Australian Government

Australian Transport Safety Bureau

Safe Transport

AIR SAFETY INVESTIGATION REPORT
200105715

SAAB 340B,VH-XDZ
93 km North East of Trepell, Qld

5 December 2001

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Cover photo: SAAB Aircraft AB

ISBN 1 877071 48 X December 2003

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INTRODUCTION

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Commonwealth Department of Transport and Regional Services. ATSB investigations are independent of regulatory, operator or other external bodies.

In terms of aviation, the ATSB is responsible for investigating accidents, serious incidents, incidents and safety deficiencies involving civil aircraft operations in Australia, as well as participating in overseas investigations of accidents and serious incidents involving Australian registered aircraft. The ATSB also conducts investigations and studies of the aviation system to identify underlying factors and trends that have the potential to adversely affect safety. A primary concern is the safety of commercial air transport, with particular regard to fare-paying passenger operations.

The ATSB performs its aviation functions in accordance with the provisions of the *Air Navigation Act 1920*, Part 2A. Section 19CA of the Act states that the object of an investigation is to determine the circumstances surrounding any accident, serious incident, incident or safety deficiency to prevent the occurrence of other similar events. The results of these determinations form the basis for safety recommendations and advisory notices, statistical analyses, research, safety studies and ultimately accident prevention programs. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations.

It is not the object of an investigation to determine blame or liability. However, it should be recognised that an investigation report must include factual material of sufficient weight to support the analysis and conclusions reached. That material will at times contain information reflecting on the performance of individuals and organisations, and how their actions may have contributed to the outcomes of the matter under investigation. At all times the ATSB endeavours to balance the use of material that could imply adverse comment, with the need to properly explain what happened, and why, in a fair and unbiased manner.

The 24-hour clock is used in this report to describe the Trepell area local time of day, Eastern Standard Time (EST), as particular events occurred. Eastern Standard Time was Coordinated Universal Time (UTC) + 10 hours. Times are accurate to within 30 seconds of the reported event.

EXECUTIVE SUMMARY

On 5 December 2001, a Saab 340B registered VH-XDZ departed Trepell Qld, at 0810 EST with 37 persons on board. The flight was planned in accordance with instrument flight rules (IFR) to Townsville Qld, via Richmond Qld, at Flight Level (FL) 190.

While on climb through FL180, the copilot's two electronic flight information system (EFIS) screens on the right side of the aircraft's instrument panel failed. After the crew had consulted the EFIS failure/disturbances checklist, the central warning panel ice protection annunciator and then the cabin pressure annunciator illuminated. An emergency descent was initiated and the crew broadcast a PAN call to Air Traffic Services (ATS) and reported that they were returning to Trepell.

During the descent a number of other cockpit warnings and cautions activated and some aircraft systems failed. The crew became aware that the right DC generation system was operating abnormally. Their attempts to rectify that situation were unsuccessful. The crew diverted the aircraft to Cloncurry and landed.

The failure of the EFIS screens and the subsequent warnings, cautions and failures were consistent with a right system voltage drop from the rated 28 volts DC to below 18 volts. During the investigation it became apparent that in some Saab 340 aircraft a starter generator could fail without taking the generator off line and alerting the crew, resulting in low system voltage. On this occasion the crew overlooked the first item of the EFIS failure/disturbances checklist, which required a check of the generator voltage. Consequently, the crew did not recognise the developing low voltage condition that led to the cascading series of warnings, cautions and failures. The bus tie relay, which was designed to automatically connect the two main electrical systems in the case of generator failure, did not operate. An optional generator control unit modification, to prevent unalerted low-voltage conditions, had not been incorporated. The investigation determined that the modification to reduce the risk of the consequences of a delayed generator failure warning was highly desirable.

The investigation found that the operator's maintenance control system and approved system of maintenance did not ensure that the starter generator was maintained in accordance with the requirements of the aircraft maintenance review board (MRB) report. A contributing factor was the disparity between a MRB requirement and the corresponding job card produced by the aircraft manufacturer.

This occurrence also demonstrates the need for well-designed checklists to be available to pilots during abnormal or emergency situations. It further demonstrates the need for pilots to be familiar with the systems of the aircraft they operate and the actions to be taken in the event of abnormal or emergency situations. As a result of this occurrence the ATSB has issued a number of recommendations to address safety concerns identified during the investigation.

1 FACTUAL INFORMATION

1.1 History of the flight

On 5 December 2001, a Saab 340B registered VH-XDZ departed Trepell Qld, at 0810 EST with 37 persons on board. The flight was planned in accordance with instrument flight rules (IFR) to Townsville Qld, via Richmond Qld, at Flight Level (FL) 190. The crew had earlier flown the aircraft from Townsville to Trepell and described that flight as normal.

After departure from Trepell and while on climb through FL180 the copilot's two electronic flight information system (EFIS) screens on the right side of the aircraft's instrument panel failed. After the crew had consulted the EFIS failure/disturbances checklist, the ice protection annunciator illuminated on the central warning panel, with an associated right engine intake failure light. Shortly after, the cabin pressure warning annunciator illuminated on the central warning panel and the crew observed erratic cabin pressure indications. In response, the crew initiated an emergency descent and broadcast a PAN call to Air Traffic Services (ATS) to report that they were returning to Trepell.

During the descent, a number of other cockpit warnings and cautions activated on the central warning panel and some aircraft systems became inoperative as follows:

- the flight attendant bell activated
- the stall warning clacker activated, and the right stall fail annunciator illuminated
- the rudder limit annunciator illuminated
- the global positioning system (GPS) long range navigation system failed
- copilot communication systems failed
- the radio magnetic indicators (RMIs) failed
- automatic direction finder (ADF) 2 failed
- the electrical system annunciator illuminated with an associated right DC generator-out light on the overhead panel
- the right engine instrumentation failed
- the right hot battery warning illuminated.

After the right DC generator-out light illuminated, the crew became aware that the bus tie had not automatically connected. They completed the applicable checklist and split the buses accordingly, resulting in sustained low voltage to the right electrical system. A subsequent attempt to connect the bus tie was unsuccessful.

The crew reported to ATS that they were over McKinlay Station at 4,000 ft and were now intending to track visually to Cloncurry. The crew also briefed the flight attendant and the passengers on the situation and their intention to divert. ATS notified emergency services and the aircraft subsequently landed safely at Cloncurry.

During an engineering inspection, the right starter generator, generator control unit, power distribution unit and battery were replaced to restore the aircraft to a serviceable condition.

Analysis of the information recovered from the flight data recorder revealed that, shortly after the failure of the EFIS screens, the recording of flight data stopped for about 18 minutes.

FIGURE 1:
Typical Saab 340B cockpit

Photo: SAAB Aircraft AB

1.2 Injuries to persons

Injuries	*Crew*	*Passengers*	*Others*	*Total*
Fatal				
Serious				
Minor				
None	3	34	-	37

1.3 Damage to aircraft

There was no report of damage to the aircraft.

1.4 Other damage

There was no other damage reported.

1.5 Personnel information

1.5.1 Pilot in command

Type of licence	Air Transport Pilot (Aeroplanes) Licence
Medical certificate	Class 1
Flying experience (total hours)	10,472
Hours on type	3,528
Hours flown in last 90 days	208
Hours flown in last 30 days	87
Hours flown in last 24 hours	7.5

The pilot in command reported that he commenced duty about 3 hours before the occurrence and slept for 7 hours during the preceding 16 hours free of duty. He reported no physiological or medical condition that was likely to have impaired his performance, and that he was adequately rested and medically fit for the flight.

Prior to joining the operator in 1997, the pilot in command held a Saab 340 type rating. He flew Metro-type aircraft for the operator until mid 1998. He was then assigned to Saab 340 operations following a Saab 340 refresher course and completion of a base check. Shortly after the base check, the operator certified the pilot in command as competent to act as a Supervisory Pilot for first officers. The operator first assigned supervisory duties to the pilot in command on 9 March 1999. The operator determined the approval of Supervisory Pilots by requiring an initial demonstration of competence. The most recent recorded training or checking of the pilot was a flight proficiency base check completed on 1 October 2001. That check satisfied the requirement for an instrument rating renewal.

The pilot in command completed a Crew Resource Management course in September 1998.

1.5.2 Copilot

Type of licence	Air Transport Pilot (Aeroplanes) Licence
Medical certificate	Class 1
Flying experience (total hours)	4,618
Hours on type	9
Hours flown in last 90 days	165
Hours flown in last 30 days	23
Hours flown in last 24 hours	4.1

The copilot reported that he slept for at least 8 hours during the preceding 17 hours free of duty. He reported no physiological or medical condition that was likely to have impaired his performance, and that he was adequately rested and medically fit for the flight.

The copilot recently obtained a Saab 340 type rating, and was operating under supervision on his second day of line flying. Training and checking records showed that he had completed a Saab 340 technical ground course between 13 and 28 November 2001. Conversion to type flight training was conducted by the chief pilot on 1 and 2 December 2001.

The copilot had not completed any crew resource management training.

1.6 Aircraft information

1.6.1 Airworthiness and maintenance

1.6.1.1 Dispatch serviceability status

The aircraft was dispatched from Townsville on the morning of the occurrence with the upper left EFIS screen unserviceable. The operator's minimum equipment list (MEL) allowed for operation of the aircraft in that configuration for 9 days, provided the operative screen on that side was able to function in the composite[1] mode. The EFIS screen was logged unserviceable on 3 December 2001, two days before the occurrence. The screen was replaced the day after the occurrence. The unserviceable upper left EFIS screen had failed for reasons unrelated to the subsequent failure of the right EFIS screens during the occurrence.

The aircraft was dispatched with a right starter generator that would be operating in excess of its scheduled time before overhaul (TBO). The pilot in command reported that, prior to dispatch, the In Service Maintenance Record (ISMR) had been annotated by one of the maintenance personnel to indicate that a 10 per cent extension had been applied to the starter generator TBO. As the operator's flight crews referred to ISMR information to obtain an understanding of the aircraft's maintenance due status, the pilot in command reported that there was no reason to believe that the aircraft was unairworthy. The operator's engineering management reported that the supporting maintenance system document required to legitimise the extension was not completed. Dispatch of the aircraft with a component that would exceed the specified time in service was not consistent with the requirements of Civil Aviation Regulation 47.

1.6.1.2 Post occurrence maintenance

The investigation calculated that the right starter generator had been installed for 1,601.9 flight hours since overhaul, when the right EFIS screens failed after departure from Trepell. Maintenance personnel reported that the starter generator was replaced at Cloncurry because it was 'due for overhaul'. The aircraft manufacturer stipulated a starter generator TBO of 1,200 hrs, or 1,600 hrs if preceded by brush replacement at 800 hrs time in service. Subsequent overhaul of the starter generator showed that the brushes were 'worn out' and the armature showed signs of overheating. The brushes, bearings and armature were replaced.

The aircraft manufacturer and the facility that overhauled the unit considered that, as a result of the 'worn out' brushes, the starter generator was probably not capable of producing power at the time of the occurrence. However, the operator's maintenance personnel considered that the repair report of the starter-generator was typical of units that had operated without brush change for about 1,600 hrs time in service since overhaul. The operator's maintenance personnel reported that over a recent 4-year period, approximately 23 Saab 340 starter generators had accrued between 1,570 and 1,600 hrs with no report of abnormal wear and tear. During that time, one starter generator was prematurely removed with 20 per cent brush wear remaining after only 1,271 hrs time in service.

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1 Refer 1.6.2.2 para 3

The right generator control unit and right power distribution unit were replaced because maintenance personnel were not sure that they were serviceable. Subsequent repair of the generator control unit included replacement of a 'sticky' relay. The operator contended that it was likely that the 'sticky' generator control unit relay had stuck in the start (closed) position after engine start. Consequently, the starter generator would have been capable of producing normal output but was electrically isolated from the bus bars. Normal generator output meant that there would be no alert of an abnormality and such isolation from the bus bars would result in battery depletion.

However, the aircraft manufacturer advised that if that relay had stuck in the start (closed) position after engine start, the engine start sequence would not be terminated, requiring immediate engine shutdown. Consequently, the starter generator would not have been able to generate power and the DC generator-out light would have remained illuminated. The crew could not recall any abnormalities during the start sequence.

The right battery was replaced because it had operated at a high temperature and in a very low state of charge.

1.6.1.3 Starter generator maintenance history

Maintenance records indicated that the right starter generator had been installed on 7 August 2000 as an overhauled unit. Maintenance of the starter generator was subsequently carried out in accordance with the operator's Saab 340 system of maintenance. That system incorporated inspection of the starter generator brushes into aircraft maintenance checks that occurred at consecutive intervals of 800 hrs aircraft time in service. Records indicated that the right starter generator brushes had been inspected at 221.31 hrs and 1,026.34 hrs starter generator time in service since installation. A notation on the aircraft's maintenance worksheets indicated that, at 1,026.34 hrs time in service, the brushes had 60 per cent life remaining. There was no record of brush replacement at any time after starter generator installation on the right engine.

The organisational aspects of starter generator maintenance are addressed in section 1.17.5.

1.6.2 Aircraft systems

1.6.2.1 DC Electrical system

The investigation established that an unalerted failure had occurred in the right DC generation system some time before the EFIS screens failed. The aircraft manufacturer attributed that failure to the worn brushes in the right starter generator, a well established failure mode. An alternative hypothesis, proposed by the operator, attributed the failure to the defective right generator control unit relay. Significantly, the failure resulted in the sustained loss of a number of aircraft systems which is explained below.

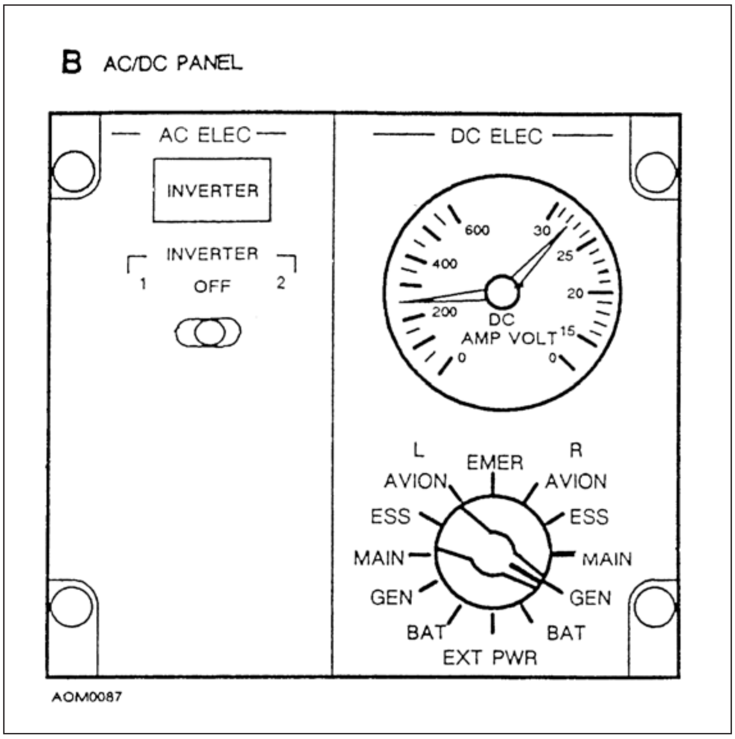
The Saab 340 DC system was divided into discrete left and right systems that were each powered by the engine driven generator and battery on that side. A generator control unit (GCU) provided voltage regulation for each generator. A power distribution unit (PDU) routed electrical power to a number of distribution buses. Power was then directed to individual components from each bus. A list of the aircraft systems powered from each bus is at Appendix 2.

The crew did not receive a warning or caution that indicated a failure in the right DC generation system until late in the sequence of warnings, cautions and failures. That was consistent with the applicable advice provided by the aircraft manufacturer in the Saab 340B Aircraft Operations Manual that stated:

> The GCU cannot detect DC generator voltage low (generator not charging) and subsequently (will) not disconnect a non-charging generator.

As a result of the above design characteristic, the DC generator-out light would not immediately illuminate if generator output is below a value insufficient to charge the battery. The only definitive indication then, of a lack of effective generator output, was available from the voltmeter/ammeter.

FIGURE 2:
Overhead AC/DC panel

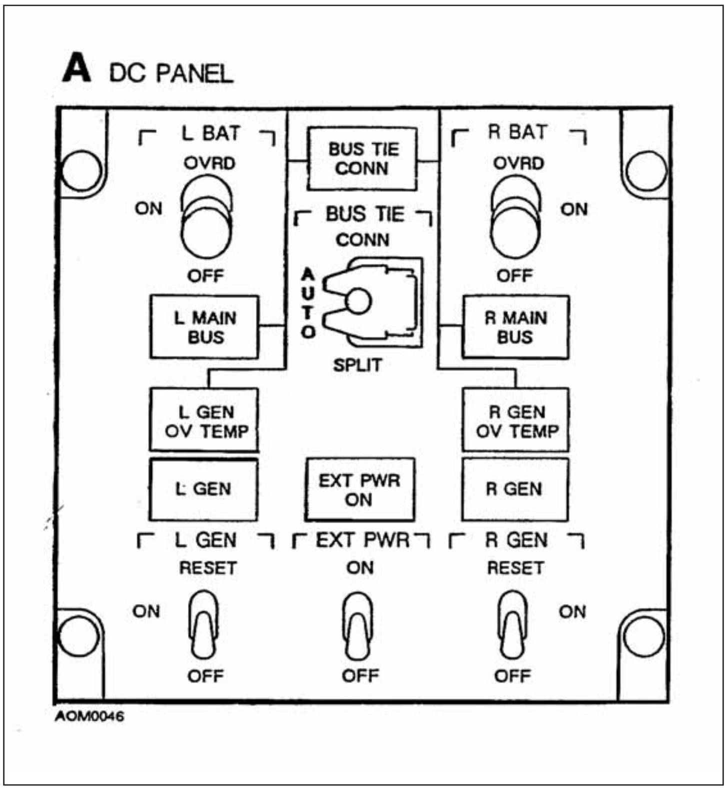


Although a check of the voltmeter/ammeter indications was required after start there were no other routine checks of the indications. The crew could not recall what the voltage and amperage readings were after engine start. Significantly, there was no warning annunciator system alert for system low voltage. It was likely that the generator-out caution eventually illuminated when the right system voltage decreased below the value required for operation of the generator control unit.

The design characteristic that produced the delayed disconnection of a failed generator could be rectified by the incorporation of a modification to the electrical system. The aircraft manufacturer had issued Service Bulletin 340-24-026 on 9 January 1996, with optional compliance. That bulletin introduced modification number 2533 that provided for the installation of a generator control unit that could detect a generator under-voltage condition and as a consequence take the generator off-line.

The right DC electrical system components remained underpowered throughout the occurrence because the bus tie relay did not connect. The bus tie relay provided the means to connect the left and right electrical systems in the event of a generator failure, thereby allowing the operative generator to provide power to both systems. Automatic operation of the bus tie relay, with the bus tie switch to AUTO, relied on a generator being taken off-line as indicated by a generator-out light. However, in this occurrence, when the right generator-out light illuminated late in the failure sequence, indicating an off-line generator, the bus tie relay did not activate. The failure of the bus tie relay to operate was due to active over-current protection. That is consistent with either incorrect start sequence actions or excessive current during failed automatic relay activation, an explanation favoured by the aircraft manufacturer.

FIGURE 3:
Overhead DC panel



Reset of the bus tie relay, although possible by selection of CONN and actuation of the 'K-1' switch located on a circuit breaker panel, was not always prescribed by the checklists. A description of the crew's response to non-activation of the bus tie relay is at 1.6.2.4

The aircraft was equipped with two Ni-Cad batteries. Ni-Cad batteries maintain their charge above 22 volts during discharge. However, when a battery's capacity reduces to about 25 per cent, the voltage subsides very quickly and the temperature of the battery increases markedly.

1.6.2.2 Electronic Flight Information System

The first indication to the crew of a problem in the aircraft was the simultaneous failure of the two right EFIS screens. The Saab 340B EFIS used two cathode ray tubes to display flight and navigational data in front of each pilot. An electronic attitude director indicator (EADI) screen and an electronic horizontal situation indicator (EHSI) screen displayed that information to each pilot in a vertical arrangement with the EADI at the top.

A failure of the right display processor unit or a right side voltage below 18 volts would result in blank EFIS screens on that side. A failure of a display processor unit could be rectified by the crew through the selection of video signals from another source. That function was enabled by selection of the EFIS drive switch to drive transfer. The pilot in command actioned the drive transfer switch during the actioning of the EFIS failures/disturbances checklist.

Given the prior failure of the upper left EFIS screen, the information normally displayed on that screen had been added to the information displayed on the adjacent screen in a composite (reversionary) mode. That composite mode provided a display of condensed EADI and EHSI information.

FIGURE 4:
EFIS screen in composite mode

Photo: SAAB Aircraft AB

1.6.2.3 Effect of low voltage on aircraft systems

There were a number of warnings, cautions and failures that resulted from the sustained low voltage on the right electrical system. The following table is a summary of those events and whether they were failures or spurious indications.

Reported event	*Event type*	*Likely reason for event*
EFIS screens blank	Failure	Supply voltage below 18 volts
Right engine intake ice protection annunciator illumination	Failure	Supply voltage to controller below 18 volts
Cabin pressure annunciator illumination	Spurious Indication	Supply voltage to indicator below 18 volts
Flight attendant bell activation	Spurious activation	Supply voltage below 18 volts
Stall warning clacker	Spurious Indication	Supply voltage below 18 volts
Right stall fail annunciator illumination	Failure	Supply voltage to right computer below 18 volts
Rudder limit annunciator illumination	Failure	Low voltage to data source
GPS inoperative	Failure	Supply voltage below 18 volts
VHF 2 and intercom inoperative	Failure	Supply voltage below 18 volts
Radio magnetic indicator inoperative	Failure	Supply voltage to the inverter selected at the time, below 18 volts
Automatic direction finder 2 inoperative	Failure	Supply voltage below 18 volts
Right engine instruments inoperative	Failure	Supply voltage below 10 volts
Right hot battery annunciator illumination	Correct Indication	Hot battery due to excessive draw

There were a number of failures that were not identified by the crew. It is likely that the services and components, listed in Appendix 2 as powered from the right electrical system DC buses, were not operating correctly after the starter generator system failed.

However, there were some components that were disabled for about 18 minutes. Shortly after the failure of the right EFIS screens, the flight data recorder failed to record for about 18 minutes. That failure was consistent with interruption of power to the recorder component of the flight data recorder. The reason for the interruption was a loss of AC output from the selected inverter. As inverter 2 would have failed as a consequence of right system low voltage, it would have been the selected inverter during the 18-minute period. The restoration of the flight data recorder function was consistent with the crew selection of inverter 1, powered from the left electrical system, to provide power to the AC buses.

The loss of power to the AC inverter buses that was indicated by the flight data recorder failure meant that the following AC powered systems were also not powered for the same time:

- Ground proximity warning system
- Compass reference
- Integral panel lighting.

1.6.2.4 Crew response to system failures

The copilot (non-handling pilot) read the EFIS failure/disturbances checklist under the pilot in command's supervision. The crew subsequently reported that they inadvertently overlooked the first item on the checklist. The first item was a check of the generator voltage. If the voltage was below 26 volts, as it would have been in this case, the crew was required to action the second item which was to refer to the DC voltage low checklist. A copy of the EFIS failure/disturbances checklist is at Appendix 1. The human factors aspects of checklist design and use are addressed in section 1.18.

In order to better manage the crew's response to the abnormal situation, the pilot in command assigned handling pilot duties to the copilot during the descent. A factor in that decision was the inability of the copilot to communicate with ATS.

The pilot in command reported that the unserviceable upper left EFIS screen influenced his initial response to the failure of the right EFIS screens. In the weeks preceding the incident flight he had been studying the aircraft's EFIS system and, in particular, how the EFIS drive transfer system functioned. He considered that the failed left EFIS screen and his recently reinforced knowledge of the drive transfer system had led him to believe that the failure of the right EFIS screens was related to a drive transfer problem.

The crew reported that they actioned the DC Gen light on/Bus tie conn fault checklist in response to the illumination of the generator-out light late in the sequence. The battery voltage was observed to be below 20 volts and the bus tie relay switch was selected to SPLIT in accordance with the checklist. Although the pilot in command reported that he attempted to force a connection of the bus tie relay, he could not recall whether that attempt was followed by actuation of the reset facility.

The investigation could not determine whether any other checklists were accomplished in response to the warnings, cautions and failures. However, the crew performed a precautionary descent in response to the cabin pressure warning.

1.6.2.5 Low voltage warning system certification

The Saab 340B was simultaneously certified to both European Joint Aviation Regulation (JAR) 25 and United States Federal Aviation Regulation (FAR) Part 25. Subpart 1309 (c) of JAR/FAR 25 stated that:

> Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action. Systems, controls and associated monitoring and warning means must be designed to minimise crew errors, which could create additional hazards.

The regulatory authority of the State of aircraft design and manufacture, Luftfartsverket, was required to certificate the Saab 340 aircraft type. As part of the original certification process, Luftfartsverket assessed the aircraft's electrical system and associated cautions and warnings for compliance with the JAR/FAR requirements.

In-service experience of the Saab 340 aircraft type later revealed the potential for an unalerted low voltage condition. In response to that failure mode, redesigned starter generator brushes were introduced in 1995 to improve reliability and service life. Concurrently, the Saab 340B Aircraft Operations Manual was revised to include an explanation of the failure mode. A new checklist was also added to the abnormal procedures to facilitate flight crew identification of, and response to, the failure mode. A copy of that checklist, EFIS failure/disturbances, is at Appendix 1.

Generator control unit modification number 2533 was also developed to address the failure mode. The modification was not mandated because Luftfartsverket was satisfied that the measures introduced in 1995 sufficiently improved the situation. However, the modified generator control unit became standard for aircraft after serial number 367. The occurrence aircraft was serial number 328.

1.7 Meteorological information

The area weather forecast overview indicated that isolated showers and local areas of smoke were expected along the aircraft's flight path. The cloud was forecast to be scattered stratus in showers and scattered cumulus/stratocumulus with bases between 6,000 and 12,000 ft with isolated cumulus tops to 20,000 ft. The visibility was expected to be 8 km in smoke and 4,000 m in showers. The crew reported that the observed weather was consistent with the forecast conditions.

The Automated Weather System recorded the weather at Cloncurry at 0900 EST as 7 to 10 kts of wind from the north-east and a temperature of 33 degrees Celsius. No cloud or visibility data was available.

1.8 Aids to navigation

The crew reported that the global positioning system (GPS) failed, automatic direction finder (ADF) 2 (right) failed, and that the indications on the radio magnetic indicators (RMIs) were inconsistent and confusing. Consequently, the crew tracked visually to Trepell and later diverted to Cloncurry.

Trepell did not have a radio navigational aid. Cloncurry was equipped with only a Non Directional Beacon (NDB).

The aircraft was equipped with two ADFs, which detected the relative bearing to an NDB. A pointer on an RMI located on each pilot's panel represented the relative bearing signals generated by an ADF. Each RMI featured a rotating heading display, normally aligned with the aircraft's magnetic heading by separate magnetic bearing inputs.

Both magnetic bearing inputs were powered from the inverter buses, which were unpowered for 18 minutes. Therefore, both heading input sources for the RMIs were unavailable for the same 18-minute period that the flight data recorder was inoperative.

The unavailability of primary heading inputs would have also rendered the heading indication on the sole EFIS screen unusable for at least 18 minutes.

The failure of ADF 2 would have driven the ADF 2 pointer on both RMIs to a parked position of 3 o'clock to indicate loss of signal. However, ADF 1 indications on both RMIs were not adversely affected.

ADF indications were not visible on an EFIS screen in composite mode.

The Aeronautical Information Publication Australia allowed for the use of visual navigation for Instrument Flight Rules flights, provided that visual contact with the ground or water could be made at intervals of 30 minutes or less. The pilot in command reported having access to the relevant world aeronautical chart and being able to identify and then follow the road to Cloncurry.

1.9 Communications

Communication was maintained between the pilot in command and ATS on VHF 1. The copilot was unable to receive or transmit on the radios or communicate with the pilot in command via the intercom system. Pilot in command to copilot communication was reportedly even more difficult while oxygen masks were being worn by the crew during the emergency descent.

The pilot in command reported no difficulties with the passenger public address system.

1.10 Aerodrome information

Cloncurry aerodrome was licensed and suitable as a landing area for the aircraft type.

1.11 Flight recorders

1.11.1 Flight recorder system

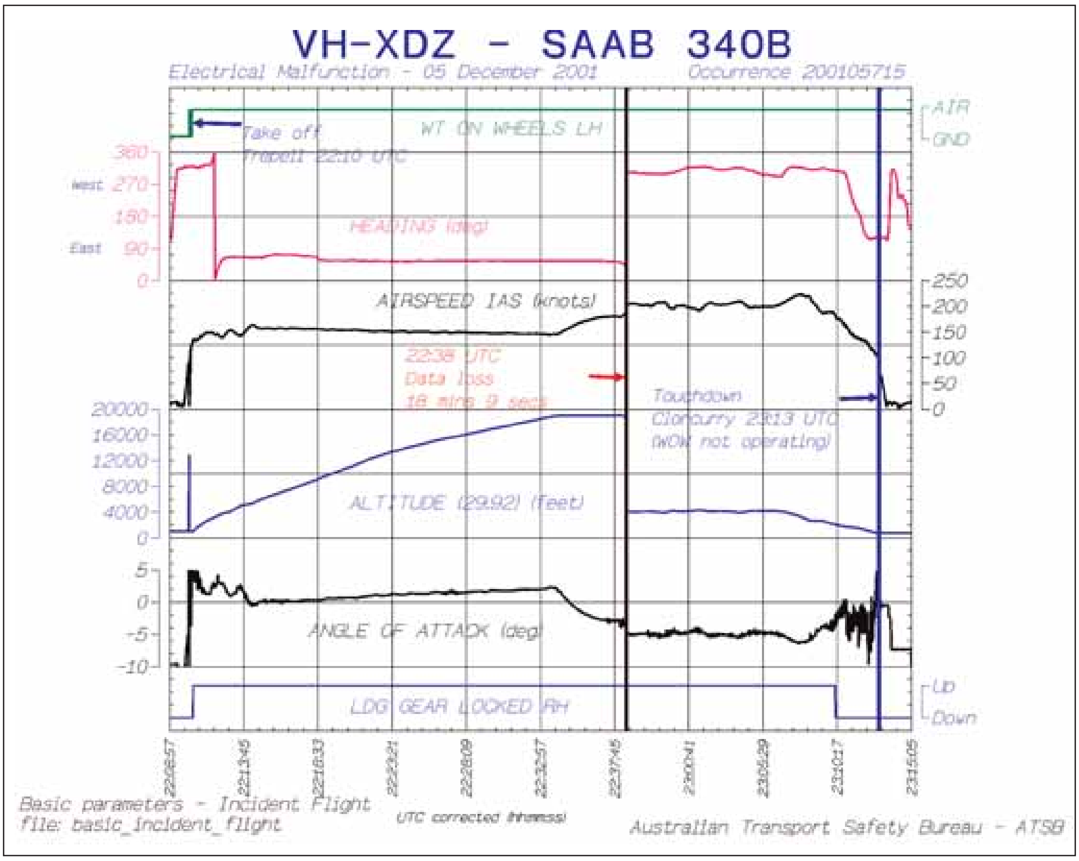
The aircraft was equipped with a flight data recorder (FDR) and a cockpit voice recorder (CVR). The ATSB did not access the CVR.

The ATSB technical analysis staff recovered the data from the flight data recorder using Recovery, Analysis and Presentation software. Tables and plots of the engineering parameters were prepared to assist in the analysis of the incident.

Analysis of the recorded data revealed that the coordinated universal time (UTC) time recorded by the FDR did not correlate with the timings reported by ATS. An addition of 1 hr, 13 minutes and 14 seconds to the recorded time was required. During the analysis it was discovered that about 18 minutes of recorded data was missing. The FDR stopped recording at 2238:31 UTC and resumed recording at 2256:39 UTC. When the FDR stopped recording, the aircraft's airspeed was 187 kts, altitude was 18,688 ft and heading was 039 degrees magnetic. When the FDR resumed recording, the aircraft's airspeed was 202 kts, altitude was 4,112 ft and heading was 302 degrees magnetic.

The reason for the loss of FDR data is discussed in section 1.6.2.3.

FIGURE 5:
Example of FDR data plot



1.11.2 Flight recorder system certification

The Saab 340B was simultaneously certified to both European Joint Aviation Regulation (JAR) 25 and United States Federal Aviation Regulation (FAR) Part 25. Subpart 1459 (a) (3) of FAR Part 25 stated that:

> It (flight recorder) receives its electrical power from the bus that provides the maximum reliability for operation of the flight recorder without jeopardizing service to abnormal or emergency loads.

The flight data recorder did not record DC voltage parameters nor was it required to.

1.12 Wreckage information

Not applicable.

1.13 Medical information

Not applicable.

1.14 Fire

Not applicable.

1.15 Survival aspects

Not applicable.

1.16 Tests and research

Not applicable.

1.17 Organisational information

1.17.1 Flight crew training

The operator conducted flight training and checking in accordance with a Civil Aviation Regulation 217 approval. Flying training and checking was conducted in the applicable aircraft type. Flight simulators were not used for regular check and training activities, nor were they required to be used. Saab 340 simulators were available in Australia at the time of the occurrence.

The operator's training requirements for a copilot, who was new to Saab 340 operations, included a type rating of about 5 hrs flight time followed by consolidation under supervision for approximately 50 hrs flight time. That consolidation period included additional instruction on the aircraft systems and company operating procedures by a supervisory pilot.

The Saab 340B ground technical training course that the copilot had completed included reference to the inability of the generator control unit to disconnect the generator in an undervoltage state. The course notes stated that the undervoltage would first be indicated by totally blank or flickering EFIS screens. The chief pilot, who was one of the course presenters, confirmed that the issue had been discussed during the ground school.

Both the pilot in command and the copilot reported that they had been aware of the inability of the generator control unit to disconnect the generator in some low voltage conditions. However, they did not appreciate that the undervoltage state prior to blanking of the EFIS screens was difficult to detect. The pilots also indicated that they were unaware of the cascade effect that an undiagnosed low voltage condition would produce.

The copilot stated that electrical failures had been discussed during his Saab 340 ground school training. Although conversion flying had included instrument flying with a failed EFIS, there was no evidence that the EFIS failure/disturbances checklist had been referred to during air training sequences. The crew and a senior instructor pilot also commented that pilots would benefit from undertaking simulator training on a regular basis to ensure that they are adequately equipped to understand and correctly handle system abnormalities and emergencies. That sentiment accorded with a National Transportation Safety Board (NTSB) recommendation A-94-003, which urged the FAA to require air transport operators to provide newly qualified crews with simulator training that would improve crewmember skills in observing and challenging errors made by other crewmembers.

There was no formal recurrent systems training, nor was there a requirement for such training.

1.17.2 Operational procedures

The Saab 340B Aircraft Operations Manual, produced by the aircraft manufacturer, provided information on normal, abnormal, and emergency procedures. The manual's 'abnormal procedures' section contained a number of checklists, one of which was the EFIS failures/disturbances checklist. The introduction to the abnormal procedures section of the manual provided guidance as to how to apply the checklists. The introduction stated that:

> The Malfunction, (Abnormal and Emergency) checklists are intended to be performed in a read-and-do manner and as such need not be committed to memory. The only exception is recall (memory) items indicated by a star (*) in the checklist. The number of recall items has been kept to a minimum.

> It is expected that the flight crew possesses sufficient knowledge to select correct checklist. The flight crew is further expected to have thorough understanding of what is accomplished by performing a certain item in the checklist. Checklist items not considered obvious and other relevant operational aspects are presented on the page preceding the checklist.
>
> It is not possible to cover all combinations of malfunctions events in checklists, and with some exceptions, it only covers single failures. If multiple unrelated failures should occur, the flight crew may have to combine in parts or in whole different checklists and to exercise good judgement to determine the safest course of action.

The operator's *Operations Manual, Part B – SF340, Specific Aircraft Operating Procedures*, included instructions as to what specific roles and checklist items each pilot was to action during normal operations. There were, however, no corresponding instructions that applied to abnormal or emergency procedures. In particular, it was not clear how the EFIS failure/disturbances checklist was to be actioned in a multi-crew environment.

The incident flight crew and senior pilots employed by the operator and other Saab 340 operators reported that Saab 340 checklists were often cluttered, contained confusing symbology, some items were misaligned, and the language and presentation of checklists promoted errors by flight crews. Moreover, a senior Saab 340 instructor pilot reported that pilots often misread or misinterpreted the checklists and either missed or actioned items in an incorrect sequence because of poor checklist presentation. For example, with reference to the EFIS failure/disturbances checklist, the crew reported that the floating ellipse containing the instruction 'Page A11' was not aligned with the applicable heading (see Appendix 1).

1.17.3 Civil Aviation Safety Authority checklist guidelines

The Civil Aviation Safety Authority produced an *Air Operator Certification Manual – Other than High Capacity RPT Operations* that included a sub-section titled 'The Design and Approval of Aircraft Flight Check Systems'. Within that sub-section, paragraph 7.14.6.9 Multi-crew procedures, stated that:

> the crew position responsible for completing each check must be clearly identified on each checklist (p. 7.14-11).

Paragraph 7.14.7.3.2 Read and Do, stated that:

> read and do procedures mean that an item is not actioned until it is called in the checklist sequence… Read and do may be required in certain circumstances where activation of equipment has a time limitation or constraint associated with it or sequencing is particularly critical. Read and do is the preferred technique for abnormal checklists and the reference (sometimes called Phase 2) items of emergency checklists (p. 7.14-15).

1.17.4 Proposed Civil Aviation Safety Authority regulations

CASA published Notice of Proposed Rule Making (NPRM) number 0211OS in April 2002. That NPRM introduced, and invited consultation on, the proposed Civil Aviation Safety Regulation (CASR) Part 121A. Part 121A will apply to the operation of aeroplanes having a maximum take-off weight (MTOW) exceeding 5,700 kg engaged in air transport operations.

The Proposed Part 121A sub-part 965 (11) recommended that each flight crew member undergo ground and refresher training at least every 12 calendar months. Part 121A, Appendix 1, proposed that recurrent training should comprise ground and refresher training that includes aeroplane systems and operational procedures. It also proposed that recurrent training should include an in-aeroplane and/or flight simulator training program that, over a three year period, covers all major failures of aeroplane systems and associated procedures.

1.17.5 Aircraft maintenance

The operator contracted their aircraft maintenance to a service provider. However, as an operator of Class A aircraft they were required to have a CASA approved maintenance controller, maintenance control manual and system of maintenance.

The operator's engineering manager reported that he was not aware of why the 10 per cent extension to the 1,600 hr starter generator maximum time in service period was applied. Furthermore, the absence of supporting documentation could not be explained.

The 1,600 hr time in service threshold and the enabling replacement of the brushes at 800 hrs time in service, were promulgated in the Maintenance Review Board (MRB) Report for the Saab 340. MRB Reports are developed by manufacturers and approved by regulatory authorities to ensure that a minimum number of maintenance tasks are in place to support the continued airworthiness of an aircraft type. A MRB Report must form the basis of an aircraft's maintenance program.

Job cards that provided specific task directions were produced by the aircraft manufacturer and incorporated into the operator's system of maintenance. However, the job card relating to brush replacement did not accurately reflect the MRB requirement. That job card specified brush inspection at 800 hr intervals, with replacement required only if wear exceeded the stated limit. Maintenance records indicated that maintenance to the right starter generator was performed in accordance with the applicable job card. The operator reported that the aircraft manufacturer had advised that the job cards combined the MRB requirements with aircraft maintenance manual procedures. As such, the operator understood that the job card requirements were sufficient.

The introduction to the Saab 340 job card document stated that if there was a conflict between information on a job card and the MRB, the information in the MRB was to take precedence over that in the job card.

The aircraft manufacturer advised that the job card would be updated to reflect the MRB requirements.

1.18 Additional information

1.18.1 Cockpit checklists

Cockpit checklists are designed for ease of reference and independent use. They are used to provide pilots with an easily accessible means to ensure that a particular series of actions are accomplished in a logical and sequential manner, and to verify that the aircraft is in the correct configuration appropriate to a particular phase of flight.

However, the checklist process is vulnerable, because internal and external interruptions and distractions can interfere with a flight crew's ability to complete the checklist accurately. In a review of 300 United States (US) National Transportation Safety Board (NTSB) aircraft accident summaries, US researchers found that improper checklist usage was listed as a contributing or primary factor in 15 per cent of the accidents.[2]

2 Doolen, T., Nicolaide, R., & Funk, K. (2002). Improper checklist usage as a factor in aircraft accidents and incidents. Electronic checklist homepage. Internet WWW page at URL:http://www.engr.orst.edu/~HFE/Checklist/accidents.html#study1. Retrieved 1 August 2002.

A review of the US NTSB accident data, for the period 1983 to 1993, by the US Federal Aviation Administration (FAA) Office of Integrated Safety Analysis, revealed that a number of accidents had occurred where checklists were not used or not followed[3]. Some accidents involved checklists that were inadequate for the aircraft involved, or failed to include critical steps for safe operation. The FAA review of the NTSB data also included an analysis of checklist error incident data. Significant areas of checklist errors were identified, and included 'crew overlooked item(s) on the checklist'.

The review also examined human performance considerations and how they affected checklist performance. The analysis suggested that human performance limitations should be given full consideration throughout the checklist design phase and emphasised in crew training.

In April 1991 an FAA report[4] was published that studied the design and use of good cockpit checklists. The report noted that the training and checking practices then in use did not promote effective use of checklists. That report referred to a study of accidents and incidents investigated by the NTSB, and of Aviation Safety Reporting System (confidential) reports. The study found that crews' non-use of checklists, missing checklist items, or improper use of checklists, featured in a significant number of occurrences. The FAA report concluded that crews were not well trained in the use of those aids and recommended that operator checklist training include:

- proper use of checklists
- crew coordination in the use of checklists
- the necessity for compliance with checklists.

1.18.2 General checklist design considerations

In 1992, NASA published NASA Contractor Report 177605[5] on the design of flight-deck documentation. The report included information on, among other things, font, type size, style, and spacing. It also included advice that line length was an important consideration in the design of checklists. A common problem with checklist layouts was the existence of large gaps between the entry (the challenge) and the corresponding information relating to that entry (the response). There was a greater chance that the reader would make a mistake through perceptual misalignment of the correct response to a particular challenge item, when the gap between those items was increased.

In January 1995 the FAA published information on the design and presentation of checklists.[6] It also included advice on legibility of print, readability and contrast, and noted that operators must format checklists with:

> reasonable care and concern for the crews ability to perform the checklist with maximum accuracy. This can only be done if it is presented in a practical and usable format.

3 U.S. Department of Transportation, Federal Aviation Administration. (1995). *Human performance considerations in the use and design of aircraft checklists.* Washington, DC: FAA.

4 U.S. Department of Transportation, Federal Aviation Administration. (1991). *Use and design of flightcrew checklists and manuals.* Washington, DC: FAA.

5 Degani, A. (1992). *On the typography of flight-deck documentation* (document prepared for U.S. National Aeronautics and Space Administration). San Jose, CA: San Jose State University Foundation.

6 U.S. Department of Transportation, Federal Aviation Administration. (1995). *Human performance considerations in the use and design of aircraft checklists.* Washington, DC: FAA.

In September 2001, CASA published draft Advisory Circular AC 91-100(0) – Flight Check Systems. The circular contained information on checklists, and advised that checklists should be:

> produced in such a manner that make them easy to read, easy to locate relevant sections and be in a logical format.

Technical documents, such as checklists, need to be presented in a style that ensures response accuracy, reader comprehension and the avoidance of ambiguity.[7] The designer of technical documents also needs to understand how the document will be read and used. In particular, documents such as checklists should be designed with reference to the research relating to optimum communication and information presentation.[8] For example, a checklist may be technically accurate but be prone to misinterpretation because of presentation problems. Checklists that are easy to read and use are more resistant to error and will contribute less to cockpit workload than those that are not.[9]

1.18.3 Abnormal and emergency checklist design considerations

The draft Advisory Circular AC 91-100(0) – Flight Check Systems, published by CASA in September 2001, advised that an abnormal checklist should be:

> set out to enable recovery from a potential emergency without jeopardising the integrity or safety of the aircraft.

The information about checklists published by the FAA in January 1995 noted that the way operators presented abnormal and emergency checklists was particularly important. Deficiencies in the design of those checklists were critical because of the time limitation, workload and stress associated with such situations, and that those checklists:

> must be in a format that allows quick retrieval and rapid identification of the correct procedure. A mistake in an emergency procedure has the potential to create an irreversible situation.

With reference to emergency checklists, Turner and Huntley (1991) commented that:

> they should have a clearly defined start and finish with a title set off by type two sizes larger than that of the text, boldfaced, and all caps. Each list of procedures should be clearly separated from other lists. This should facilitate quick identification under conditions of stress and low illumination.[10]

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7 Hawkins, F. H. (1993). *Human factors in flight* (2nd Ed.) (p. 209). Aldershot, UK: Ashgate.

8 Ibid.

9 Turner, J. W., & Huntley, M. S. (1991). *The use and design of flightcrew checklists and manuals* (FAA/AM- 91/7). Washington, DC: FAA.

10 Turner, J. W., & Huntley, M. S. (1991). *The use and design of flightcrew checklists and manuals* (FAA/AM- 91/7). Washington, DC: FAA.

2 ANALYSIS

2.1 Introduction

The operation of a Saab 340 aircraft is a complex and safety-critical activity. This occurrence indicates the need for well-designed aircraft systems and checklists, supported by effective crew training, to achieve the necessary degree of safety in the operation of such aircraft. The circumstances also indicate the importance of effective maintenance systems.[11]

This analysis examines why the occurrence developed from a failure of one of the aircraft's two DC generation systems into a sustained low voltage condition for half of the aircraft's electrical components and services. The impact, actual and potential, of the warnings, cautions and failures on the safe operation of the aircraft is explained. Ultimately, the prevailing visual meteorological conditions and the ability of the crew to operate with minimal flight and navigation equipment mitigated the consequences of the occurrence.

2.2 Aircraft systems

2.2.1 Electrical system

The reason for the low voltage output from the right generator could not be clearly established. Opinions from the aircraft manufacturer, operator's maintenance personnel and the overhaul/repair facility varied and were not conclusive. The concurrent replacement of the key electrical system components and the subsequent identification of significant wear in the right starter generator and a defect in the generator control unit, made it difficult to isolate the primary failure. The condition of the right battery was an expected consequence of extended output, following failure of the right generator system.

The investigation considered that the likely reason for the low voltage output from the right generator, was the 'worn out' starter generator brushes. That failure mode was a well-established precondition for unalerted generator failure and accorded with occurrence specific advice from the aircraft manufacturer. While a number of starter generators had apparently achieved 1,600 hrs of trouble free time in service without brush change, that record did not preclude a brush-related failure in this occurrence. There was no explanation given as to why the condition of the brushes apparently deteriorated from being 40 per cent worn at 1026.34 hrs in service to being 'worn out' at just over 1,600 hrs in service.

The alternative hypothesis, proposed by the operator, was predicated on the 'sticky' generator control unit relay being stuck in the start position. However, there was no evidence that the relay had, in this case, stuck in the start (closed) position. Additionally, there was no compelling evidence that in a Saab 340B that a starter generator capable of generating could be electrically isolated from the buses and battery without warning or caution to the crew.

Given that the failure was likely a result of worn brushes, an electrical system incorporating a generator control unit modified in accordance with Service Bulletin 340-24-026, would have taken the right generator off line at a higher voltage. That would have produced a

11 The importance of well-designed systems for Class A aircraft has recently been highlighted in the ATSB's report on Ansett Australia Boeing 767 maintenance deficiencies, Safety Investigation Report BS/20010005.

much earlier generator-out caution and, in the absence of a serious under-voltage, would probably have automatically connected the bus tie, resulting in sustained powering of the right system. If, as happened in this occurrence, the bus tie had not connected, the higher system voltage afforded by the earlier caution would have provided the crew with the checklist option to reset the relay and restore power. Unfortunately, this was not an option available to the occurrence crew because the applicable checklist precluded a reset.

Although the most likely origin of the low voltage output in this occurrence was the worn out brushes, the investigation could not discount the possibility of other failure modes with the potential for starter generator under-voltage output.

Although the failure of the right EFIS screens was the first tangible indication that the system had dropped below 18 volts, the crew did not recognise low system voltage as a likely reason for the blank screens. When the crew overlooked reference to generator voltage on the EFIS failure/disturbances checklist, they missed the opportunity to correctly identify low system voltage as the reason for the right EFIS failure. Correct identification of the low voltage condition and implementation of the DC voltage low checklist would have facilitated connection of the bus tie relay and avoided the sequence of warnings, cautions and failures that were consistent with a progressive depletion of power from the right battery. An analysis of flight crew actions and checklist issues are discussed in detail in section 2.3.

2.2.2 Starter generator maintenance

The 800 hr brush replacement was not applied largely because the relevant job card, produced by the aircraft manufacturer, did not accurately reflect the requirements of the Maintenance Review Board (MRB) Report. That lack of consistency suggests that the aircraft manufacturer’s document control system was not sufficiently robust. The operation of the starter generator beyond 1,200 hrs, which was the applicable limit if the brushes were not replaced, provided the opportunity for brush wear beyond serviceable limits.

Despite the operator having recognised the limit of 1,600 hrs it is apparent that maintenance personnel that applied the extension to those hours did not appreciate the potential consequences of exceeding that limit. If, as the operator reported, worn out brushes were historically common on full life units, then any further extension of life was inadvisable.

Given that excessive brush wear was implicated in the unalerted failure of the starter generator system, replacement of the brushes after 800 hrs or removal of the starter generator at 1,200 hrs should have prevented the occurrence.

2.2.3 Significance of low voltage on aircraft systems

The significance of the various reported warnings, cautions, and failures is as follows:

- The failure of the right EFIS screens leaving one remaining left screen in composite mode significantly limited the display of flight information, which increased the crew’s workload and limited their ability to control the aircraft with reference to instruments
- Right engine intake anti-ice system – as the valve fails in the open position there is no significant effect
- Cabin pressure system – the aircraft was descended to a low altitude although it probably remained pressurised
- Flight attendant bell – had the potential to distract the flight crew

- Stall warning system – spurious clacker activation had the potential to distract the crew. The loss of one of the two stall warning channels indicated by the 'stall fail' warning was not significant
- Rudder limiter system – there was an increased risk of exceeding the structural limit of the aircraft's rudder
- GPS system – loss of long range navigation capability
- Copilot communications – difficult for crew to communicate with each other especially during the descent with oxygen masks on
- Heading reference – the standby compass was the only means of heading reference for about 18 minutes
- Right engine instruments – potential for crew difficulty in the event of an abnormal engine condition
- Right battery – complete loss of battery power after hot battery light illumination

The significance of some of the various unreported failures is:

- GPWS system – loss of terrain alerting for about 18 minutes removed key terrain clearance protection
- Right fuel shut-off – removed the means to shut off fuel from the right engine compartment
- Right fuel gauge – potential for fuel management problems

2.2.4 Flight data recorder

The flight data recorder is not the only source of information sought by an investigation, but it is an important tool in determining the circumstances of an occurrence. The absence of flight data recorder information for a period of about 18 minutes limited the investigation's ability to fully document and analyse the occurrence sequence. Given the availability of left electrical system power, the continued operation of the recorder relied on crew action to switch from the failed inverter. Crew workload was probably the main reason for the 18-minute delay in switching inverters. Although the power supply system design satisfied the requirements of the relevant Federal Aviation Regulations, the potential safety benefit of flight recorder data was lost.

2.2.5 Low electrical power indication certification

The method of compliance with FAR Part 25.1309(c) in Saab 340 aircraft with unmodified generator control units relied, in some cases, on the failure of the EFIS screens to alert a pilot to a low voltage condition. This method of compliance may be appropriate for indicating low voltage to the screens only. However, it is not suitable as a de-facto low voltage warning for an electrical system because the indication of low voltage, provided by screen failure, is not produced until the battery is seriously depleted. Furthermore, the meaning of screen failure is ambiguous as EFIS screens can fail for reasons other than low system voltage.

The investigation could not clearly establish if the Saab 340, with an unmodified generator control unit, was fully compliant with FAR subpart 1309(c) of FAR 25. However, the investigation considered that a situation where an aircraft could have a delayed low voltage warning as low as 18 volts was a safety deficiency.

2.3 Flight crew

2.3.1 EFIS failures/disturbances checklist

The circumstances indicate that the crew focused on the checklist references to EFIS failures to the exclusion of the first two items, both addressing generator voltage. When the crew consulted the checklist, the absence of a generator-out alert and the failure of the left screen for a reason other than low supply voltage predisposed the pilot in command to seek an EFIS system related solution. That influence on the pilot in command would have been reinforced by his familiarity with the EFIS drive transfer system.

Notwithstanding the above influences on the pilot in command, the crew needed to action the first item of the checklist to identify the source of the screen failures. That they did not reflects both on their use of the checklist and on the checklist design. Well-disciplined use of checklists and regular practice of abnormal and emergency procedures are defences against slips or lapses that may result in missed items on a checklist. Re-designing a checklist in accordance with the applicable human factors research is an effective strategy for minimising human error. A combination of these strategies would provide an improved level of safety.

A checklist first item that was more clearly defined by a boldfaced larger font size and separation from following procedures, consistent with the advice of Turner and Huntley (1991) and the FAA (1995), would have facilitated correct use of the checklist. Alternatively, the repetition of critical items, such as a generator check, after the title of each possible condition would have increased the likelihood of crew compliance with that particular requirement.

Given that the screens remained blank after the checklist was actioned, the crew may have reassessed the checklist requirements. However, the appearance of the multiple alerts and failures diverted the attention of the crew and increased their workload. Consequently, they did not check the generator voltage at any stage of the occurrence and thereby missed the opportunity to identify the source of the EFIS failure.

2.3.2 Crew coordination in checklist execution

The sequence of activities and the nature of the interaction between the pilot in command and the copilot during the execution of the EFIS failure/disturbances checklist could not be clearly established. Nonetheless, it would seem appropriate that the copilot would action the EFIS failure/disturbances checklist given that the right side EFIS screens had lost power. Furthermore, it is considered appropriate that the pilot in command continued to handle the aircraft during the crew's initial response to the EFIS failures. The absence of clear documented guidance for the specific distribution of crew tasks and responsibilities for completing the checklist may have increased the likelihood of the crew missing checklist items, performing items out of sequence, or failing to cross check and confirm that items had been actioned.

2.3.3 Training

The incident flight was the copilot's second line flight after the completion of a Saab SF-340B type rating. The low experience on type suggests that the copilot was probably not fully familiar with the abnormal procedures. Furthermore, he was probably more reliant upon, and confident in, the experienced pilot in command's understanding of the aircraft's electrical system and the use of the EFIS failure/disturbances checklist.

The failure of the EFIS screens and the multiple system warnings, cautions and failures had the potential, given a reasonable systems understanding, to direct the crew's attention to the low voltage condition. However, once the cascade of low voltage effects began, the associated workload and stress reduced the capability of the crew to properly diagnose the low voltage condition. Had the pilot in command received regular systems refresher training, as proposed by CASR Part 121A, he would have had a better understanding of the nature of the EFIS failures and the potential implications of a severe under-voltage condition.

2.4 Summary of technical and flight crew related Issues

2.4.1 Introduction

A number of safety concerns relating to technical issues and flight crew performance have been identified by the investigation. Potential safety defences have also been identified. Defences refer to what is in place to minimise risk in the future and are those measures put in place by an organisation to facilitate and assure safe performance of the operational components of the system.[12]

A general principle of hazard management is that some types of defences are preferable to others, in terms of their ability to reduce risk. This has led to various lists of 'hierarchy of control' or risk treatment priorities. For example, it is widely accepted that it is preferable to first redesign a system/task/equipment (to eliminate the hazard, reduce exposure to the hazard, or reduce the likelihood of unsafe acts) than rely on administrative controls such as procedures, training or education.

JM Christensen[13] has proposed a preferred risk treatment protocol or hazard control hierarchy. Advocates of this approach have further developed the model and recommended that after a hazard has been identified the process of reducing the influence of this hazard should follow the priority listed below:

- design (or redesign) to eliminate the hazard
- remove or minimise exposure to the hazard
- guard
- warn
- procedures
- train
- selection.

After design, the two most common types of defences in the transportation industry in response to safety critical events are procedures and training. These defences can be effective and are necessary for many tasks, provided they are designed, implemented and used appropriately. A series of in-depth defences including sound design, procedures and training will decrease the likelihood of unsafe acts.

12 Reason, J. T. (1997). *Managing the risks of organisational accidents*. Aldershot, UK: Ashgate.

13 Christensen, J. M. (1987). *The human factors profession*. In G. Salvendy (Ed.), Handbook of human factors. New York: Wiley.

2.4.2 Technical issues

In this occurrence, adherence to the aircraft manufacturer's starter generator time in service limits would have prevented 'worn out' brushes and the consequent unalerted low voltage condition. However, as this occurrence demonstrates, compliance with aircraft maintenance requirements cannot be assured. Additionally, worn out brushes may not be the only defect with the potential for generator low voltage output. A defence to effectively reduce the potential for unalerted low voltage conditions is therefore desirable.

Incorporation of the modified generator control unit in Saab 340 aircraft constitutes a change that reduces the risk of low voltage output from a starter generator remaining undetected. A timely warning to the crew of generator low voltage output assumes greater importance in the absence of any system low voltage alert. Installation of modified generator control units would have a significant safety benefit in ensuring immediate and specific crew awareness of a developing low voltage condition. Enhanced crew awareness means that they could address a failure in the generation system well before any associated EFIS screen failure. It is also much more likely that any non-connection of the bus tie relay would be avoided or rectified successfully, preventing sustained low voltage to key elements of the electrical system.

2.4.3 Flight crew related issues

Correct use of the checklist and thorough systems knowledge, on this occasion, would have enabled identification of the low voltage condition and the appropriate response. However, as this occurrence demonstrates, those defences were not as robust as they could have been. Strengthening the defences to be more effective in assisting the crew to deal with abnormal and emergency situations is therefore desirable.

Well-designed abnormal and emergency checklists, and improved systems training represent a strengthening of the procedural and training defences. There is a demonstrated need for pilots to be thoroughly familiar with the systems of the aircraft they operate, and the actions to be taken in the event of abnormal or emergency situations. Regular practice of those procedures is also essential if they are to be accomplished effectively. The proposed arrangements in the Civil Aviation Safety Regulations Part 121A (Air Transport Operations – Large Aeroplanes) should lead to improved pilot proficiency and knowledge in abnormal situations and emergencies, specific to the aeroplane type.

3 CONCLUSIONS

3.1 Findings

3.1.1 Aircraft

1. The aircraft was dispatched with an unserviceable upper left EFIS screen in accordance with the aircraft's minimum equipment list.
2. The starter generator was not maintained in accordance with the aircraft maintenance review board report. In particular, the starter generator brushes were not replaced nor was the starter generator retired as required.
3. A failure occurred in the right DC power generation system.
4. The generator-out light illumination was significantly delayed.
5. The aircraft was fitted with a generator control unit that wasn't modified in accordance with the optional modification number 2533.
6. The aircraft did not have an effective low voltage warning in some circumstances.
7. The first indication of low voltage in the right DC electrical system was blank copilot EFIS screens, which was consistent with the right system voltage being below 18 volts.
8. The bus tie system did not connect due to automatic activation of the over current protection feature.
9. All electronic heading reference failed for about 18 minutes.
10. The aircraft's flight data recorder system did not record for about 18 minutes.
11. All the identified system warnings, cautions, and failures were consistent with a right system voltage below 18 volts.

3.1.2 Certification

1. Compliance with JAR/FAR 25.1309 (c), which was applicable to low voltage warnings, was reviewed after in-service experience revealed an unalerted generator failure mode.
2. As a result of the JAR/FAR 25.1309 (c) certification review, the aircraft manufacturer introduced redesigned generator brushes, improved documentation, and an additional checklist. A modified generator control unit was made available as an option.

3.1.3 Flight crew

1. The pilot in command held a Saab 340 type rating prior to joining the operator.
2. The copilot had recently obtained a Saab 340 type rating.
3. The copilot was operating under supervision on his second line flight.
4. The crew missed the first item (GEN Voltage) when they actioned the aircraft manufacturer's EFIS failure/disturbance checklist.
5. Ground training provided to the copilot included training on the aircraft's electrical systems.

6. Improved knowledge and understanding of the aircraft's systems through refresher training would have assisted the pilot in command in this occurrence.
7. Before the occurrence flight, the crew was not aware of the magnitude of the potential consequences of a declining power supply.

3.1.4 Operator's documentation and procedures

1. The operator's maintenance control system did not ensure that the starter generator was maintained in accordance with the aircraft manufacturer's specifications.
2. The operations manual did not identify the roles of the non-flying pilot and flying pilot when executing all checklists for abnormal and emergency situations.
3. Pilots did not receive regular recurrent or refresher training on the aircraft's systems and associated checklists.
4. The operator conducted regular training and checking activities in the aircraft, rather than simulators.
5. The abnormal and emergency checklists used by the operator were produced by the aircraft manufacturer.
6. The Saab 340 EFIS failure/disturbances checklist has not been updated to reflect the current research findings on the human factors of checklists.

3.1.5 Weather

1. At the time of the occurrence, the weather conditions were consistent with the forecast of visual meteorological conditions.

3.2 Significant factors

1. The starter generator was not maintained in accordance with the aircraft maintenance review board report.
2. A fault developed in the right DC generation system.
3. There was a significant delay to illumination of the right generator-out light because the generator control unit did not immediately take the generator off-line.
4. The aircraft was not fitted with a generator control unit modified in accordance with the optional modification number 2533.
5. The crew overlooked the first item of the EFIS failure/disturbances checklist.

4 SAFETY ACTION

Central to ATSB's investigation of aviation accidents and incidents is the early identification of safety deficiencies in the civil aviation environment. The Bureau issues recommendations to regulatory authorities, operators, manufacturers or other agencies in order to address safety deficiencies. Recommendations may be issued in conjunction with ATSB reports or independently. A safety deficiency may lead to a number of similar recommendations, each issued to a different agency.

The ATSB does not have the resources to carry out a full cost-benefit analysis of every recommendation. The cost of any recommendation must always be balanced against its benefits to safety, and aviation safety involves the whole community. Such analysis is a matter for the body to which the recommendation is addressed (for example the Civil Aviation Safety Authority in consultation with the industry).

4.1 Recommendations

4.1.1 Saab Aircraft AB

Recommendation R20030008

The Australian Transport Safety Bureau recommends that Saab Aircraft AB redesign the Saab 340 abnormal and emergency checklists to improve usability, with reference to current human factors research findings on the use and design of aircraft checklists.

4.1.2 Aviation Safety Authority of Sweden (Luftfartsverket)

Recommendation R20030009

The Australian Transport Safety Bureau recommends that the Aviation Safety Authority of Sweden (Luftfartsverket) review the design of the Saab 340 abnormal and emergency checklists, with reference to current human factors research findings on the design and use of aircraft checklists.

Recommendation R20030015

The Australian Transport Safety Bureau recommends that the Aviation Safety Authority of Sweden (Luftfartsverket) assess the safety benefit of mandating Saab Aircraft AB Service Bulletin 340-24-026 incorporating generator control unit modification number 2533.

4.1.3 Civil Aviation Safety Authority

Recommendation R20030010

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority review their existing approvals of the Saab 340 abnormal and emergency checklists, with reference to current human factors research findings on the design and use of aircraft checklists.

Recommendation R20030018

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority review their existing approvals of Saab 340 systems of maintenance to ensure continued consistency with maintenance review board report requirements for the Saab 340.

Recommendation R20030014

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority assess the safety benefit of mandating Saab Aircraft AB Service Bulletin 340-24-026 incorporating generator control unit modification number 2533.

4.1.4 Federal Aviation Administration

Recommendation R20030016

The Australian Transport Safety Bureau recommends that the Federal Aviation Administration assess the safety benefit of mandating Saab Aircraft AB Service Bulletin 340-24-026 incorporating generator control unit modification number 2533.

4.1.5 All Australian Saab 340 operators

Recommendation R20030007

The Australian Transport Safety Bureau recommends that all Australian Saab 340 operators review the design of the Saab 340 abnormal and emergency checklists, with reference to current human factors research findings on the design and use of aircraft checklists.

Recommendation R20030013

The Australian Transport Safety Bureau recommends that all Australian Saab 340 operators assess the safety benefit of implementing Saab Aircraft AB Service Bulletin 340-24-026 incorporating generator control unit modification number 2533.

4.2 Local safety action

4.2.1 Saab Aircraft AB

Saab Aircraft AB advised that they have decided to take into consideration a review of the checklist.

4.2.2 Aviation Safety Authority of Sweden (Luftfartsverket)

Aviation Safety Authority of Sweden (Luftfartsverket) advised that they will make an assessment of the status of Service Bulletin 340-24-026 against the new JAR-39/EASA Part 21 criteria.

4.2.3 Civil Aviation Safety Authority

The Civil Aviation Safety Authority advised that they will be incorporating comprehensive training and recurrent checking of flight crew on the proposed Civil Aviation Safety regulation Part 121A Subpart N.

The Civil Aviation Safety Authority advised that they will assess the safety benefit of mandating Service Bulletin 340-24-026 incorporating generator control unit modification number 2533.

4.2.4 The Operator

The operator advised that as a result of this incident and other factors, including CASA's published intention to improve training (CASR 121), they have introduced technical refresher training and a Safety Management System.

Appendix 1. EFIS failure/disturbances checklist

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ABNORMAL CHECKLIST

ABNORMAL PROCEDURES

EFIS FAILURE / DISTURBANCES

INDICATION: EFIS totally black, blurred, fluctuates, flickers or distorted.

1. GEN Voltage .... CHECK

◆– **GEN Voltage LOW (below 26 V):**

Apply procedure DC VOLTAGE LOW.

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◆– **EADI AND EHSI failure:**

– Total loss of presentation (black screen), blurred or distorted picture on EADI <u>and</u> EHSI.

2. EFIS switch .... DRIVE XFR
3. End of procedure.

◆– **EADI OR EHSI failure:**

– Total loss of presentation (black screen), blurred or distorted picture on the EADI <u>or</u> EHSI.

2. EFIS switch .... ADI REV or HSI REV
   – Switch towards operating display.

◆– **If composite mode comes on without any failure:**

3. Cb for failed display .... PULL

Left side:		Right side:	
L ADI	G–16	R ADI	N–14
L HSI	G–15	R HSI	N–13

4. End of procedure.

◆– **If failure remains when in composite mode:**

3. EFIS switch .... NORM
   – ADI REV or HSI REV back to NORM.
4. EFIS switch .... DRIVE XFR
5. End of procedure.

Appendix 2. DC power distribution list

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ABNORMAL CHECKLIST

ABNORMAL PROCEDURES

Electrical power distribution list

DC POWER

L HOT BAT BUS	R HOT BAT BUS
– L engine fire extinguisher.	– R engine fire extinguisher.
– Cargo fire extinguisher.	– R fire handle: HP, Bleed and Gen shut off.
– L Fire handle: HP, Bleed and Gen shut off.	– Refueling/defueling power.
– Dome, entrance and cargo lights.	– Clock
– L battery voltage indication.	– Additional cargo extinguisher (if installed).
– AHRS 1 backup power.	– R battery voltage indication.
	– AHRS 2 backup power.
	– ACARS backup power (if installed).

L BAT BUS	R BAT BUS
– Emergency battery charging (JET PACK).	– Fuel used indication (if installed).
– Cabin pressurization control.	– Outflow valve auto dump on ground.
– Cabin pressure emergency dumping.	– R pilot audio.
– L pilot audio.	– Lavatory and cargo smoke detection.
– P/A amplifier and handsets.	– Flap indication.
– Avionic compartment smoke detection.	– Stby trim indicator backup power.
– Flap control.	– Stby pitch and stby roll trim backup power.
– Stby trim indicator main power.	– Main trim indicator.
– Stby pitch and stby roll trim main power.	– Main roll and main pitch trim.
– Pitch/roll disconnect.	– Yaw trim.
– L stby fuel pump, power and control.	– Pitch trim synchronization.
– L main fuel pressure control and indication.	– Rudder limiter override.
– L fuel shutoff valve.	– R stby fuel pump, power and control.
– L windshield wiper.	– R main fuel pressure control and indication.
– Cockpit voice recorder.	– R fuel shutoff valve.
– Landing gear extension and retraction.	– R landing gear emergency extension.
	– Landing gear relays.
(Cont'd)	

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ABNORMAL CHECKLIST

L BAT BUS	R BAT BUS
(Cont'd)	
– L landing gear emergency extension.	– Navigation lights, one bulb each position.
– Nose wheel steering.	– Map lighting.
– Taxi light.	– Flood lighting, right.
– Rotating/flashing beacons.	– Cabin signs.
– Pilot reading lights.	– R engine autoignition.
– Flood lighting, left and center.	– R engine GCU.
– L engine autoignition.	– R engine start control.
– L engine GCU.	– R engine speed (Ng).
– L engine start control.	– R engine temp (ITT).
– L engine speed (Ng).	– R engine torque.
– L engine temp (ITT).	– R engine oil temp and press. indication.
– L engine torque.	– R engine fuel flow.
– L engine oil temp and press indication.	– R engine CTOT.
– L engine fuel flow.	– R engine intake anti–ice control.
– L engine CTOT.	– R prop, oil temp and press. indication.
– L and R engine anti–ice control lights.	– Propeller brake.
– L engine intake anti–ice control.	– R propeller de–ice control.
– L prop oil temp and press indication.	– L bleed valve control.
– L propeller de–ice control.	– R stall warning (channel 2).
– R bleed valve control.	– Stick pusher servo.
– L stall warning (channel 1).	– Windshield heat, R front and side control.
– Cabin overhead lighting.	– Wing and stab de–ice man. and control ind.
– Wing and stab de–ice CONT mode.	
– Windshield heat, L front and side control.	– Wing and stab de–ice air supply control.
– Bus tie relay AUTO function.	– Warning annunciator system, channel 2 (with mod 2328 and a/c 300–up).
– Warning system test and bright/dim function (with mod 2328 and a/c 300–up)	
– Hydraulic pump OVRD (with mod 2414 and a/c 300–up).	– ACARS, VHF COM 3 if installed (with mod 2544).
– Warning annunciator system, channel 1 (with mod 2328 and a/c 300–up).	– INVERTER 2 (with mod 2544).
– INVERTER 1 (with mod. 2544).	– FI STOP (with mod no 2558 and a/c 376–up).

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ABNORMAL CHECKLIST

L ESS BUS	R ESS BUS
– Cabin temperature indication.	– OAT probe heating control.
– Rudder gust lock.	– Cabin pressurization indication.
– Fuel interconnect valve.	– L and R battery and fuel temp indication.
– L fuel quantity.	– Emergency lights, battery charging (a/c 3–359)
– Hydraulic pump OVRD (without mod 2414).	– Emergency lights manual control.
– Landing gear in transit light.	– Fuel crossfeed valve.
– Brake pressure indicator, emergency and outboard.	– R fuel quantity.
– L propeller speed (Np).	– Brake pressure indicator, main and inboard.
– L BETA indication.	– R altimeter vibrator and R overspeed warning.
– L autocoarsen system.	– Stby pitot heat.
– Autocoarsen computer.	– Landing gear downlock indication.
– Propeller overspeed test.	– R propeller speed (Np).
– Warning annunciator system, channel 1 (without mod 2328).	– R BETA indication.
– Warning system test and bright/dim function (without mod 2328)	– R autocoarsen system.
– GWPS indicators and flap override.	– Warning annunciator system channel 2 (without mod 2328).
– L Essential bus voltage indication.	– R Essential bus voltage indication.
	– Lavatory flush and light (light for a/c 3–359)

L MAIN BUS	R MAIN BUS
– Flight deck temperature control.	– R galley control (if installed).
– Recirculation fan overheat detection.	– Cabin window lighting.
– Avionic rack fan control.	– Cabin temperature control.
– Avionic rack fan power.	– R battery ventilation.
– L battery ventilation.	– R engine anti–ice air valve (fails open).
– Hydraulic pump AUTO.	– R Windshield wiper.
	– Anti–skid outboard.
	– Emergency lights, battery charging (a/c 360–up)
(Cont'd)	

L MAIN BUS	R MAIN BUS
(Cont'd)	
– L engine anti–ice air valve (fails open).	– R landing light.
– Anti–skid inboard.	– Strobe lights.
– L landing light.	– Wing inspection lights.
– Navigation lights, one bulb each position.	– R HP manual control (fails closed).
– Cabin window lighting, lavatory light (a/c 360–up).	– R HP auto control.
– Propeller synchrophazing.	– Standby Inverter 26 V (or INVERTER 2, without mod 2544).
– L HP auto control.	– R bleed air leak detection and indication.
– L HP manual control (fails closed).	– X–valve control (fails closed).
– L bleed air leak detection and indication.	– R MAIN BUS voltage indication.
– Main inverter 115 V 26 V (or INVERTER 1, without mod 2544).	– ACARS, VHF COM3 if installed (without mod 2544).
– L MAIN BUS voltage indication.	
– Entrance and cargo lighting.	
– Bus data rec. (if installed)	

L MAIN START BUS	R MAIN START BUS
– Instrument lighting left, center and center pedestal.	– Instrument lighting right.
	– Logo lights (if installed).
	– Emergency light cabin (a/c 360–up)

L AVIONIC BUS	R AVIONIC BUS
– Flight director and MSP.	– Flight director and MSP.
– Autopilot controls and servos.	– Autopilot controls and servos.
– HF COM (if installed).	– VHF COM 2.
– MFD and MPU (if installed).	– Cabin attendant call buttons.
– ADF 1.	– FDAU (for a/c 160–249 without mod 2245 and/or without mod 2948).
– DME 1.	– ADF 2 (if installed).
– ATC transponder 1 (depending on national regulations).	– VOR/ILS 2.
– Radio altimeter (GPWS is lost).	– DME 2 (if installed).
(Cont'd)	

L AVIONIC BUS	R AVIONIC BUS
(Cont'd) – FDAU (for a/c 160–249 with mod 2245 and and/or with mod 2948, and for a/c 250–up) – AHRS 1 main power. – L AVION BUS voltage indication.	– Weather Radar power. – ATC transponder 2 (if installed). – AHRS 2 main power. – R AVION BUS voltage indication. – RNAV (if installed).

L AVIONIC START BUS	R AVIONIC START BUS
– Rudder limiter. – ADC/Altimeter. – ADC/IAS indicator. – VSI or VNI and altitude preselector. – EFIS 1.	– EFIS 2.

ESS AVIONIC BUS	UTILITY BUS
– VOR/ILS/Marker 1 and VOR/ILS indicator. – ATC Transponder 1 (depending on national regulations.)	– Passenger reading lights. – Tail compartment shutoff valve. – Lavatory water heater (if installed). – R Galley fan light and liquid heater. – Pilot footwarmer (if installed). – L Galley. – F/A seat heater (if installed). – Active Noise Control (if installed).

EMERGENCY BUS	EMERGENCY AVIONIC BUS
– Audio system backup power. – Bus tie relay CONN function. – L and R engine fire detect. – L and R tailpipe hot detect. (Cont'd)	– VHF COM 1. – Stby horizon. – FLT Data backup (with mod 2143, optional)

EMERGENCY BUS	EMERGENCY AVIONIC BUS
(Cont'd) – Warning system backup pwr. – Emergency voltage indic. – 28 to 5 VDC converter for instrument emergency lighting.	

L GEN BUS	R GEN BUS
– Cabin recirc fan. – Hydraulic pump pwr.	– Cockpit recirc fan.

AC POWER

L INV BUS 26 V AC	R INV BUS 26 V AC
– AHRS 1 compass reference. – NAV 1 compass reference.	– AHRS 2 compass reference. – NAV 2 compass reference.

L INV BUS 115 V AC	R INV BUS 115 V AC
– Flight recorder power (for a/c 160–249 without mod. 2245 and/or without mod. 2948). – Integral panel lighting. – GPWS power.	– Flight recorder power (for a/c 160–249 with mod. 2245 and/or with mod. 2948, and for a/c 250–UP). – Weather radar stabilization. – ACARS (if installed).

WILD FREQUENCY AC POWER

L GEN BUS 115 V AC	R GEN BUS 115 V AC
– L propeller de–ice power. – Windshield heat left front and side. – L pitot heat. – L angle of attack probe heat. – Galley hot jugs heating.	– R propeller de–ice power. – Windshield heat right front and side. – R pitot heat. – R angle of attack probe heat. – OAT probe heat.

L GEN 115 V AC	R GEN 115 V AC
– L engine intake anti–ice.	– R engine intake anti–ice.

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ISBN 1 877071 48X

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