SERIOUS INCIDENT

Aircraft Type and Registration:	Saab 340B, G-NFLB
No & Type of Engines:	2 General Electric Co CT7-9B turboprop engines
Year of Manufacture:	1998 (Serial no: 340B-456)
Date & Time (UTC):	14 September 2021 at 1125 hrs
Location:	6 nm east of the Isle of Islay, Argyll and Bute
Type of Flight:	Training
Persons on Board:	Crew - 4 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Failed Generator
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	59 years
Commander's Flying Experience:	14,894 hours (of which 7,208 were on type) Last 90 days - 92 hours Last 28 days - 25 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and subsequent enquiries made by the AAIB

Synopsis

Following the intentional shutdown of the left engine for training purposes, the crew were unsuccessful in re-starting the left engine, owing to a failure of the right engine starter/generator. This resulted in the aircraft being in a one engine inoperative state on battery power only. The crew made a VOR approach to Campbeltown and landed safely about 40 minutes after the failure of the generator.

History of the flight

The crew departed Glasgow airport on G-NFLB for a training flight as part of a programme to convert crews to the type, which had recently been introduced into the fleet of the operator. The crew for the flight consisted of four persons:

- The commander was contracted by the operator to provide his services as a type rating examiner qualified to deliver training on the SAAB 340 aircraft and simulator; this enabled him to conduct engine shutdown and re-lights on the aircraft. The commander's primary employment was with another operator that operated in Scotland and had SAAB 340 aircraft in its fleet. The commander operated in the right seat for the flight and was delivering training on the handling characteristics of the aircraft.

- The trainee was a commander and nominated person with the operator. He was converting to type and operated in the left seat as pilot in command under supervision.
- The observer in the jump seat, was the operator's programme manager for the introduction into service of the SAAB 340. He had previously held training qualifications for the aircraft type.
- A further crew member, contracted to provide his services to the operator as a TRI and line trainer, was in the cabin, having completed his training earlier in the flight and subsequently swapped seats with the incident trainee.

The flight profile was intended to cover aircraft handling characteristics including stalling as well as an intentional in-flight engine shutdown and restart. This was to enable the trainee to experience the one engine inoperative (OEI) handling characteristics of the aircraft. (Experience from another operator indicated that the simulator exhibited more severe OEI handling characteristics than the actual aircraft.) The pre-flight briefing considered the threats and typical scenarios, such as failure to re-light an engine.

At FL120 in VMC, following completion of other demonstrations and exercises, the commander initiated a scenario involving a drop in oil pressure in the left engine, resulting in the shutdown of an engine in-flight. The commander then demonstrated OEI aircraft handling. For the engine re-light in-flight, the commander was PF, and the trainee was PM.

Prior to the re-light, the commander discussed the possibilities in the event of a start malfunction, including the vital actions. The commander then initiated a manual start for the left engine, which drew on the right engine generator. Engine speed was seen to stagnate at 40% N_g before dropping, resulting in an unsuccessful re-light.

A few seconds later, as the crew were discussing the hung start, the electronic flight instrument system (EFIS) screens went blank. The commander handed control to the trainee and the crew conducted a diagnosis, identifying that the right engine generator had failed. They performed relevant vital actions and carried out the emergency procedure for generator reset, but without success. The crew now recognised that the aircraft was flying on one engine only and electrically powered only by the batteries. Consequently, in addition to the loss of the flight instruments, among other systems lost, the Flight Management Computer (FMC) was also lost. At this point, in view of the aircraft state, the trainer in the cabin made a note of the time. He continued to monitor the time and advise the commander as appropriate throughout the rest of the flight.

The commander recognised that the key threat was time remaining to the exhaustion of battery power. He delegated the completion of the emergency procedure for the *Loss of Both Generators (Both Engines Running)* and the load-shed of non-essential electrical equipment to the observer. Meanwhile, he declared a MAYDAY and requested the weather for Glasgow, Prestwick, Islay and Campbeltown Airports.

The trainee, now as PF, focused on flying the aircraft, with only the standby instruments available, and descended the aircraft to FL100 in VMC in the area between the Mull of Kintyre and Islay. While there was a layer of cloud over the water below, the crew could see that the cloud was more widespread over the land; though they were able to see the southern end of the Mull of Kintyre through it.

The crew reviewed the situation using the decision analysis tool TDODAR[1] and considered a re-light of the left engine using battery power. However, they recognised that, after load shedding, the batteries would provide only 60 minutes power from full charge; they were concerned by how much battery power would be consumed in attempting a re-light, with the hazard that the re-light might not be successful. Consequently, they decided not to attempt a re-light. However, the crew decided to tie the battery busses together, even though this was not a stated action in the emergency procedure.

On reviewing the weather, the crew recognised that they would need to fly an instrument approach to be able to safely descend below minimum sector altitude (MSA) and make an approach to an airport. They recognised that the remaining aircraft systems only allowed a VOR or ILS approach to be flown by tuning the relevant frequency on NAV box 1 and the display of the Standby Omni Bearing Selector (OBS). The loss of the FMC removed the option to make a GNSS approach. The Radio Magnetic Indicator (RMI) and ADF were also not available.

The commander identified that while Prestwick only had an NDB approach available and was consequently not an option, Glasgow offered a VOR and ILS approach. While the weather at Glasgow was deteriorating with the cloud base likely precluding the availability of a VOR approach, the ILS remained possible. However, the commander discounted the option of making an approach to Glasgow owing to the time constraints resulting from the aircraft being powered only by the batteries. The weather at Islay and Campbeltown was more favourable, and these airports were visible through the cloud layers, but they only offered an GNSS approach. However, the commander had the Electronic Flight Bag (EFB) of his primary operator to hand; this included a VOR approach for Campbeltown which was approved for use by his primary operator. Consequently, the decision was made by the crew to make an approach to land at Campbeltown using the VOR approach.

The PM requested a radar vector for Campbeltown, and the PF descended the aircraft to MSA at which height the crew had sight of the surface through breaks in the cloud. The PF intercepted the final approach track for the VOR procedure and saw the runway at about 6 nm. The aircraft landed safely about 40 minutes after the right engine generator failed.

Footnote

1 TDODAR is a decision-making tool, often used in emergency situations to help structure the decision-making progress. The mnemonic stands for Time, Diagnose, Options, Decide, Act or Assign, Review.

Aircraft information

The Saab 340B is a regional aircraft powered by two General Electric CT7-9B turboprop engines. It can be configured to hold up to 36 seats, but in its role as a flying classroom, G-NFLB was configured with 33 seats.

There are four main electrical systems on the aircraft:

- a 28 V DC system, powered either from two engine driven generators, from two batteries or from an external power source.
- an emergency power system, powered from the ordinary DC system or from an emergency battery.
- a frequency-controlled AC system, powered from the DC system through a main or standby inverter.
- a "wild" frequency system used for ice protection only.

The two engine driven generators also serve as engine starters. These starter generators are controlled by separate generator control units (GCUs) which control the DC system and protect it against faults in the generation system. The GCUs also control the engine start cycle and disengage the starter at 55% N_g.

An external power receptacle on the right aft fuselage wing fairing (Figure 1) allows a ground power unit (GPU) to be connected to the aircraft. Under normal circumstances engine starts are carried out with the GPU connected, as it has been found that repeated battery starts can damage the batteries and reduce their service life. When using external power to start the engines the left engine is normally started first. Once the engine is stabilised the GPU is disconnected, and the right engine can be started using cross fed power generated from the left engine. Starting the right engine first would create a hazard for the ground operations staff when disconnecting the GPU in the propeller wash from the engine.

During an in-flight engine start the opposing engine's generator, in combination with aircraft batteries, will provide the electrical power to start the engine. Although an engine start can be conducted from the main batteries alone, it can significantly deplete their stored energy and reduce their endurance. The aircraft operating manual does not state the amount of battery charge a single engine start will consume.

If both generators go offline, the emergency checklist procedures E5-1 to E5-3 specify immediate load reduction[2]. Without it, the endurance of the main batteries is less than 15 minutes; it is approximately 45 minutes if the load reduction is carried out within five minutes. If additional load reduction[3] is carried out, the checklist states that the endurance

Footnote

[2] Immediate load reduction includes, switching off both recirculation fans, the left and right avionics switches, the inverters, the emergency lights, the hydraulic pump and pulling the circuit breakers for the utility bus, all external lights and some internal lights.

[3] Additional load reduction includes, switching off engine ice protection, windshield heating, standby pitot heating, the windshield wiper, propeller and wing de-icing, the flood lights and the passenger address system.

can be extended to '*a minimum of 60 minutes*'. This leaves only essential equipment connected to the hot[4] battery bus, essential busses and emergency busses available to the crew.

Figure 1
External power connection rear of right wing

G-NFLB had recently been acquired by the operator, having been in long term storage for the previous nine years. At the time of the incident the aircraft had a valid certificate of airworthiness, and the airworthiness review certificate was in date. The aircraft had flown approximately 31 hours since it was owned by the operator.

Aircraft examination

The starter/generator, which had accrued 261 hours since its last overhaul, was removed from the right engine and sent to a component repair organisation for investigation. The examination revealed that the generator armature had two raised bars (Figure 2) and damage to the brushes. This resulted in arcing and subsequent failure to generate current.

The maintenance organisation suggested that the most likely cause of the damage was repeated starts with insufficient cooling time between them. It identified this is a known failure mode attributed to current being applied to the stationary armature during the start sequence, which heats it and results in the commutator bar lifting.

Footnote

4 The hot battery busses are electrical busses powered directly from the battery and power systems, such as the engine fire extinguishers, cargo fire extinguishers, attitude and heading reference system back-up power and battery controllers.

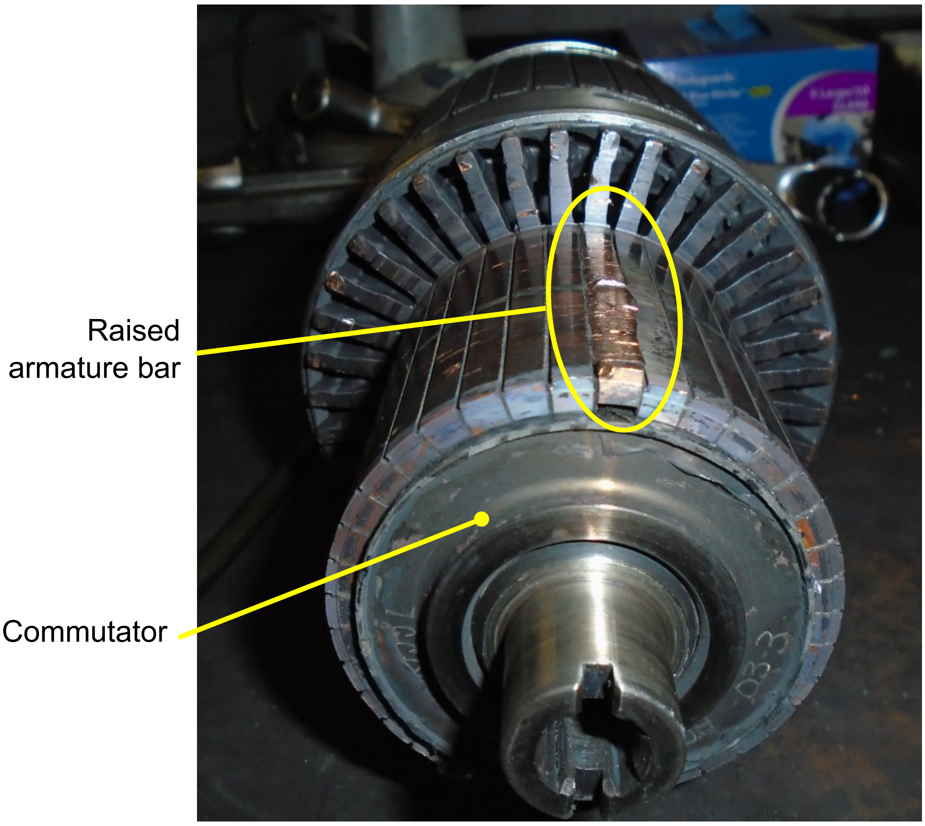


Figure 2

Starter Generator Armature showing lifted raised
and damaged bar on the commutator

During the 31 hours of operation by the operator, there had been no repeat starts carried out. It was therefore considered likely that if insufficient time between starts had been the cause of the issue, this occurred whilst the aircraft was operated by its previous owner, the damage remaining dormant until the generator was heavily loaded during the in-flight engine start of the opposite engine.

Meteorology

An aftercast provided by the Met Office for the morning of 14 September covering Glasgow and Prestwick, and the area to the west stated:

> *There were outbreaks of rain, drizzle and occasional showers, with heavy rain or showers at times. There were multiple layers of cloud: stratus with bases from 400-1200FT and tops of 1500FT away from sea fog, and bases on the surface in sea fog. Further thick layers of cloud with bases 1500-4500ft and tops 7000-12000FT away from fronts and the trough…. Away from fronts and the trough there would have been gaps between stratocumulus and altocumulus layers, but close to fronts and the trough cloud would likely have been thick. Visibility was generally good, dropping to moderate in rain or showers, and poor in sea fog.*

There was an occluded front running north-south to the west of the western isles. There was also a trough running approximately south-west to north-east, which is indicated by the rainfall seen on the radar picture (Figure 3).

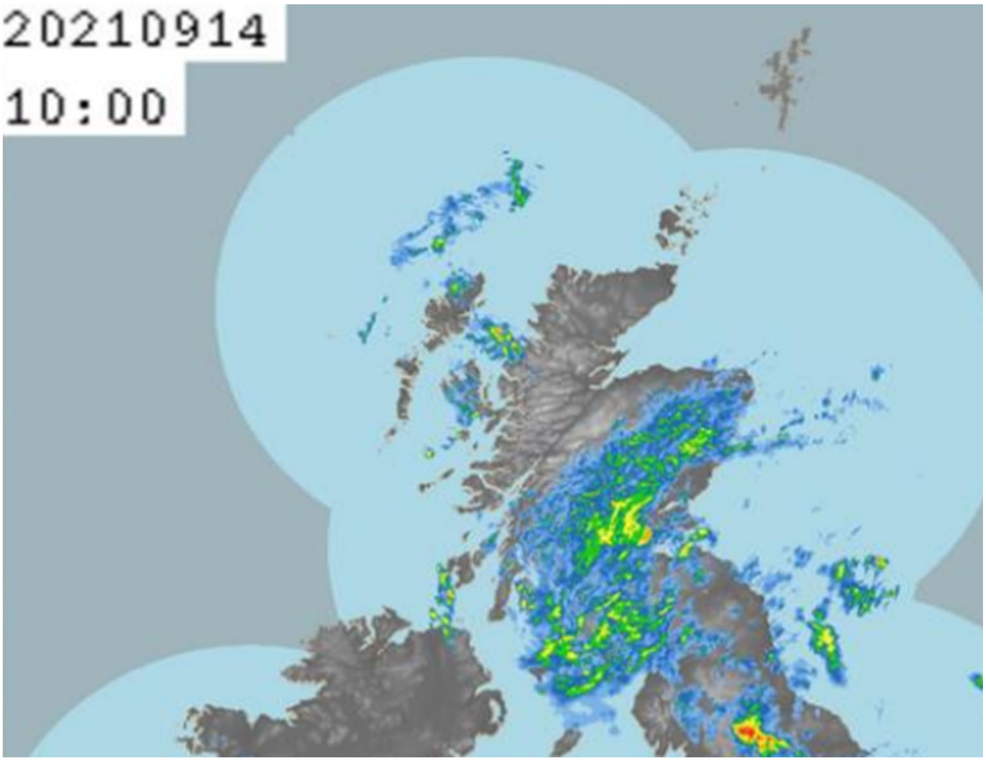


Figure 3

Radar picture of northern British Isles at around time of departure

Glasgow was forecast to have a cloud ceiling of 1,800 ft reducing to 1,000 ft temporarily, with 6 km visibility and a possibility of further reductions temporarily in the morning to 400 ft in 2 ½ km in rain and drizzle. Prestwick forecast a cloud ceiling of 3,000 ft. There would also be periods of the cloud ceiling temporarily reducing to 1,200 ft with 7 km visibility, and a possibility of further reductions temporarily in the morning to 600 ft in 3 km in rain and drizzle.

Meanwhile, the weather forecast for Campbeltown indicated a cloud base of 700 ft and cloud ceiling of 1,600 ft, though there was a probability that the cloud ceiling would reduce to 400 ft in 4 km visibility. The forecast weather for Islay was similar.

At the time of the incident, Glasgow had a cloud ceiling of 700 ft in light rain while Campbeltown had a cloud base of 900 ft and cloud ceiling at 2,100 ft in good visibility; Islay was similar.

Aerodrome information

Glasgow Airport

Glasgow has a single runway aligned 05/23 which provides for ILS, NDB, VOR and Surveillance Radar (SRA) approaches. The minima for the SRA approaches were higher than the actual weather while the VOR approach gave a minima of 484 ft aal.

Prestwick Airport

The main runway for Prestwick is 12/30 to which there are GNSS, ILS, and NDB approaches available. The secondary runway, 03/21, offers NDB DME or GNSS approaches. There is also an SRA approach to Runways 12/30 and 21.

At the time of the incident the main runway was unavailable due to resurfacing.

Campbeltown Airport

The AIP for Campbeltown specifies only GNSS approaches, even though the airport retains the VOR/DME and NDB radio navigation aids. The primary operator of the commander, which operates in this area, has an operator approved VOR approach for Campbeltown (Figure 4). This can be accessed through the primary operator's EFB which is maintained on a tablet.

Organisational information

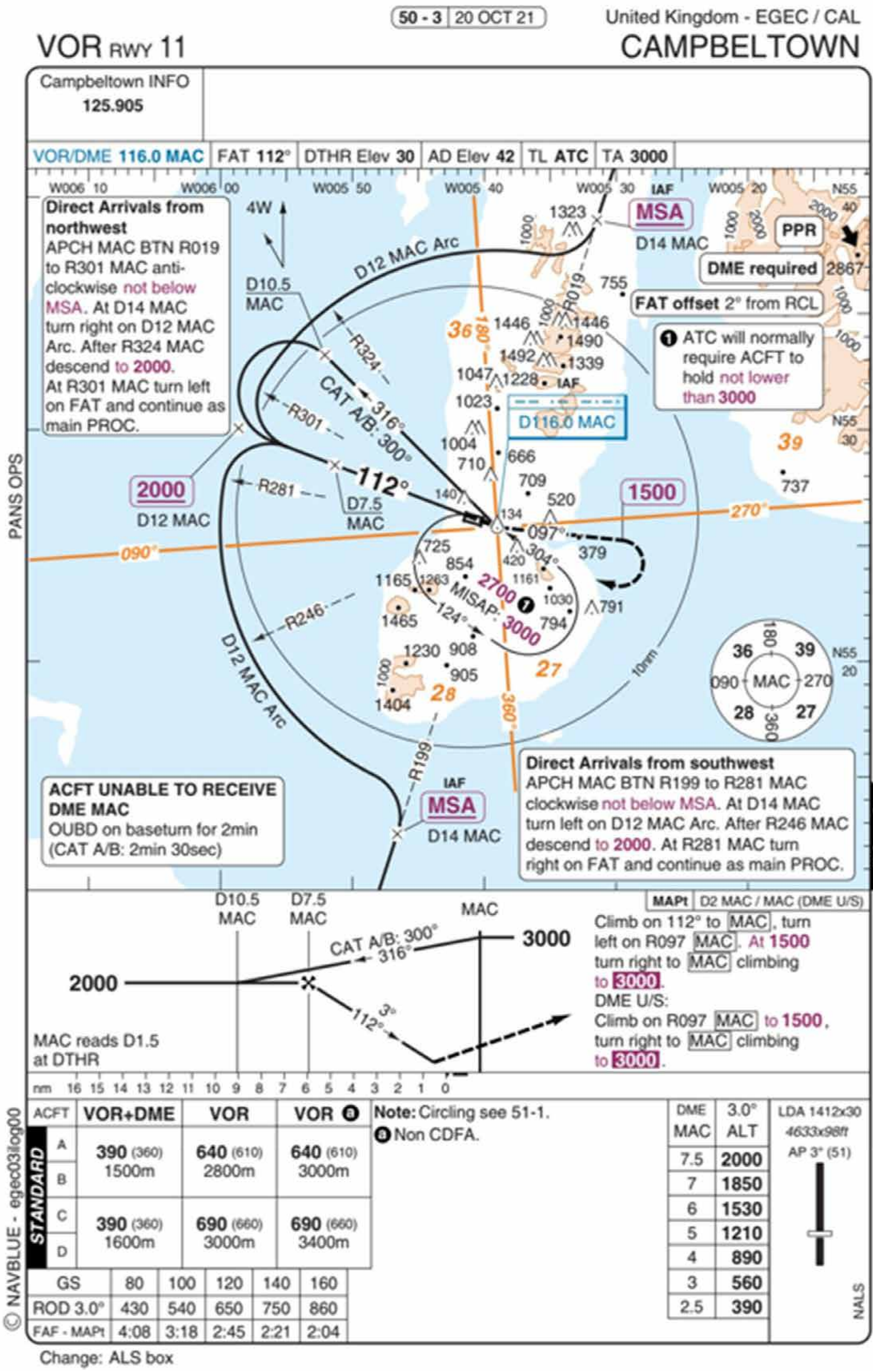
Operator

The operator operates G-NFLB as a flying classroom and engineering laboratory used to support teaching, research, and consultancy. The aircraft is fully instrumented to provide passengers and students with real-time data on a range of performance parameters. The flight profiles also include:

- flight trials of customers' experimental equipment.
- flight testing technologies associated with unmanned air vehicles.
- flight clearance testing of aircraft modified for special roles.
- measurement and analysis of an aircraft's characteristics for use in future airborne equipment.

As part of this operational remit, there is a requirement at times to intentionally shut down an engine to demonstrate the aircraft's performance in an OEI state.

The operator was in the process of introducing the SAAB 340B into its fleet and conducting conversion training for its crews when the incident occurred.



ACFT		VOR+DME	VOR	VOR ❶
STANDARD	A	390 (360) 1500m	640 (610) 2800m	640 (610) 3000m
	B			
	C	390 (360) 1600m	690 (660) 3000m	690 (660) 3400m
	D			

GS	80	100	120	140	160
ROD 3.0°	430	540	650	750	860
FAF - MAPt	4:08	3:18	2:45	2:21	2:04

DME MAC	3.0° ALT
7.5	2000
7	1850
6	1530
5	1210
4	890
3	560
2.5	390

Figure 4

Plate for approach to Campbeltown

Other information

The GEN busses are connected automatically by the closing of the bus tie relay, thereby connecting the batteries when the aircraft is on battery power only (Figure 5). The bus tie relay is open when both generators are operating, but close following the loss of a single generator.

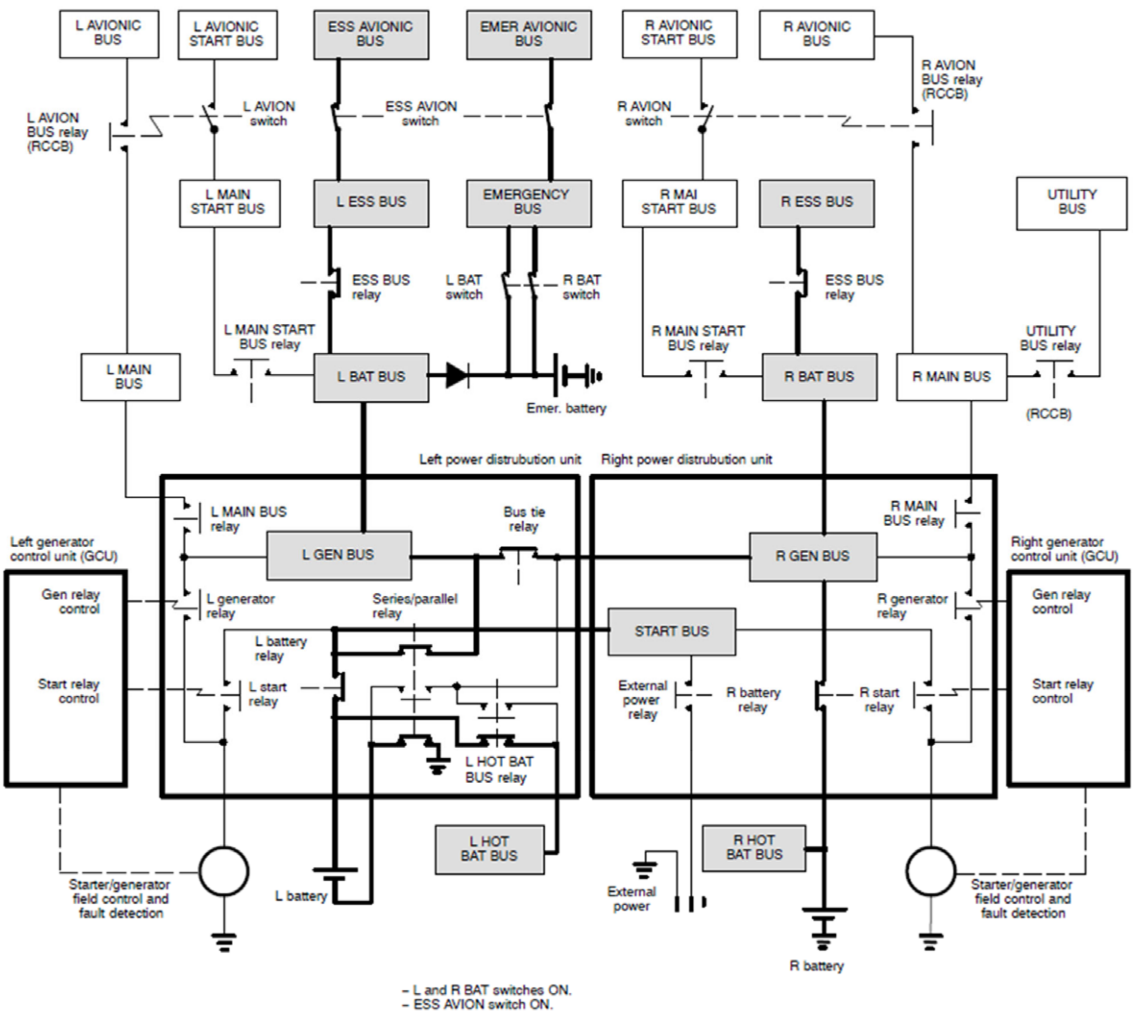


Figure 5

Electrical system showing busses (shaded) powered by battery power only

The emergency procedure in the aircrew flight manual (AFM) for the loss of both generators with both engines running states:

> *'The immediate actions for loss of both generators is to set the Bus tie to* SPLIT *and try to reset one generator at a time (Maximum two reset attempts per generator). If the generators cannot be reset, set them off and reduce electrical load.'*

This is reflected in the procedure, on pages E5-1 to E5-3 of the emergency checklist, entitled '*Loss of Both generators (Both Engines Running)*'. The checklist does not specify connecting the batteries in parallel by setting the bus tie to CONN[ect] in the event neither generator can be reset.

There is no procedure in the emergency checklist or the AFM for the loss of both generators when in an OEI configuration.

Analysis

Following the unsuccessful re-light of the left engine and the failure of the right generator, the aircraft was operating on one engine and on battery power only.

The situation was the result of a considered decision to conduct an in-flight shut down of the left engine in-flight for training purposes and the latent damage to the generator of the live engine. The shutdown was not required as part of the training for conversion to the aircraft type but was conducted to demonstrate the single engine handling qualities of the aircraft, which the simulator was not thought to represent accurately. It also stemmed in part from the prospect that, owing to the nature of the operation, there would likely be occasions requiring an engine to be shut down in-flight.

An examination of the right engine starter/generator found that it had failed and could not provide any power to allow a cross start of the left engine. The failure of the generator was considered by the component overhaul organisation to be the result of multiple starts with insufficient time between them to allow the unit to cool. The operator reported that there were no starts of this nature during the time that aircraft had been operated by them. It is therefore likely that, if the cause of the generator failure was insufficient cooling between successive starts, these starts occurred whilst the aircraft was operated by the previous owner. The damage sustained by the generator then became apparent when operated under high load during engine start.

During routine operation the left engine was always started first using the GPU. The right engine was then started using electrical power from the generator on the left engine. The left engine's generator is routinely loaded to provide power to start the right engine. Conversely, the right engine's generator usually only provides power for the right electrical system and is normally lightly loaded. Only when it was highly loaded during the attempted in-flight re-light of the left engine did the generator fail. As the location of the aircraft GPU receptacle does not allow for starting on the right engine first, the right generator had not previously been sufficiently highly loaded to induce failure. Had the right engine been used to cross start the left engine whilst on the ground, the generator failure may have occurred earlier, resulting in the inability to start the left engine but doing so in a safe environment.

The use of TDODAR as a decision-making tool in an emergency situation aided the crew to consider the relevant issues in a structured manner and resulted in effective management of the situation.

The crew recognised that time, because of limited battery life, was a crucial resource to manage. The trainer in the cabin immediately took on the role to note and monitor the time, ensuring this important element was not overlooked. The commander was able to delegate the urgent requirement to load-shed the electrical system in order to maintain battery endurance, while he spoke with ATC and gathered information on the weather at the nearby airfields. This enabled the PF to focus on flying the aircraft without undue distraction. The number, experience and composition of the crew aided the commander to manage a high workload and time critical situation.

The emergency procedure for the loss of both generators considered this scenario with both engines running, and not in the OEI configuration. However, system knowledge enabled the crew to act appropriately and ensure effective load shedding of non-essential equipment was carried out in a timely manner, preserving battery power. System knowledge also assisted the crew to make the decision to re-tie the batteries together, even though this was not required by the procedure. Connecting the batteries in parallel ensured that the available battery life would be shared by the systems on each side.

Faced with the need to descend below MSA safely and only the means to make a VOR approach, it was fortuitous that the commander had the EFB of his primary operator to hand which had a plate for a VOR approach to Campbeltown. Although this was an approach only approved for use by the commander's primary operator, the situation with which the crew were faced was an emergency.

Conclusion

The engine was shutdown intentionally as part of a training exercise. The right starter/generator had latent damage probably caused by insufficient time between starts in service with a previous operator. The right starter/generator then failed under loads higher than those it was normally subjected to, which had not occurred previously because it was not normally used for engine starts. The crew of four, who all had relevant experience, coordinated their activities to produce a successful outcome, and were assisted by the availability of a non-precision approach procedure approved for use by another operator for whom one of them also flew.