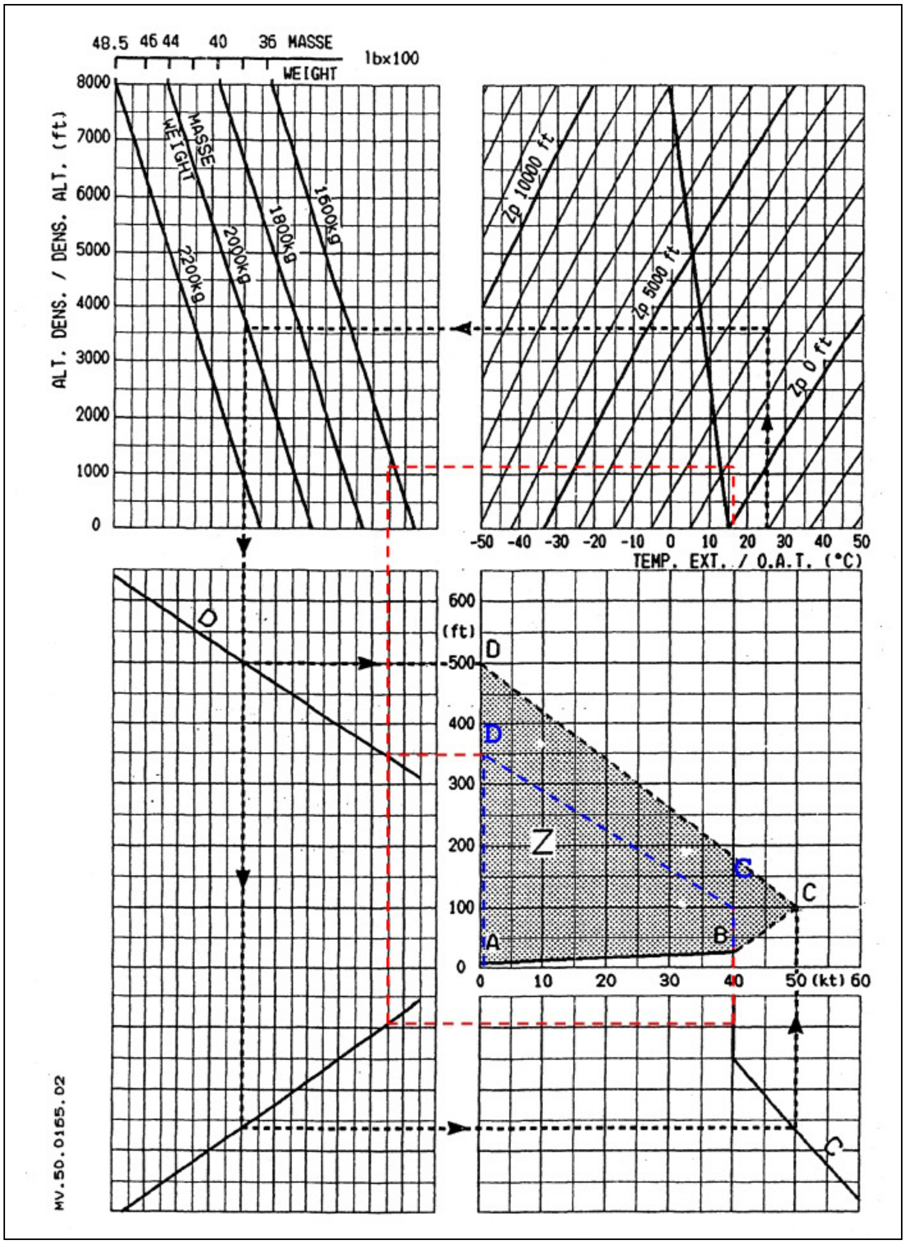

Figure H17: Airspeed-Height envelope

The above performance diagram is taken from the
AS350B1 Flight manual, Section 5.1 (Regulatory Performance Data)

Airspeed-Height Avoidance Zone:

The avoidance zone (Z) is defined by four points: A, B, C, D. To determine points A and B: Point A is located at a height of 8 ft (2.5 m) at zero airspeed. Point B is located at a height of 25 ft (8 m) for an airspeed of 40 kts (74 km/hr). To determine points C and D: Point C is defined by: a constant height of 100 ft (30 m), a variable airspeed depending on the altitude and on the aircraft weight as determined by line C. Point D is defined by: a constant zero airspeed, a variable height depending on the altitude and on the aircraft weight as determined by line (D).

Analysis of avoidance zone for the accident flight on 12 July 2007:

Points C and D have been plotted (indicated by red lines) based on Outside air temperature, Pressure Altitude and aircraft weight as follows:

- Outside air temperature of 17°C, corrected for altitude to 15°C,
- Pressure altitude of 1,000 ft, with QNH of 1013 hPa.
- Aircraft weight at lift-off of 1,885 kg, corrected to approximately 1,585 kg due fuel consumption.

The analysis produces a representative avoidance zone at the time of the accident (indicated in blue).

GLOSSARY

°C	Degree Centigrade
μm	Micro-metre
σ	Stress (symbol)
A	Ampere (unit of electrical current)
Ah	Amp-hour
AAIU	Air Accident Investigation Unit (Ireland)
AGL	Above Ground Level
AIP	Aeronautical Information Publication
AIS	Aeronautical Information Services Unit
AMSL	Above Mean Sea Level
AOC	Air Operator's Certificate
AVTUR	Aviation Turbine Fuel
BEA	Bureau d'Enquêtes et d'Analyses (France)
CVR	Cockpit Voice Recorder
daN	DekaNewton
DCGU	Direct Current Generating Unit
DGAC	Direction Générale de L'Aviation Civile (France)
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration (USA)
FAR	Federal Aviation Regulation (USA)
FCU	Fuel Control Unit
FDR	Flight Data Recorder
FSI	Flying Staff Instruction (Operator)
ft	Feet
FTIR	Fourier Transform Infrared Spectroscopy
g	Gravity (Force)
GASU	Garda Air Support Unit
HP	Horse Power
GPS	Global Positioning System
hPA	HectoPascal
HV	Hardness Value
IAA	Irish Aviation Authority
IAS	Indicated Air Speed
IAW	In Accordance With (Engineering)
JAR	Joint Airworthiness Requirements
Jet A1	Grade of Turbine fuel
kg	Kilogram
km	Kilometre

km/hr	Kilometre per hour
kPA	KiloPascal
kts	Knot
kV	KiloVolt
kW	KiloWatt
MPa	MegaPascal (unit of stress)
MHz	MegaHertz
mm	Milimetre
N1	Speed of Accessory drive shaft (Helicopter)
Ng	Gas Generator rotation speed (Engine)
Nr	Main Rotor speed (Helicopter)
O/H	Overhaul (Engineering)
P/N	Part No.
PWM	Pulse Width Modulation
QNH	Altimeter barometric setting with reference to sea level (Q-code)
RPM	Revolutions per minute
S.I.	Statutory Instrument (Irish Law)
S/N	Serial No.
SAR	Search and Rescue
SB	Service Bulletin
SEM	Scanning Electron Microscope
SR	Safety Recommendation
TSB	Transport Safety Board (Canada)
TSN	Time Since New (Engineering)
V	Volt (unit of electrical potential)
VFR	Visual Flight Rules

- END -