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GENERAL CIVIL AVIATION AUTHORITY

United Arab Emirates

Air Accident Investigation Sector

Incident

- Summary Report -

AAIS Case Nº: AIFN/0005/2014

Uncommanded Engine In-flight Shutdown

Operator: Qantas Airways Limited
Aircraft Type: Airbus A380-842
Nationality and Registration: Australian, VH-OQL
Place of Occurrence: Dubai International Airport
State of Occurrence: The United Arab Emirates
Date of Occurrence: 27 March 2014

Investigation Objective

This Investigation was performed pursuant to the UAE *Federal Act No. 20 of 1991*, promulgating the *Civil Aviation Law, Chapter VII– Aircraft Accidents*, Article 48. It is in compliance with *CAR Part VI, Chapter 3*, in conformity with *Annex 13 to the Convention on International Civil Aviation*, and in adherence to the *Air Accidents and Incidents Investigation Manual*.

The sole objective of this Investigation is to prevent aircraft accidents and incidents. It is not a function of the Air Accident Investigation Sector (AAIS) to apportion blame or determine liability.

This Summary Report is made public at:

http://www.gcaa.gov.ae/en/epublication/pages/investigationReport.aspx

Investigation Process

The AAIS was notified about the occurrence via the Duty Investigator (DI) hotline (+971506414667). The AAIS immediately dispatched an investigator to Dubai International Airport.

After the Initial/Onsite Investigation phase, the occurrence was classified as an 'Incident'.

In accordance with *Annex 13,* the AAIS assigned an Investigation Team. The Aircraft State of Manufacturer and Design (France), the State of the Engine Manufacturer (the United Kingdom), and the State of the Operator and Registry (Australia) were notified and each of the States assigned an Accredited Representative to the Investigation. In addition, Singapore, being the State of the Engine Inspection, was notified. Italy, being the State of Manufacture of the Engine Gearbox, was also notified. The AAIS lead the investigation and issued this Summary Report.

This Summary Report is adapted from the Final Report format depicted in *Annex 13* in order to suit the purpose of this short investigation. This Summary Report is treated similar to the Final Report *Standard and Recommended Practices* set forth in *Annex 13*.

Notes:

1. Whenever the following words are mentioned in this Report with first Capital letter, they shall mean the following:
   - (Aircraft)- the aircraft involved in this incident
   - (Investigation)- the investigation into the circumstances of this incident
   - (Incident)- this incident referred to on the title page of this Summary Report
   - (Commander)- the commander of the incident flight
   - (Operator)- Qantas Airways Limited
   - (Report)- this incident Summary Report.
2. Unless otherwise mentioned, all times in the Report are UTC (Local time in UAE was UTC+ 4h).
3. Photos and figures used in this Report are taken from different sources and are adjusted from the original for the sole purpose to improve the clarity of the Report. Modifications to images used in this Report are limited to cropping, magnification, file compression, or enhancement of color, brightness, contrast, or addition of text boxes, arrows or lines.

Factual Information

History of the Flight

On 27 March 2014, at approximately 2147 UTC, a scheduled passenger flight operated by an Airbus A380 Aircraft, powered by four Rolls-Royce Trent 900 engines, departed from Dubai International Airport, the United Arab Emirates, as planned enroute to London, the United Kingdom. A total of 503 persons were onboard: 19 crewmembers and 484 passengers.

The takeoff and the initial climb were normal. Upon reaching approximately 2,000 feet (ft) altitude, an ECAM[1] warning message of ENG FAIL appeared indicating that No. 3 engine had failed. The engine had suffered an un-commanded In-flight engine shutdown (IFSD) prior to which all engine indications were normal. A PAN was declared by the flight crew, and they leveled the Aircraft at 6,000 ft.

At 6,000 ft, an unsuccessful starter assisted re-light of the engine was attempted by the crew. In addition, as per the crew statement, there was no rotation of the engine high pressure stage. The Commander initiated jettisoning of fuel for a return to the departure airport.

At approximately 2249 UTC, the crew performed an uneventful landing after approximately one-hour total flight time.

After the Aircraft arrived at the parking stand, the Operator's maintenance staff confirmed that the No. 3 (the right hand inboard) engine had sustained an internal failure as was clued by the engine master chip detector which contained several metal chips. Visually, the engine did not show any signs of external damage.

There were no injuries to the passengers or crewmembers.

Aircraft Information[2]

Engines data

Table 1. Aircraft/engine data				
Type and model: Rolls-Royce Trent 972-84				
Engine Position	No. 1	No. 2	No. 3	No. 4
ESN	91155	91135	91137	91103
TSN	11816	8960	12871	12507
CSN	1070	819	1173	1149

Engine description

The RR Trent 900 engine is a three shaft high bypass ratio, axial flow, turbofan with low pressure (LP), intermediate pressure (IP), and high pressure (HP) compressors driven by separate turbines through coaxial shafts.

Figure 1 is a cross-section of the Trent 900 engine showing the engine compressor, turbine stages and the location of the SAGB.

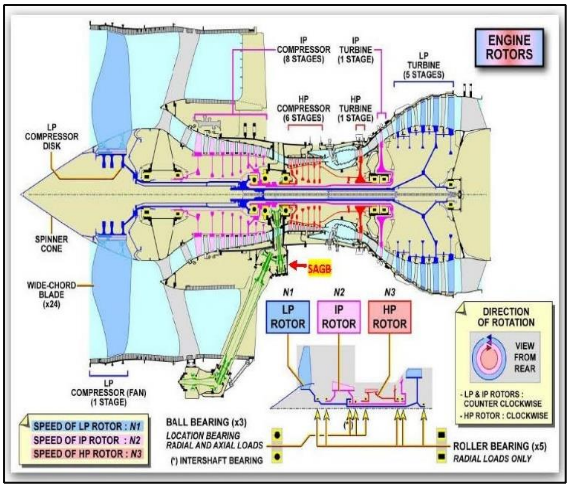

Figure 1. Cross Section View of RR Trent 900 Engine

The LP compressor fan diameter is 2.95 meters with a swept fan blade and outlet guide vanes (OGV) to increase efficiency and reduce noise. The combustion system consists of a single annular combustor.

The LP and IP assemblies rotate independently in a counter-clockwise direction, whereas the HP assembly rotates clockwise, when viewed from the rear of the engine. Table 2 illustrates the construction stages of the compressor and turbine.

Table 2. Rolls-Royce Trent 900 engine, compressor and turbine information	
Compressor	**Turbine**
LP – Single stage	LP – 5 stage
IP – 8 stage	IP – single stage
HP – 6 stage	HP – single stage

Significant aircraft system reported messages

During the previous flight to Dubai, the Aircraft engine health monitoring (EHM) recorded an advisory message for debris detected on the No. 3 engine electrical magnetic chip detector [3] (EMCD) at

[1] ECAM is Airbus terminology denoting electronic centralized aircraft monitor (ECAM) that monitors aircraft functions and relays information on them to the pilots on cockpit display units. It also produces messages detailing failures, and in certain cases, lists procedures to undertake to correct the problem.

[2] Information provided by the Operator.

[3] The electric master chip detector (EMCD) is installed in the scavenge return line on the forward side of the oil tank. The EMCD is a two-pole magnet detector unit with an electrical connection to the engine electronic controller (EEC). If metallic contamination in the oil makes a connection between the two poles, a change in the current through the EMCD will happen. The change in current will cause an indication of metal

approximately 1859 UTC. The engine continued operating uneventfully without any abnormal engine parameter shift that might require flight crew attention.

During the transit at Dubai Airport, the defect was deferred, and the Aircraft was released to service according to item 79-35-01 of the onboard *Minimum Equipment List (MEL)*, which refers to ECAM message ENG3 OIL CHIP DETECTED.

After departure, a second EMCD debris message was recorded at approximately 2149 UTC. This was followed by the un-commanded engine shutdown and the ECAM warning message.

Initial inspection following the Incident flight

The following actions were taken after the Incident flight:

1. The Operator's engineering personnel reviewed the Aircraft generated post-flight report (PFR) which indicated engine failure code 7100W230.
2. This failure code was referred to the Aircraft *Troubleshooting Manual (TSM)* 71-00-00-810-805A– Engine Flameout.
3. The inspection of the N1 and N2 stages did not reveal any finding.
4. The engine EMCD was inspected and fuzzy deposits with metal contamination were observed.
5. The engine was manually cranked via the external gear box (EGB), and while the EGB spun, there was no associated N3 rotation.
6. The front and rear inspections found the engine clean with no metal observed in the exhaust jet pipe.
7. The fan rotated, wind milling freely.
8. The initial inspection of the step-aside gear box (SAGB) found internal damage.
9. The Aircraft could not be returned to service due the No. 3 engine inspection findings.

Accordingly, the Operator shipped the EMCD for laboratory analysis, but upon arrival at the laboratory, none of the debris initially observed on the EMCD (when it was removed from the engine) was still attached to the magnet.

No. 3 engine history

The Engine, RR Trent 972-84, serial number (S/N) 91137, rated at 72,000 lbs thrust, entered into service in January 2011, and was installed on position No. 3 of the A-380 (MSN 0074). At the time of the event, the engine had a life of 1,173 cycles since new (CSN), and 12,871 hours since new (TSN). The Incident Aircraft had all certificates valid at the time of the occurrence.

In June 2013, during a shop visit for the removal of the high pressure turbine (HPT) disc due to time expiry, the SAGB bearing support

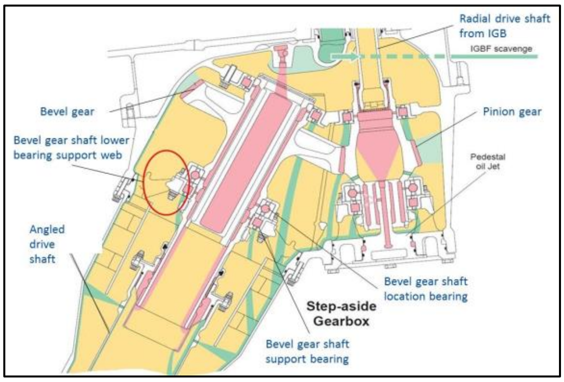

Figure 2. Schematic of step aside gearbox (SAGB)

was found damaged and it was replaced.

Since the shop visit, the engine operated 198 cycles, 2,224 hours, all on the Incident Aircraft.

Analysis

Inspection of the SAGB

The drive for the EGB comes from the high pressure spool of the engine. Manual engine cranking was done by attaching a turning tool to the EGB in order to rotate the drivetrain to the engine's HP spool. The EGB rotated manually by the engine cranking, but the HP spool did not rotate indicating a likely disconnection. As the engine fuel and oil pumps were driven by the

contamination in the oil to be displayed. Indication of metallic oil contamination on the EMCD is displayed on the electronic centralized aircraft monitoring (ECAM) in the cockpit. If an indication is given from the EMCD it must be removed and examined. The quantity and type of contamination on the EMCD will give an indication of the general condition of the engines lubricated internal components.

EGB, a disconnection in-flight would cause an un-commanded engine shutdown.

Based on these observations, a preliminary inspection of the drive system was carried out and damage was noted in the SAGB.

Borescope inspection of IGB/EGB/TGB

A borescope inspection of the internal gearbox (IGB), EGB, and transfer gear box (TGB) was carried out and no secondary or primary damage was observed in any of these gearboxes. The original timing marks were correctly aligned between the driveshaft, adapter and coupling. In addition, the radial driveshaft was confirmed to have moved slightly down and no damage to the driveshaft was noted. The EGB, TGB, and the angled drive shaft (ADS) were removed from the engine and returned to the manufacturer for examination.

Angled drive shaft

The ADS balance records (at manufacturing) indicated that the shaft was within the acceptance limits and had been accepted for manufacture with radial run-out that was very slightly above the upper tolerance limit. A new balance test of the shaft in the as-received condition revealed an unbalance condition outside of the acceptance limits. The drain holes were confirmed to be free of blockage and no abnormal wear was observed on the ADS splines.

As a result of a major quality investigation, the imbalance condition was found to be real. The cause was identified to be the balancing process variability, and that there had been insufficient quality controls in place to ensure process consistency.

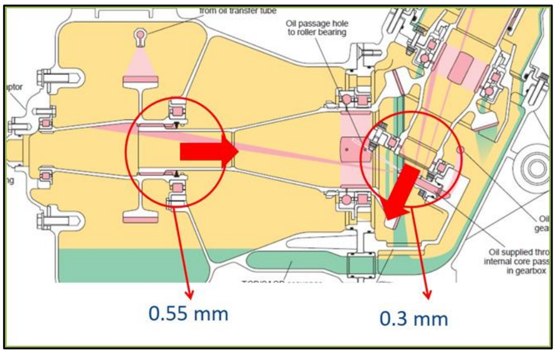

Figure 3. TGB showing bearing displacement

Transfer gear box (TGB)

Minor displacement noted in two bearing locations within the TGB. This was considered to be non-contributory to the event. (Figure 3).

Step aside gearbox (SAGB)

The preliminary inspection revealed fractures of the cast webs of the SAGB driven bevel bearing support. (Figure 4).

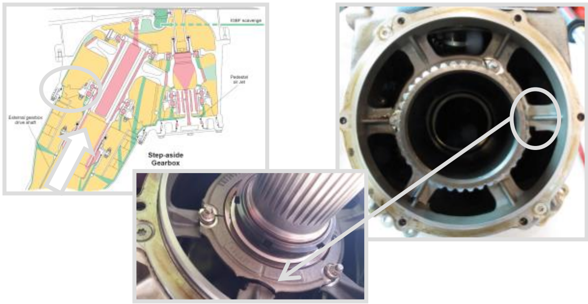

Figure 4. SAGB Bevel bearing support web

Figure 5 illustrates a closer view of the cracked webs which indicates the bolted webs cracked (two cracks adjacent to the bolt holes and one crack through bolt hole) and the arcs between bolt positions worn to different extents. The Incident SAGB was removed and sent to the manufacturer for a detailed inspection.

The borescope inspection revealed damage and displacement of the driven bevel gear (figure 6). A significant amount of debris

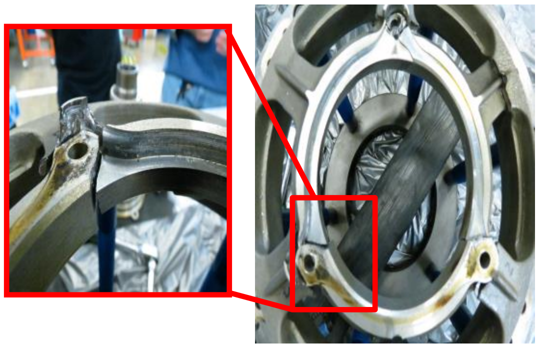

Figure 5. SAGB support web cracks (close-up)

was retrieved from the oil pump inlet screen

Figure 6. Damaged bevel gear

(figure 7) and sent for further analysis. The gear material was Pyrowear 53 and the bearing support webs material was Al-Si Alloy. However, no bearing material was present.

Figure 7. Debris from oil pump screen

Engine parameters- data analysis

As mentioned earlier (in Engine Description); disconnection of the drive between the EGB and the IGB during engine operation would lead to loss of drive to the engine oil and fuel pump causing an engine shutdown. The IGB is driven by the HP spool of the engine.

Figure 8 shows the effect of the Engine speeds, N1/N2/N3, and fuel flow following the disconnection.

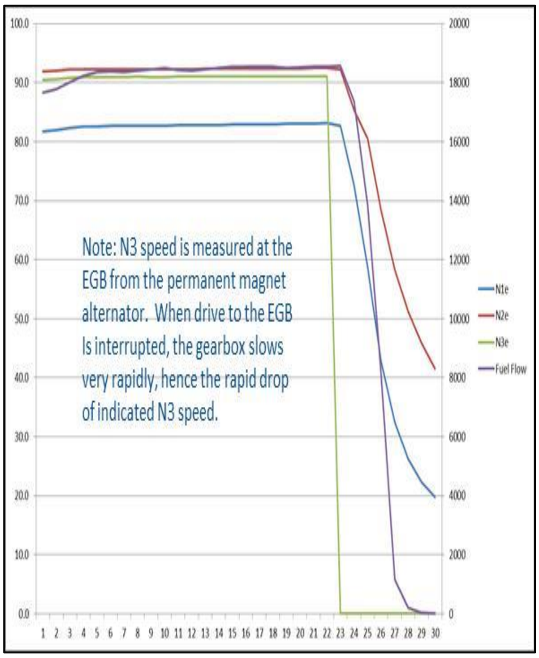

Figure 8. The effects of the HP spool disconnection

Vibration data analysis

Additional examinations

Hardware was examined in the laboratory at the SAGB manufacturer (Avio Aero). A cracked lower bearing support from another engine was examined by Avio and Rolls-Royce in the Rolls-Royce laboratory. These examinations identified that crack had initiated from stress concentration features resulting from the wear step generated on the lower bearing support. Examination of the fracture surface in the scanning electron microscope (SEM) identified characteristic of propagation under a high cycle fatigue mechanism.

A stress review between Rolls-Royce and Avio Aero was performed. The difference between starting loads and engine running loads was agreed.

Analysis of the bolted joint at the interface of the bearing with the lower bearing support found that the original, specified bolt torque did not produce a sufficient clamping load to prevent relative movement between the components during engine running. This was identified as the primary root cause.

The ADS imbalance condition was concluded to exacerbate the movement and was therefore a contributory factor that influenced the rate of wear. Any out-of-tolerance radial run-out of the ADS would also influence the out-of-balance at high shaft speeds and was therefore concluded to be contributory factor.

Further analysis, with increased bolt torque applied, demonstrated that the increased clamping load at the joint would prevent movement when a correctly balanced and in-tolerance ADS is installed. The analysis also indicated that there was reserve margin in the current design under these conditions.

The major quality investigation at Avio Aero identified the reason for the ADS unbalance condition. This resulted in effective, remedial processes being incorporated that addressed the imbalance condition and identified shafts with unacceptable radial run-out.

Conclusions

Cause

The Air Accident Investigation Sector determines that the cause of the inflight engine shutdown was the mechanical damage of the SAGB that had resulted in a loss of drive to the EGB.

The loss of drive resulted in the uncommanded shutdown of the engine along with the disconnection of the fuel pump fuel, oil pumps and generators, which were driven from the EGB. The primary root cause was insufficient clamping load to prevent relative movement between the SAGB driven bevel gear shaft lower support bearing and the bearing support housing.

Safety Recommendations

Safety actions taken

Actions taken by Avio Aero - production and overhaul

The SAGB manufacturer issued *Service Bulletin (SB) AVIO-T900-72-004*, introducing the following modifications and improvements:

- The bolt torque is increased from 8.8 Nm-10.8 Nm. (78 lbf.in-96 lbf.in) to 11.5 Nm. (100 lbf.in) in-line with Rolls-Royce recommendations.
- The SAGB manufacturer amended accomplishment instructions to incorporate best practice for flange bolt torque tightening in-line with Rolls-Royce recommendations.
- A new balance procedure has been implemented at both new production and overhaul.
- The SAGB manufacturer has demonstrated that the balance procedure is robust and repeatable.
- The SAGB manufacturer has introduced a new optical measurement system for the ADS run-out.
- The optical measurement is being applied to all new ADSs and also service run shafts.
- As a result, a small number of service run shafts have been rejected for radial run-out anomalies and have been replaced with new shafts.
- Concessions for geometry deviation are no longer accepted.
- The SAGB manufacturer has revised the *Component Maintenance Manual (CMM)* to incorporate the changes to cleaning, inspection and assembly and also the revised bolt torque tightening.
- Corrective action to remove debris from the support bearing outer race has been introduced to the overhaul procedure as well as additional inspections and checks at bearing installation.
- No clearance is allowed between the bearing race and the support housing. (Also instructed in *RB.211-72-J023*).
- The cleaning, inspection and assembly revisions are currently instructed in the process route cards.

Actions taken by the engine manufacturer

<u>Production and overhaul assembly</u>

RR *SB RB.211-72-J023* was published on 9 December 2014. This *SB* introduces an increased tightening torque for 20-off bolt joints in the SAGB assembly to mitigate the risk of relative movement between components.

The *SB* incorporates Avio Aero *SB AVIO-T900-72-004*, which details the accomplishment instructions. *SB RB.211-72-J023* is applicable to both new production and overhaul, both of which are exclusive to Avio Aero.

An *Immediate Operational Requirement* document *(IOR) 72-H974 Rev. 1,* was issued on 14 January 2015 to increase the torque at the three bolt positions at the interface between the lower bearing outer race and the bearing support. This will provide improved joint clamping load, as introduced by *SB RB.211-72-J023*, at the critical interface.

The *IOR* is applicable to 22 uninstalled SAGB assemblies that had already been built to pre-modification standard.

<u>IFSD investigation: containment</u>

As a result of findings during the Investigation, Rolls-Royce issued *Non-Modification Service Bulletins (NMSB)* to instruct actions necessary to mitigate other similar IFSD events.

NMSB 72-H838 (revised on 28 August 2014) instructs the removal of hardware from 13 in-service engines, which was completed. In addition, it instructs the return of SAGB and ADS hardware to Avio Aero for reassessment, which includes balance and geometry checks on the ADS in accordance with new procedures.

NMSB 72-H792 (issued on 29 October 2014) instructs on-wing inspection of all engines to look for evidence of cracking in the SAGB lower bearing support and also instructs acceptance and re-inspection criteria.

NMSB 72-H971 (issued on 12 December 2014) was issued to remove SAGB hardware from 10 engines that have been overhauled where there was the potential for aluminium debris to have been left on the lower bearing outer race mating flange. Hardware replacement has been completed on all ten engines.

Eight SAGB assemblies have been assessed. Four have already been confirmed to have residual aluminium debris on the lower bearing outer race mating flange and are being rectified by Avio Aero and all assemblies will be rebuilt to embody SB RB.211-72-J023.

NMSB 72-J100 (issued on 9 May 2016) defined the criteria for repeat inspections and the modification standard embodiment required for alleviation of inspections between shop visits.

Documentation

The engine manufacturer has, through the SAGB manufacturer, completed a revision of engine manual and component maintenance manual publications to incorporate revised torque tightening and other best practice.

IFSD Investigation: Containment- All *NMSB Inspection Findings*

Table 3. All fleet inspections

Inspection	Number of Engines	%
Cracked	11	4.3
Loose Bolts	10	3.91
Frettage	17	6.64
No findings	218	85.16
Total engines inspected	266	

In accordance with the engine manufacturer data, engines inspected, worldwide, since March 2014 and revealed the results shown in tables 3 and 4.

Table 4. All non-modification service bulletins specific inspections results

	No Findings	Frettage	Loose Bolts	Cracked
H838 (On Wing High Risk Concern)	1	5	5	3
H838 (In Shop)	21	11	3	1
H792 (>2500 Hours On Wing)	190	0	2	7
H971 (Build Quality Concern)	6	1	0	0
Total	218	17	10	11

Work in Progress

Approximately 20% of rejected lower bearing supports exhibit visual evidence of non-uniform seating of the washer at one or more bolted positions.

The gear box manufacturer reviewed the component tolerance stack-up for the lower roller bearing to support housing bolted joint and concluded that the possibility exists for the bolted joint washer to encroach into the corner radius of the lower bearing support housing in the event of an adverse tolerance stack.

Washer encroachment is mitigated by graphical in-shop instructions at both new production and overhaul, pending issue of minor modification to the pocket geometry.

The engine manufacturer, along with the gear box manufacturer, will continue to embody *SB RB.211-72-J023* and improved drive shafts across the fleet at every available opportunity.

Additionally, a 3-plane balance process for the ADS has been developed which will further improve shaft balance resolution. The 3-plane balanced shafts (to *SB RB.211-72-J139* standard) are have been made available from 28 January 2016. Incorporation of both *SB RB.211-72-J023* and *SB RB.211-72-J139* remove the requirement for on-wing inspections between engine shop visits.

Summary Report Safety Recommendations

There are no safety recommendations issued after this Investigation.

This Summary Report is issued by:

The Air Accident Investigation Sector
General Civil Aviation Authority
The United Arab Emirates

P.O. Box 6558
Abu Dhabi, United Arab Emirates
E-mail: ACCID@gcaa.gov.ae
Website: www.gcaa.gov.ae