AP-3C Reduction GearBox In-Flight Failures

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Scope

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AP-3C Overview

- The AP-3C is operated by 10SQN and 92WG at RAAF Base Edinburgh

- Mission mix includes:
  - Land and maritime surveillance,
  - Anti-submarine and anti-ship warfare
  - Naval fleet support
  - Search and rescue operations

- Support and Sustainment Organisations
  - Surveillance and Response Systems Program Office
  - Multiple ADF Agencies (DASA, NDT&CT, ALSMU)
  - Industry Partners (Airbus, BAE Systems, Raytheon, Standard Aero)
The AP-3C is a 4-engine, propeller driven aircraft

- Allison T-56-A-14 single spool axial-flow engine
  - Power Section Assembly
  - Accessory Gearbox Assembly
  - Reduction Gearbox Assembly
  - Torquemeter Assembly
- Hamilton Standard 54H60-77 propeller
Background – Increased RGB Failures

Failures

- The RAAF has experienced six RGB failures from Jun 16 to Apr 17.
- Five failures occurred in flight.
- 5 x Alternator Drive Shaft failures (known failure mode)
- 1 x Front Pinion Bearing Failure

Reduction Gear Assembly (Accessory Drives). The Alternator Drive Shaft is highlighted red, the Hydraulic Pump Idler Spur Gear is highlighted green and the Alternator Drive Spur Gear is highlighted blue [4].
Reduction Gear Box Failures and Reliability

![Gear box with labels: Not Installed in RAAF Rules, Failed Gear, No Rotation](image-url)
Background – Aircrew Response

Narrative of 2 events

“After take-off the aircraft was passing 700ft in the climb, with normal-rated power set. A loud bang was heard, associated with significant yaw and indications of power loss from the number one engine…The crew elected to pull the e-handle of the number one engine. After the e-handle was pulled, the chips annunciator remained illuminated….A PAN was declared and the aircraft returned to the vicinity of RMAF Butterworth.”

“Approximately 6 hrs into flight, the #3 RPM gauge started to fluctuate erratically 100 +/- 4% and detected audibly, the #3 sync servo was immediately turned off. As soon as the #3 sync servo was turned off the engine suffered a total power loss accompanied with a chips light. The propeller was sitting on 38% RPM and was subsequently secured with the e-handle. Aircraft returned to base.”
Background – Increased RGB Failures

- This was inconsistent with prior failure rates, with no in-flight RGB failures in the last six years.

![Drive Shaft Failures Graph](image-url)
StandardAero Breakdown Report

- Minor, normal fuzz on Mag Plug. No major debris in oil.
- Oil dark but no major shavings found in RGB
- RGB still coupled to engine.
- Power Section rotated with no indication of scraping or bearing roughness.
- When rotating the Starter Motor Drive Spline, the Input Shaft, Prop Shaft and Generator Shaft rotate. However, when hand pressure/resistance is applied to the EDC Shaft Drive, the EDC Shaft, Tachometer Generator and Oil Pump Shafts do not rotate.
- Scavenge Pump Idler Gear found freely rotating on Alternator Drive Shaft
Photograph of the Alternator Drive Shaft which was worn on the splines that contacted the Alternator Drive Spur Gear and the Hydraulic Pump Spur Gear.

Photograph showing the different wear profiles on the Alternator Drive Shaft where it contacted the Alternator Drive Spur Gear and the Hydraulic Pump Spur Gear.
Investigation – Considerations

- The RAAF has an 8,000 ENHR overhaul soft-life policy, while other operators have overhaul intervals of between 6,000 and 6,600 ENHR.
- The RGBs failed between 2000 and 6000 ENHRs since overhaul/new.
  - None exceeded the RAAF 8,000 ENHR soft overhaul life.
Investigation – Considerations

- The RAAF has nickel plated components (based on Rolls Royce CEB 72-266) in its RGBs to reduce accessory drive shaft spline wear by decreasing relative movement between accessory drive shafts and gears.

- Alternator Drive Spline failures are a known failure mechanism across T56-A-14 users. Rolls Royce produced a modification via ATP18639 that was adopted by some P-3 users, however the RAAF did not incorporate. This kit is no longer available.
  - Rolls and Lockheed investigation revealed that increased capacity Environmental Control System cause more load on the Engine Driven Compressor (EDC). Original EDCs were 84 HP and increased through modification to 121HP. The increased capacity EDCs caused more load on the RGB Accessory Drive gear train, which resulted in the shaft failures.

- Five of the six RGBs failed in inboard positions, where the EDC is located.
  - The installation location of RGBs has not historically been recorded.
Investigation - Actions

• Since Jun 16, the RAAF:
  – Sampled oil from the RGB and Power sections of four failed engines.
    • The oil was found serviceable in each case.
  – Reviewed RAAF mission mix from the last 10 years.
    • Based on possible relationship to EDC overload at lower altitudes.
  – Reviewed the effect of other modifications to the Environmental Control System.
  – Reviewed maintenance history, component changes and modifications applicable to the RGBs.
  – Engaged DST Group for forensic investigation of the failure mode to verify it was the known failure mode.
Investigation – Results

- Changes in mission mix over the last 10 years have led to an increase in lower altitude maritime tasking.
  - 50% of missions are now lower altitude maritime tasking versus 10-25% from 2007/2008 to 2009/2010.
  - Likely put additional strain on the EDC’s

- DST Group analysis indicates the damage was the result of Fretting Fatigue, the known failure mode
  - Not detectable via Wear Debris Analysis.
Management

• StandardAero Limited innovated a unique borescope inspection.

• Using a specially made SAL guide tube and a 4mm borescope probe, the Inspector would slip the borescope through the upper starboard pad on the rear of the RGB to a point between the two gears mounted to the Alternator Drive Shaft Assembly.

• The Inspector would rock the EDC drive and look for wear and debris.
No microphone available. Recording without audio.
Management

• The Wear Rate was broken into 6 categories:
  – Stage 1 - No signs of wear; no staining, no metal debris, no relative movement.
  – Stage 2 - Initial signs of wear; black staining.
  – Stage 3 - Additional wear; metal debris between gears on shaft.
  – Stage 4 - Additional wear; metal debris flung out on web of gear.
  – Stage 5 - Loss of interference fit, minor relative movement between the gears and shaft.
  – Stage 6 - Loss of interference fit, significant relative movement between the gears and shaft.

• Inspection had to be conducted by limited number of very experienced technicians IOT ensure consistency of results
Stage 1 Wear
Stage 3 Wear
Stage 4 Wear

Debris On Web
Debris In Groove
Management

- The RAAF sent 10 RGBs for overhaul and replacement of the alternator drive shaft.
- The fleet was inspected and poor health RGBs were removed from inboard positions. CAT 6 RGBs were removed from aircraft.
- SRSPSO and StandardAero developed a Deviation, using DVI policy, which required on-going inspections of the RGBs based on wear category and engine placement
- Management of RGB issue under DASRs
Management

- The DVI policy was associated with each individual serial-numbered RGB.
  - All Wear Stage RGBs are to be re-inspected at R2 (60 ELPWKS) interval.
  - Wear Stages 4 to 6 on inboard engines and 5 to 6 on outboard engines are to be re-inspected at S10 (160 AFHRS) interval.

- Inspection results were recorded in CAMM2 using a specific sentence structure, which allowed a data-mining program to auto-populate a monitoring page.
  - “DVI-7948-002 carried out, RGB Serial Number RXXXX deteriorated to Wear Stage X. RGB SN RXXXX inspected IAW Deviation Orion 7948”
Close Out

- A collaborative approach by Commonwealth and Industry to solve an airworthiness issue, using several innovative techniques.

- On-going monitoring of Spline health through borescope inspections.
  - Only 1 RGB had its wear category downgraded in 20 months.

- Other operators who run the higher horsepower EDC with the original RGB designed for 84 HP EDC, probably have worn RGBs in the in-board position and should consider doing borescoping to monitor health.
Discussion Close
Questions?