Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

AVIATION INVESTIGATION REPORT
A07O0314

IN-FLIGHT ENGINE FAILURE

ROYAL CANADIAN MOUNTED POLICE
AEROSPATIALE AS 350 B3 (HELICOPTER) C-FRPQ
STONEY POINT, ONTARIO
23 NOVEMBER 2007

Canada

Aviation Investigation Report

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Summary

An Aerospatiale AS 350 B3 helicopter (registration C-FRPQ, serial number 3636), operated by the Royal Canadian Mounted Police, was en route from London, Ontario to Windsor, Ontario at 2000 feet above sea level. At approximately 0755 eastern standard time, the helicopter yawed sharply to the right, the rotor rpm dropped, the engine chip and governor light illuminated, and the warning horn sounded. The engine (a Turbomeca Arriel 2B) had failed and the pilot commenced an autorotation landing into a farm field. During the descent, the pilot transmitted a mayday call and activated the emergency locator transmitter. The helicopter landed without further incident. There were no injuries and the helicopter was not damaged. The pilot completed the shutdown checklist and switched off the battery.

Ce rapport est également disponible en français.

Other Factual Information

Weather in the area at the time of the incident was reported as good with scattered clouds. The visibility at 2000 feet was approximately 6 miles; winds were out of the north at approximately 22 knots and the temperature was -3°C.

Records indicate that the pilot was certified and qualified for the flight in accordance with existing regulations. He had been on duty for 1 hour prior to the occurrence following 13 hours off duty.

An examination of the engine determined that the 41-tooth bevel gear (part number 0292127330) had fractured due to high-cycle fatigue cracking. The gear was installed during engine manufacture and had accumulated a total of 1644 hours since new. Metallurgical examination (TSB Laboratory report LP 005/2008) 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. There were no relevant manufacturing flaws found in the gear that could contribute to the failure.

The 41-tooth bevel gear (see Figure 1) is located in the accessory gearbox module 1 (MO1) and has a 20-tooth idler gear mounted to its shaft. The MO1 is composed of the accessory gear box and the transmission shaft. The starter-generator output shaft is coupled to the compressor through a series of bevel gears that includes the 41-tooth gear. The 20-tooth idler gear drives all the accessories mounted to the MO1. During the starting sequence, the starter-generator drives both gears, which in turn drive the compressor and accessories. Conversely, once the engine is running, the compressor drives the 41-tooth bevel gear which, in turn, drives the accessories and starter-generator. Failure of the 41-tooth bevel gear will decouple the engine from the accessories and result in an uncommanded engine shut down. Once the engine is shut down, it can not be restarted.

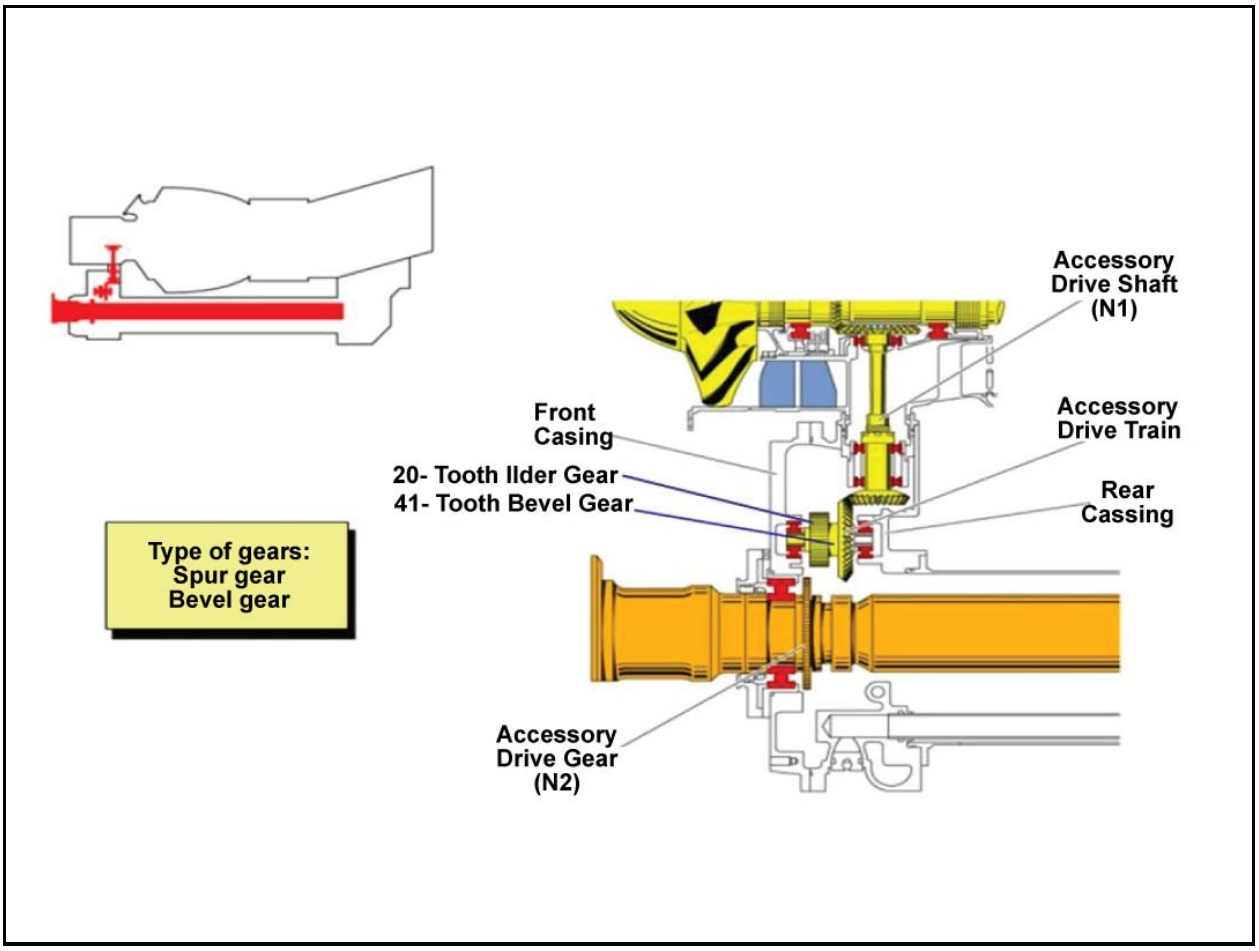

Figure 1. Accessory gearbox

The starter-generator was originally manufactured by Aircraft Parts Corporation (APC) now operating under the Unison Industries LLC name. The starter-generator was originally installed on a different RCMP helicopter, C-FMPH, as new on 19 March 2003 and had accumulated 1212 hours before removal for overhaul on 06 June 2004. The starter was then overhauled by Flyrite Accessory Overhaul. The starter-generator was installed on the incident helicopter on 26 September 2006 at a total airframe time of 1199 hours. At total airframe time 1492 hours, new brushes were installed during routine maintenance. On the day of the incident, the starter-generator had accumulated a total of 444.9 hours since installation, 152 hours since the brushes were installed, and a total of 1657 hours since new.

The starter-generator design incorporates a dampening system. Dampening systems are state-of-the-art features in starter-generator design (for APC: USA spec. MIL TDL 6162) and are systematically taken into account during the design of all starter-generators. For the APC starter-generator, this is comprised of a pair of damper plates on each side of a friction plate 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 (see Figure **2**). With the drive shaft nut correctly tightened, the appropriate pressure is applied to the damper plates and friction disc.

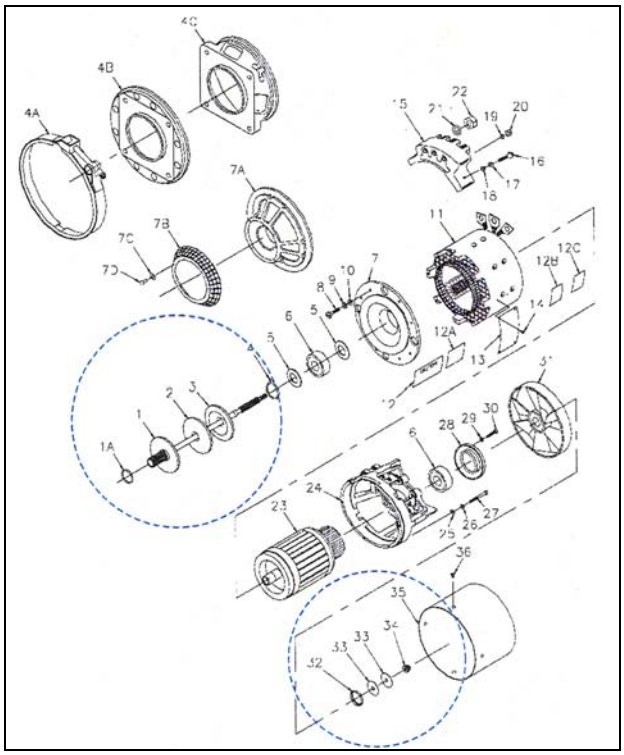

Figure 2. Exploded view of starter-generator

In addition to this occurrence, there have been eight other reported failures of the 41-tooth bevel gear. The initial five failures occurred on low-time engines and were attributed to improper shimming of the 41-tooth bevel gear during assembly. Turbomeca addressed these cases by improved assembly instructions and modifications TU 302A (on the Arriel 1) and TU 61A (on the Arriel 2). Details of the other three occurrences are as follows:

- On 17 March 2001, an East Bay Regional Park District Police Department AS 350 B2 helicopter (registration N996PD), powered by a Turbomeca Arriel 1D1 engine, was involved in a power loss event near Hayward, California, United States (U.S.). The helicopter was conducting night-time aerial surveillance at 600 feet above ground level (agl) when the engine lost all power. The helicopter was substantially damaged and there were no reported injuries. The U.S. National Transportation Safety Board (NTSB) investigated the accident (LAX01TA119) and an examination of the engine determined that the 41-tooth bevel gear (part number 0292107960) had failed due to high-cycle fatigue. The gear was installed during the engine manufacture and had accumulated a total of 1023 hours since new. On 28 June 2001, Turbomeca issued Service Letter 2106/01/Arriel 1/61 to all operators of Arriel 1 engines.
  This service letter referred to the failure on 17 March 2001 and outlined an inspection method for engines currently in service. It suggested: "At each return to a Turbomeca-approved service repair centre, the 41-tooth bevel gear will be checked systematically if the removal level makes them accessible." The service letter reported, in part: "The rupture was the result of fatigue propagation. Metallurgical and dimensional analyses have not revealed any defect."

- In October 2005, a Pfizer Inc. Sikorsky S-76C+ (registration N844CP), powered by a Turbomeca Arriel 2S1 engine, was involved in a power loss while en route to New York, U.S. An examination of the engine by Turbomeca determined that 41-tooth bevel gear (part number 0292127350) had failed due to high-cycle fatigue. The total engine time was 2393 hours. The 41-tooth bevel gear was replaced by a new one during the last overhaul of the MO1 by Turbomeca and had accumulated 79 hours.

- On 12 July 2007, an Irish Helicopters Ltd. AS 350 B1 helicopter, registration EI-IHL, powered by a Turbomeca Arriel 1D engine (serial number 7035), was involved in a power loss event near Ballynacally, Ireland. The helicopter was carrying-out a low-altitude gas pipeline inspection when the engine lost all power. The helicopter was substantially damaged and one passenger was fatally injured. The Irish Air Accident Investigation Unit (AAIU) is currently investigating this accident (2007-015), but preliminary investigation confirms the 41-tooth bevel gear (part number 0292107960) failed due to fatigue. The total engine time was 6224 hours. The 41-tooth bevel gear was replaced by a new one during the last overhaul of the MO1 by Turbomeca and had accumulated 992 hours.

On 24 August 2007, Turbomeca issued Service Letters 2546/07/Arriel 1/91 and 2565/07/Arriel 2/26 to all operators of Arriel 1 and 2 engines. These service letters reported the failure on 12 July 2007 and indicated the following: "Investigation of the gear shows that the rupture follows the initiation of a fatigue crack at the tooth bottom and its growth in the rim. The crack does not seem to be linked to the adjustment of the bevel gear during assembly. In addition, an anomaly was found on the APC type starter-generator which was installed on the engine at the time of the accident. The friction plate (Drawing Find No. 2 of figure 4.1 of CMM 80-09-01 of the APC starter-generator included in the helicopter maintenance documentation) of this accessory shows a significant off-set. This off-set created an imbalance which could be the root cause of an unusual dynamic loading of the gear." Tests and additional investigations were carried out at Turbomeca and Eurocopter facilities to determine the root cause of the gear rupture. Further tests are still in progress at Turbomeca.

There are an estimated 346 AS 350 B series helicopters registered in Canada equipped with the Turbomeca Arriel series engine. The Arriel series engine is also installed in several other helicopter models in use in Canada including the Eurocopter EC 130 B4 and the Sikorsky S-76C.

There are 28 variants of the Arriel series engine that power helicopters worldwide, including the Eurocopter EC 130, EC 145, BK 117, EC 155, Ecureuil AS 350 B series, Dauphin AS 365 N and N3, the Sikorsky S-76A++, S-76C+ and S-76C++, and the Augusta A109 K2. This encompasses both single and dual engine helicopters used in both military and civilian operations. According to Turbomeca, over 7000 Arriel engines have been manufactured, representing a total of about 26 million flight hours.

Turbomeca and Eurocopter, in coordination with the TSB, the Irish AAIU and France's Bureau d'Enquêtes et d'Analyses (BEA), attempted to determine the root cause of these failures. Tests were conducted at Turbomeca and Eurocopter's facilities in France under the direct supervision of investigators from the AAIU and the BEA. During these tests, discrepancies were found with

the dampening system in the starter-generators from both this occurrence and the Irish occurrence. In particular, the following discrepancies were found with the incident starter-generator:

- A check of the dampening system showed that the Belleville springs were excessively compressed, preventing the dampening system from functioning properly.
- The Belleville springs as visible from the outside appeared to be concave.
- The shaft was noted to be off-centred.

The Irish starter-generator, which was dismantled after the visual inspection, showed similar discrepancies and it was established that the status of the dampening system was the consequence of a wrong positioning of the damper disc and an over-tightening of the nut.

Following the investigation of the Irish and Canadian occurrences and the subsequent discovery of discrepancies with the starter-generator dampening systems, Turbomeca recovered the starter-generator from the East Bay Regional Park Police helicopter. Its investigation showed that the dampening system was incorrectly adjusted by being too loose. The starter-generator from the Pfizer occurrence remained in service after the incident until it was routinely overhauled.

It was also demonstrated during testing that the APC overhaul procedure to assemble and adjust the dampening system by tightening the nut was imprecise and did not ensure a proper functioning dampening system as it was only possible to see the outermost Belleville spring: "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, ¾ of a turn."

The overhaul of APC starter-generators was undertaken by various service centres prior to the takeover of that company by Unison Industries in 2005. Since that time, only two maintenance centres are authorized to carry out overhaul of the APC starter-generators. Unison industries indicate that the procedure for installing and adjusting the Belleville springs in the factory inverts the top washer and bottoms-out the assembly (metal-to-metal) before being backed-off to allow the necessary free-play in the system (see Figure 3). The top washer takes a set after the first cycle, but subsequent cycles repeat a consistent hysteresis loop. Therefore, the force is quite predictable.

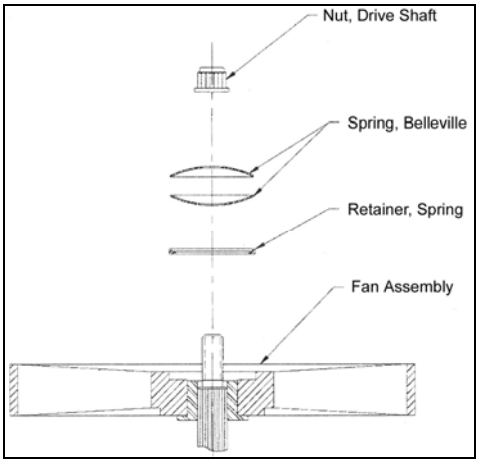

Figure 3. Belleville spring installation

Various tests were carried out in a helicopter configuration on a Eurocopter test rig (in collaboration with Unison Industries/APC) and at Turbomeca on an instrumented engine. The tests utilized a variety of starter-generators (APC and Auxilec) and were conducted with various configurations of the dampening system settings (loose, over-tightened). The following observations were noted:

- Vibration measurement on Eurocopter test rig evidenced a vibration spike at approximately 9300 rpm for the occurrence starter-generator (at approximately 10 400 rpm for the Irish occurrence starter-generator).

- The tests in generation mode revealed torsional oscillations when using an APC starter-generator with an over-tightened dampening system. These tests were representative of the status of the dampening of both Canadian occurrence and Irish occurrence starter-generators. It was also noticed that these oscillations caused, in certain cases, the disappearance of the vibration signature of the 41-tooth gear meshing order. In addition, the torque was found to be oscillating at certain frequencies, leading to alternate shocks and losses of contact between the teeth flanks.

- The tests in generation mode have also showed the presence of torsional oscillations when using an APC starter-generator with a loose dampening system. The amplitude of the oscillations was found to be equivalent, but the frequency was different.

- When the dampening system was properly adjusted, these torsional oscillations were well-damped.

Since the Arriel engine began operation (26 million hours), four failures of 41-tooth bevel gear due to high-cycle fatigue have occurred that were not readily attributed to an assembly problem. All four of these were equipped with APC starter-generators. Three of these four starter-generators had the same part number. The amperages were different, but the dampening system was the same for the four starter-generators. Three of them were investigated and their dampening systems were found to be incorrectly adjusted (two were over-tightened and one loose). According to Turbomeca, a Fisher-Snedecor statistical evaluation that took into account the proportion of APC starter-generators of the Arriel fleet on Eurocopter single-engine helicopters concluded that a relation exists between the 41-tooth bevel gear failure and the starter-generator brand. It was also established early in the development of the Arriel engine that undampened Auxilec starter-generators contributed to failures of accessory drive components other than the 41-tooth bevel gear. None of these discrepancies would affect the operating capability of the starter-generators, their ability to generate power, or start the engine.

Analysis

There are a large number of Arriel engines in service worldwide and the 41-tooth bevel gear is a critical component of the Arriel engine because its failure results in an uncommanded engine shutdown. In addition to this occurrence, there have been eight other reported failures of the 41-tooth bevel gear. The initial five failures occurred on low-time engines and were attributed to improper shimming of the 41-tooth bevel gear during assembly. The remaining four failures

were all on engines equipped with APC starter-generators. Discrepancies were found with the dampening system in three of the examined starter-generators. This means that the starter-generators were not operating in accordance with their design specification. Vibration tests indicated a vibration spike at approximately 9300 rpm for the occurrence starter-generator (10 400 rpm for the Irish occurrence starter-generator).

Other vibration tests were conducted with various configurations of dampening system settings (loose, over-tightened) and types of starter-generators (APC and AUXILEC). These showed torsional oscillations when using an APC starter-generator with an over-tightened dampening system, as in both the occurrence and Irish occurrence starter-generators. These oscillations, which affected the 41-tooth bevel gear, are of significance and can have a detrimental effect on its fatigue life. Examination of the fourth starter-generator was not possible. There does not appear to be any relation in the amount of hours or the type of operation being flown for any of the noted failures. Moreover, no metallurgical anomalies were found that would have contributed to the high-cycle fatigue failure. Though there was a discrepancy found with the torque dampening system of the starter-generator on the occurrence helicopter, it did not affect the operational ability of the starter-generator nor would it have presented itself as an identifiable vibration during normal operation.

The failure of the 41-tooth bevel gear in this and other occurrences suggests there is a relationship between the failure mode and the torque dampener of the APC brand starter-generators. There is concern that the overhaul instructions for adjusting the torque dampener are imprecise and it would be difficult to adjust the torque dampener correctly.

Although Turbomeca designed a new 41-tooth bevel gear with a thickened rim to improve the tolerance of the 41-tooth bevel gear to dynamic stress caused by high or excessive levels of electrical power tapped from the generator, it has concluded that this new design will not prevent failures related to incorrectly adjusted torque dampeners as found in this occurrence. It continues to conduct tests, in cooperation with other parties, to better understand the complex electro-mechanical relationship between the starter-generator, the electrical system, and the engine that may have contributed to the failures.

The following TSB Engineering Laboratory report was completed:

LP 005/2008 – Engine Failure Analysis

This report is available from the Transportation Safety Board of Canada upon request.

Findings as to Causes and Contributing Factors

1. The 41-tooth bevel gear of the accessory gearbox module 1 (MO1) accessory gear box failed due to high-cycle fatigue causing an uncommanded in-flight engine shutdown.

2. The dampening system of the starter-generator was found to be over-tightened which caused torsional oscillations (vibration) under certain operational conditions. This most likely contributed to the high-cycle fatigue failure of the 41-tooth bevel gear.

Safety Action Taken

Eurocopter has issued the following two alert service bulletins to check for the proper adjustment of the torque dampening system on Unison starter-generators installed on the Eurocopter fleet of aircraft:

- AS 350 Alert Service Bulletin No. 80.00.07 Rev.0 dated 19 December 2008
- EC 130 Alert Service Bulletin No. 80A003 Rev.0 dated 19 December 2008

In July 2008, Turbomeca issued Service Bulletins (SB) No. 292 72 0325 and No. 292 72 2090 regarding, respectively, TU 325 modification for Arriel 1 and TU 90 modification for Arriel 2 engines. According to Turbomeca, the aim of these modifications, which introduce a 41-tooth bevel gear with a thickened rim, was to improve the tolerance of the 41-tooth bevel gear to dynamic stress caused by high or excessive levels of electrical power tapped from the generator. The application of the SB was as follows:

- Systematic on the new engines for Sikorsky S76 and single-engine Eurocopter helicopters;
- At the operators request for engines in service; and
- In case of replacement of the 41-tooth bevel gear during repair of module 01.

However, given the results of its investigations, Turbomeca has concluded that TU 90 and TU 325 do not resolve the last two occurrences of 41-tooth bevel gear failures or other situations where a starter-generator is installed with an incorrectly adjusted dampening system. Turbomeca can only confirm that the new design is at least as robust as the current design relative to abnormal vibration and torsional oscillation.

As well, the European Aviation Safety Agency has issued Airworthiness Directive (AD) 2009-0004 requiring mandatory compliance with the service bulletins.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 07 May 2009.

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