Analysis of Civil aircraft Electrical Power System Load Shed Issue Based on QAR Data

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Abstract. As the significant recording equipment of civil aircraft, Quick Access Recorder (QAR) record the operation status of the aircraft system and QAR Data is the important basis for safety assessment, maintenance check and fault analysis. About civil aircraft system faults or fails, sometimes we can’t give a reasonable explanation just based qualitative analysis. Via the integrity and accuracy of the QAR Data, the crew can give quantitative analysis and get exact determination. Based on the quantitative analysis of the relevant QAR Data, this paper has found the Load Shed caution root cause of a certain type of aircraft.

1. Introduction
Under normal power supply mode, Electrical Power System provides power for the whole aircraft system. However, in some special power supply conditions, GCUs (Generator Control Units) shall shed all non-essential loads in order to ensure normal operation of aircraft as much as possible. For example, LOAD SHED logic of a certain type of civil aircraft is that if one GCU enters an overload condition or when the aircraft is in air mode and only a single generating source is on-line GCUs shall shed electrical loads such as kitchen, bathroom, and reading lights in the cabin. When the LOAD SHED logic is triggered, a ‘LOAD SHED’ caution will be displayed on EICAS to tell the crew take corrective compensatory actions. During one certain flight of this type of aircraft Load Shed was triggered during gliding phase after landing when the aircraft was powered by a single generating source APU Generator. There were not relevant CAS (Crew Alerting System ) and CMS (Central Maintenance System) messages when the issue happened. Hence, in order to find the root cause of the caution QAR data need be analyzed in conjunction with system principle.

QAR is an airborne data recording equipment which records exactly the operation parameters of each system every other second. QAR record the flight data obtained from DCU (Data Concentrator Unit) to the compact flash card. The flash memory card can be detached or be connected to a laptop or a portable data downloader with a USB interface. The recorded flight data is downloaded and sent to the ground station for reading. The maintenance engineer converts the read raw data into identifiable data. The QAR data can be used to analyse and monitor the flight status of the aircraft system. All analyses are aimed at this type of aircraft below.

2. Load Shed Philosophy
Electrical Power System of the certain type of civil aircraft is comprised of two main AC channels each of which powered by an Integrated Drive Generator (IDG), an Auxiliary Channel powered by an Auxiliary Generator , and an Essential Channel powered by a Ram air Turbine driven AC generator.
The primary load distribution for the power sources is controlled through three Power Distribution Assemblies (PDAs). These PDAs house the system distribution buses, contactors, and current transformer assemblies. The main system includes three Generator Control Units (GCUs) and one Bus Power Control Unit (BPCU) to control the Electrical Power System.

Electrical Power System Load Shed includes Configuration Load Shed and Overload Load Shed. When the aircraft is in air mode and only a single generating source is on-line the GCUs shall shed all non-essential loads, called Configuration Load Shed. Independent of aircraft configuration, if a GCU enters an overload condition that generator phase current greater than 122 +/−5 amperes for 150 +/−1 seconds or generator phase current greater than 152+/-5 amperes for 2.5+/-0.1 seconds GCUs shall shed all non-essential loads, called Overload Load Shed.

Figure 1. Electrical Power System Configuration Load Shed Schematic Diagram

Electrical Power System Configuration Load Shed Schematic Diagram is shown in Figure 1. For the GCUs, the air/ground determination is based on an input from the Weight on Wheels (WOW) switch and an input from the engine tach. DCU will transmit WOW signal received from Position and Actuation Control Unit (PACU) to GCUs via ARINC 429 BUS. The engine tach input received by the main channel GCUs shall be compared to predetermined setpoints to determine if the engine is operating above or below air mode speed. For the AGCU, air/ground information is forwarded from the main channel GCUs via 1553. The AGCU shall compare the data from both the LGCU and the RGCU to determine its air/ground state. To transition the AGCU to ground mode, the LGCU and RGCU must both be in the ground state. When the aircraft is in air mode and only a single generating source is on-line the GCUs shall shed all non-essential loads by simultaneously drive the Left and Right Load Shed Relay.

Either Configuration Load Shed or Overload Load Shed meet the Load Shed condition, the GCUs shall provide +28 V dc to drive Left and Right Load Shed Relay to close.

3. Analysis of Load Shed reasons based on QAR data
Overload Load Shed situation generally caused by feeder line problems or electromagnetic interference (EMI). When overload occurs there will be an OVERCURRENT information displayed in Central Maintenance System. The Left IDG, Right IDG and the APU Generator feeders are protected with shielding layer and no circuit problems was found through inspection. Meanwhile, there were no
any relevant OVERCURRENT information in CMS. Hence, Load Shed caused by Overload can be excluded.

When the aircraft is in air mode and only a single generating source is on-line then there will be a Configuration Load Shed. For the GCUs, the air/ground determination is based on an input from the Weight on Wheels switch and an input from the engine tach. The air/ground logic shall be set to the air mode if the WOW input indicates air mode OR if the N2 speed is operating above 72.38% (12,422 +/- 97 rpm) and after a time delay of 1 +/-0.1 second. The air/ground logic shall be set to ground mode if the WOW input indicates ground and the N2 speed is less than 72.38% (12,422 +/- 97 rpm) and after a time delay of 30 +/-1 seconds. Hence, either the WOW signal or the N2 speed meet the air mode condition the aircraft will be determined in air mode. Specific aircraft mode and power configuration when Load Shed happened can be obtained through QAR data.

3.1. Analysis of Load Shed logic based on WOW signal

During cruising phase, the aircraft is powered by L IDG and R IDG and the APU Generator is not available. The pilot shall start the APU Generator before landing or during gliding phase. During gliding phase, the pilot shall shut down L IDG and R IDG then the aircraft is powered by the APU Generator. At last, when aircraft stop operation, the APU Generator is shut down. In the process above, there might be only a single generating source on-line when the aircraft is in air mode due to misoperation. In order to find out specific aircraft mode and power configuration during landing and gliding phase, L IDG, R IDG, APU Generator state and WOW signal data acquired from QAR need be analyzed.

Table 1. Generator State and WOW Signal

| Relative Time | L IDG | R IDG | APU GEN | MLG LH WOFW sensor1 | MLG RH WOFW sensor1 |
|---------------|-------|-------|---------|---------------------|---------------------|
| 1:39:31       | 0     | 0     | OFF     | 1                   | 1                   |
| ...           | ...   | ...   | ...     | ...                | ...                |
| 1:39:50       | 0     | 0     | OFF     | 1                   | 1                   |
| 1:39:51       | 0     | 0     | OFF     | 0                   | 0                   |
| ...           | ...   | ...   | ...     | ...                | ...                |
| 1:40:45       | 1     | 1     | 0       | 0                   | 0                   |
| ...           | ...   | ...   | ...     | ...                | ...                |
| 1:41:00       | 1     | 1     | 0       | 0                   | 0                   |

Table 1 is relevant parameters data extracted from QAR data of one certain flight in which Load Shed happened. Relative time refers to time compared to the initial time 0:0:0 when the flight data is first recorded. L IDG OFF, R IDG OFF and APU GEN OFF refer to corresponding generator state. Value '1' means the Generator is shut down and '0' means the Generator is started. Left Main Landing Gear (LMLG) and Right Main Landing Gear (RMLG) have two WOW Proximity Sensors respectively to detect position of aircraft. In QAR data, values of the two WOW Proximity Sensors are the same, so we just choose one of them here. MLG LH WOFW (Weight Off Wheel) sensor1 and MLG RH WOFW sensor1 refer to the position of Left Main Landing Gear and Right Main Landing Gear. Value '1' means the Landing Gear is in air position and '0' means the Landing Gear is in ground position (aircraft landed).
The Landing Gear WOFW signal is shown in Figure 2. It can be seen in the figure that the parameters change from 1 to 0 at 1:39:51 which means the aircraft landed at that moment. According to the air/ground logic GCUs will determine the aircraft as Ground mode 30 seconds later at 1:40:21. Before 1:40:21 GCUs determine the aircraft as air mode. When the aircraft is in air mode and only a single generating source is on-line there would be a Load Shed caution. Whether there was only a single generating source before 1:40:21 shall be analyzed below.

The Power Configuration of EPS Curve between 20 seconds before landing and 20 seconds after only a single generator powering the aircraft is shown in Figure 3. It can be seen in the figure that the parameter L IDG OFF changes from 0 to 1 at 1:40:41 and parameter R IDG OFF changes from 0 to 1 at 1:40:45 which means the aircraft is powered by APU Generator (only a single generator) after 1:40:45. Hence, there was not a single generating source before 1:40:21. And the situation that only a single generating source was on-line when the aircraft in air mode (determined based on WOW signal) is excluded.

3.2. Analysis of Load Shed logic based on N2 speed signal

Figure 2. WOFW Signal Curve

Figure 3. Power Configuration of EPS Curve
Another signal for GCUs to determine the air/ground mode is N2 speed signal. N2 speed is High Pressure Compressor rotor Speed of the engine. The air/ground logic shall be set to the air if the N2 speed is operating above 72.38% (12,422 +/- 97 rpm) after a time delay of 1 +/- 0.1 second. The air/ground logic shall be set to ground mode if the N2 speed is less than 72.38% (12,422 +/- 97 rpm) after a time delay of 30 +/- 1 seconds. In order to find out specific aircraft mode (determined based on N2 speed signal) and power configuration during landing and gliding phase, L IDG, R IDG, APU Generator state and N2 speed signal data acquired from QAR need be analyzed.

Table 2. Generator State and N2 Speed

| Relative Time | L IDG | R IDG | APU GEN | L ENGINE N2(%) | R ENGINE N2(%) |
|---------------|-------|-------|---------|-----------------|-----------------|
| 1:39:31       | 0     | 0     | 0       | 89.6875         | 90.3125         |
| 1:39:32       | 0     | 0     | 0       | 90.25           | 88.75           |
| 1:39:33       | 0     | 0     | 0       | 88.1875         | 87.625          |
| ...           | ...   | ...   | ...     | ...             | ...             |
| 1:40:19       | 0     | 0     | 0       | 74.75           | 73.625          |
| 1:40:20       | 0     | 0     | 0       | 72.75           | 71.75           |
| ...           | ...   | ...   | ...     | ...             | ...             |
| 1:40:59       | 1     | 1     | 0       | 20.25           | 21.25           |
| 1:41:00       | 1     | 1     | 0       | 19.5            | 20.375          |

Table 2 is relevant parameters data extracted from QAR data. Besides L IDG OFF, R IDG OFF and APU GEN OFF signals, Values of L ENGINE N2 and R ENGINE N2 refer to speed of the Left Engine and the Right Engine.

![Figure 4. Engine N2 Speed Curve](image)

The N2 Speed Curve of Left Engine and Right Engine is shown in Figure 4. It can be seen in the figure that L ENGINE N2 was 72.75% and R ENGINE N2 was 71.75% at 1:40:20, then the N2 Speed of the two engines became lower than 72.38% after 1:40:20. According to the air/ground logic GCUs will determine the aircraft as Ground mode 30 seconds later at 1:40:50. Before 1:40:50 GCUs determine the aircraft as air mode. When the aircraft is in air mode and only a single generating source is on-line there would be a Load Shed caution. It can be seen in Power Configuration of EPS Curve (Figure 3) that the aircraft is powered by APU Generator (only a single generator) after 1:40:45. Hence, between 1:40:45 and 1:40:50, there was a single generating source when the aircraft is in air mode. Then the Load Shed was triggered.
According to the analysis, since Left IDG and Right IDG were shut down during gliding phase when the two Engines were still in a high speed based which GCUs determined aircraft was still in air mode, and then the Load Shed logic was triggered. In normal operation, the Engines must run in slow speed at least two minutes before being shut down. Hence, if pilots drive the aircraft in strict accordance with the procedures, there would not be a Load Shed Caution.

4. Conclusion
This paper analysed the Load Shed principle firstly. In conjunction with system principle and electrical circuit inspection the Overload reason was excluded. Then by extracting relevant parameters from QAR data, the paper analysed the two input conditions based on which GCUs determine the aircraft mode and the power configuration of EPS when the caution happened. By analysing the QAR data, we found there was a single generating source when GCUs determined aircraft still in air mode based on N2 speed. This situation had triggered the Load Shed. Meanwhile, the paper also explained how to prevent the issue happened again.

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