AIRCRAFT SERIOUS INCIDENT REPORT AND EXECUTIVE SUMMARY

				Reference:	CA18/3/2/1325		
Aircraft Registration	ZS-OAF	**Date of Accident**	22 November 2020			**Time of Accident**	0820Z
Type of Aircraft	Boeing 737-400			**Type of Operation**		Air Transport Operations, Passengers (Part 121)	
Pilot-in-command Licence Type	Airline Transport Pilot			**Age**	37	**Licence Valid**	Yes
Pilot-in-command Flying Experience	**Total Flying Hours**			7 924.0		**Hours on Type**	3 383.0
Last Point of Departure	Cape Town International Aerodrome (FACT), Western Cape						
Next Point of Intended Landing	East London Aerodrome (FAEL), Eastern Cape						
Damage to Aircraft	Minor						
Location of the incident site with reference to easily defined geographical points (GPS readings if possible)							
Runway 29 at George Aerodrome (GPS position: 34°00'24.13" South 022°22'27.41" East), elevation 648ft							
Meteorological Information	Surface wind: 210°/10kt; temperature: 19°C; dew point: 14°C; clouds: Scattered at 3300ft						
Number of People On-board	6 + 158	**Number of People Injured**	9	**Number of People Killed**	0	**Other (On Ground)**	0
Synopsis							

On Sunday, 22 November 2020 during daytime, a Boeing 737-400 aircraft with registration ZS-OAF, performing flight FA146, took off on a scheduled domestic flight from Cape Town International Aerodrome (FACT) to East London Aerodrome (FAEL). On-board the aircraft were six crew members and 158 passengers.

While the aircraft was climbing through 32 920 feet (ft) above mean sea level (AMSL) to its cruising altitude of 33 000ft, the crew encountered a cabin depressurisation warning, whereafter they broadcasted a *Cabin Altitude Warning* followed by a *Mayday, "requesting an emergency descent"*. The aircraft commenced with an emergency descent to 10 000ft. Once the crew levelled off at flight level (FL) 100, the area controller who had the aircraft visual on primary surveillance radar asked the crew if they would be returning to FACT, but the crew opted to divert to George Aerodrome (FAGG) as it was the closest suitable aerodrome where the aircraft could land at the time.

After landing at FAGG, one of the passengers required medical attention, three passengers complained of nosebleed and five passengers suffered from severe ear pain following the cabin altitude warning and emergency descent. These medical treatments were viewed as minor.

Probable Cause			
It is likely that this serious incident occurred as a result of the following failures: (i) The air/ground proximity sensor becoming defective, which rendered certain cues to remain in ground mode and causing certain warning lights to illuminate in the cockpit which required crew intervention, whilst certain cues functioned normally. (ii) Loss of cabin pressure, which was attributed to air leaking from the fuselage, including the aft cargo compartment door seal that was worn out. This situation was further aggravated by the left air-conditioning pack outlet duct fracture in an area that was previously repaired, which resulted in reduced air supply to the system.			
SRP date	12 April 2022	Publication date	14 April 2022

DESCRIPTION OF THE SERIOUS INCIDENT

Reference Number	**:** CA18/3/2/1325
Name of Owner	**:** Safair Operations (Pty) Ltd
Name of the Operator	**:** FlySafair
Manufacturer	**:** Boeing Aircraft Company
Model	**:** 737-400
Nationality	**:** South African
Registration markings	**:** ZS-OAF
Place	**:** George Aerodrome (FAGG), Western Cape Province
Date	**:** 22 November 2020
Time	**:** 0820Z

Purpose of the Investigation:

In terms of Regulation 12.03.1 of the Civil Aviation Regulations (CAR) 2011, this report was compiled in the interest of the promotion of aviation safety and the reduction of the risk of aviation accidents or incidents and ***not to apportion blame or liability****.*

All times given in this report are Co-ordinated Universal Time (UTC) and will be denoted by (Z). South African Standard Time is UTC plus 2 hours.

Investigation Process:

The serious incident was reported to the Accident and Incident Investigations Division (AIID) on 25 November 2020 via the ASQS IQSMS Air Safety Reporting System. The investigator/s co-ordinated with all authorities by initiating the serious incident investigation process according to CAR Part 12 and investigation procedures. The AIID is leading the investigation as the Republic of South Africa is the State of Occurrence.

Notes:
1. Whenever the following words are mentioned in this report, they shall mean the following:

- *Serious Incident — this investigated serious incident*
- *Aircraft — the Boeing 737-400 involved in this serious incident*
- *Investigation — the investigation into the circumstances of this serious incident*
- *Pilots — the pilots involved in this serious incident*
- *Report — this serious incident report*

2. Photos and figures used in this report were taken from different sources and may have been adjusted from the original for the sole purpose of improving clarity of the report. Modifications to images used in this report were limited to cropping, magnification, file compression; or enhancement of colour, brightness, contrast; or addition of text boxes, arrows or lines.

Disclaimer:
This report is produced without prejudice to the rights of the AIID, which are reserved.

Abbreviation	Description
AGL	Above Ground Level
AMSL	Above Mean Sea Level
AMO	Aircraft Maintenance Organisation
AIID	Accident and Incident Investigations Division
ARFF	Aerodrome Rescue and Firefighting
ATC	Air Traffic Control
CAR	Civil Aviation Regulations
CAVOK	Ceiling and Visibility OK
C of A	Certificate of Airworthiness
C of R	Certificate of Registration
CVR	Cockpit Voice Recorder
°C	Degrees Celsius
DME	Distance Measuring Equipment
EADI	Electronic Attitude Director Indicator
FACT	Cape Town International Aerodrome (ICAO code)
FAEL	East London Aerodrome (ICAO code)
FAGG	George Aerodrome (ICAO code)
FDR	Flight Data Recorder
FL	Flight Level
FMC	Flight Management Computer
FO	First Officer
Ft	feet
GPS	Global Positioning System
GRV	Golf Romeo Victor (VOR beacon)
hPa	Hectopascal
IIC	Investigator-in-charge
Kts	knots
LNAV	Lateral Navigation
METAR	Meteorological Aerodrome Report
MHz	Megahertz
Nm	Nautical Miles
NOSIG	No Significant Change
OEM	Original Equipment Manufacturer
PIC	Pilot-in-command
QAR	Quick Access Recorder
QRH	Quick Reference Handbook
SACAA	South African Civil Aviation Authority
SAWS	South African Weather Service
SCCM	Senior Cabin Controller Member
SSR	Secondary Surveillance Radar
TBO	Time Between Overhaul
THR	Throttle
VMC	Visual Meteorological Conditions
VHF	Very High Frequency
VFR	Visual Flight Rules
VNAV	Vertical Navigation
VOR	Very High Frequency Omnidirectional Range
Z	Zulu (Term for Universal Coordinated Time - Zero hours Greenwich)

1. FACTUAL INFORMATION

1.1 History of Flight

1.1.1 On Sunday morning, 22 November 2020 at approximately 0746Z, a Boeing 737-400 aircraft with registration ZS-OAF, performing flight FA146, departed Cape Town International Aerodrome (FACT) to East London Aerodrome (FAEL) on a scheduled domestic flight with 158 passengers and 6 crew members on-board. The flight was conducted under the provisions of Part 121 of the Civil Aviation Regulations (CAR) 2011 as amended.

1.1.2 Prior to take-off and before push back, the senior cabin crew member (SCCM) informed the pilot-in-command (PIC) that she thought the doors 1R and 2R were not closed properly. The doors were then disarmed and closed again with the assistance of a technician, from the outside. This procedure was repeated three times before the doors could be closed properly.

1.1.3 After take-off from Runway 19, the crew had no lateral navigation (LNAV) and vertical navigation (VNAV) indication in the cockpit. The throttle (THR) HOLD stayed on after take-off and the auto throttle was disconnected manually. For the remainder of the flight, there was no auto throttle available.

1.1.4 The crew was cleared to climb to flight level (FL) 330 (33 000) feet (ft) above mean sea level (AMSL). The aircraft was, however, not being interrogated by secondary surveillance radar (SSR) after take-off and the area controller informed the crew that there was no mode C readout. The crew was then advised to recycle the transponder and to squawk 3226. The crew advised that they have recycled the transponder, but they were informed that there was still no mode C readout. The crew then asked the controller if it was an aircraft problem or a radar problem, whereupon the controller indicated that the problem appeared to be on their side (aircraft's side). Approximately 5 minutes later, the crew was advised by the area controller that he had no radar return and instructed them to route via golf, romeo, victor (GRV); pappa, echo, victor (PEV) and echo, lima, victor (ELV), which was acknowledged by the crew. At 08:06:10Z (20 minutes after take-off) while the aircraft was passing through 32 920ft, the Cabin Altitude Warning alert activated, and the crew declared a MAYDAY. The cabin altitude was at 10 000ft, climbing at approximately 700ft per minute. The crew commenced with a descent to 10 000ft at 63 nautical miles (nm) distance measuring equipment (DME) GRV very high frequency omnidirectional range (VOR beacon) at George Aerodrome. The area controller asked the crew if they would be returning to FACT or if they would be landing at George Aerodrome (FAGG). A short while later, the crew indicated that they would be diverting to FAGG.

1.1.5 The crew then initiated the memory items for an emergency descent as per the Quick Reference Handbook (QRH) procedures. Attempts to reduce the cabin rate were unsuccessful and an emergency descent was executed. During the initial stages of the descent, the thrust levers retarded to LOW IDLE (N1 decreased to approximately 30%, according to Quick Access Recorder [QAR] data) with an amber warning activation on the overhead panel (see Figure 1) for both engines. This was supported by an amber alert speed (SPD) activation on the electronic attitude director indicator (EADI) (see Figure 2). Engine thrust was increased to achieve flight idle. The cabin rate of descent started to reduce, and the crew decided not to deploy passengers oxygen masks.

Figure 1: LOW IDLE warning for both engines, located on the overhead panel.

(Aircraft in ground mode)

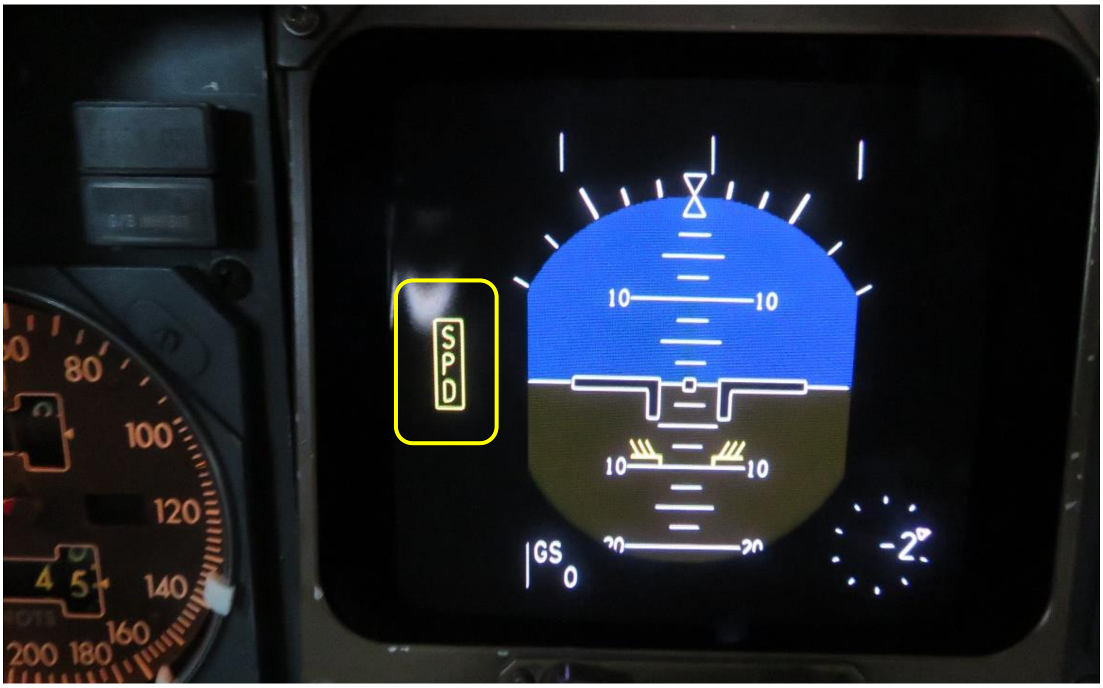


Figure 2: Amber SPD warning (in yellow window) displayed on the EADI (aircraft in ground mode).

1.1.6 At 08:16:08Z, the aircraft was handed over to George Approach on the VHF 128.20 Megahertz (MHz). The crew requested to make a descent to 8 000ft and to enter the right-side hold over GRV. There was no primary radar available at FAGG and the approach controller had to rely on SSR or visually identify the aircraft in the holding pattern as the transponder was inoperative. At the time, scattered clouds (3-4 octas) were overhead the aerodrome at 3 300ft, and the aircraft was not being interrogated by SSR. The flight was also conducted with the traffic collision avoidance system (TCAS) inoperative. The aircraft was briefly detected on SSR for the first time when it was in the right-side hold over GRV descending through 2 500ft on a left downwind for landing Runway 29 at FAGG.

1.1.7 The aerodrome rescue and firefighting (ARFF) personnel were alerted by air traffic control (ATC), whereafter they moved into position. The crew followed the instrument landing system (ILS) approach for Runway 29 and the aircraft touched down at 0840Z.

1.1.8 After landing, the SCCM informed the crew that one passenger required medical assistance, three passengers had nosebleed and five passengers indicated that they had severe ear pain.

1.1.9 It was noted by the cockpit crew after landing that the cabin pressure was very high. The outflow valve was in the 'close' or 'near close' position and it was slowly opened by the crew to release cabin pressure.

Figure 3: The visual indicators displaying the cabin altitude, the cabin pressure and the rate of cabin altitude change. (Source: B737.org.uk)

Figure 4: Google Earth overlay of the aircraft flight path (magenta line).

The 3D position data was taken from the quick access recorder (QAR).

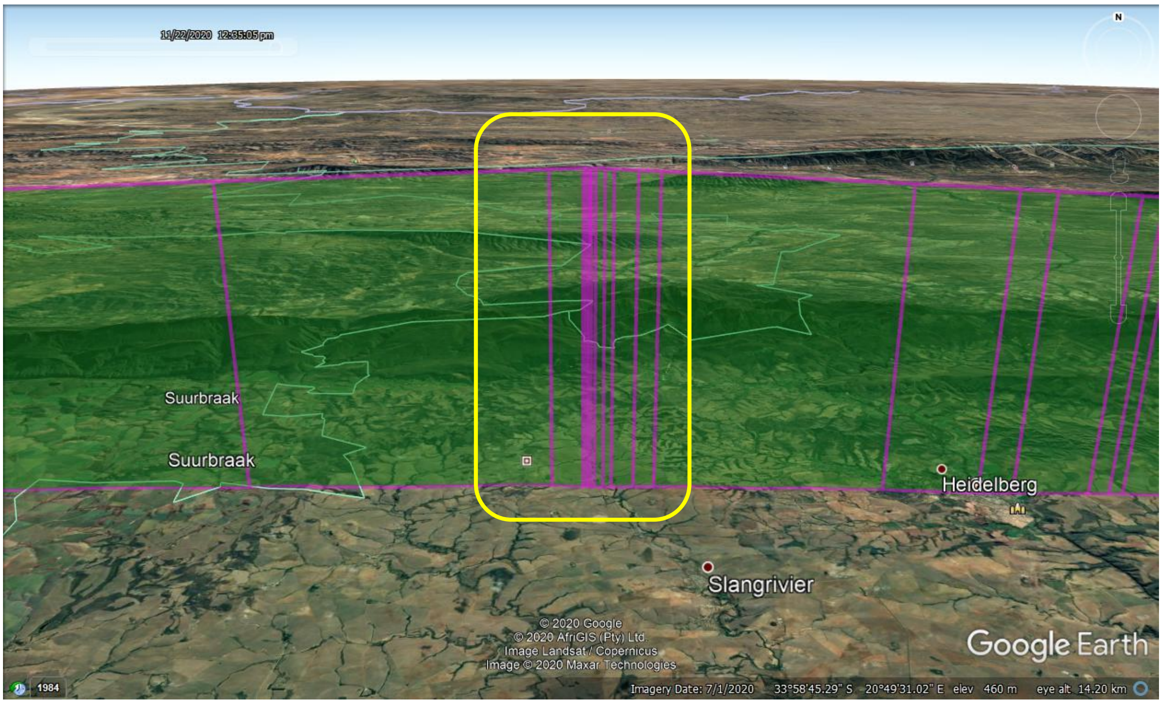


Figure 5: Google Earth overlay indicating events where the Cabin Altitude, as well as the engine low idle warning activated.

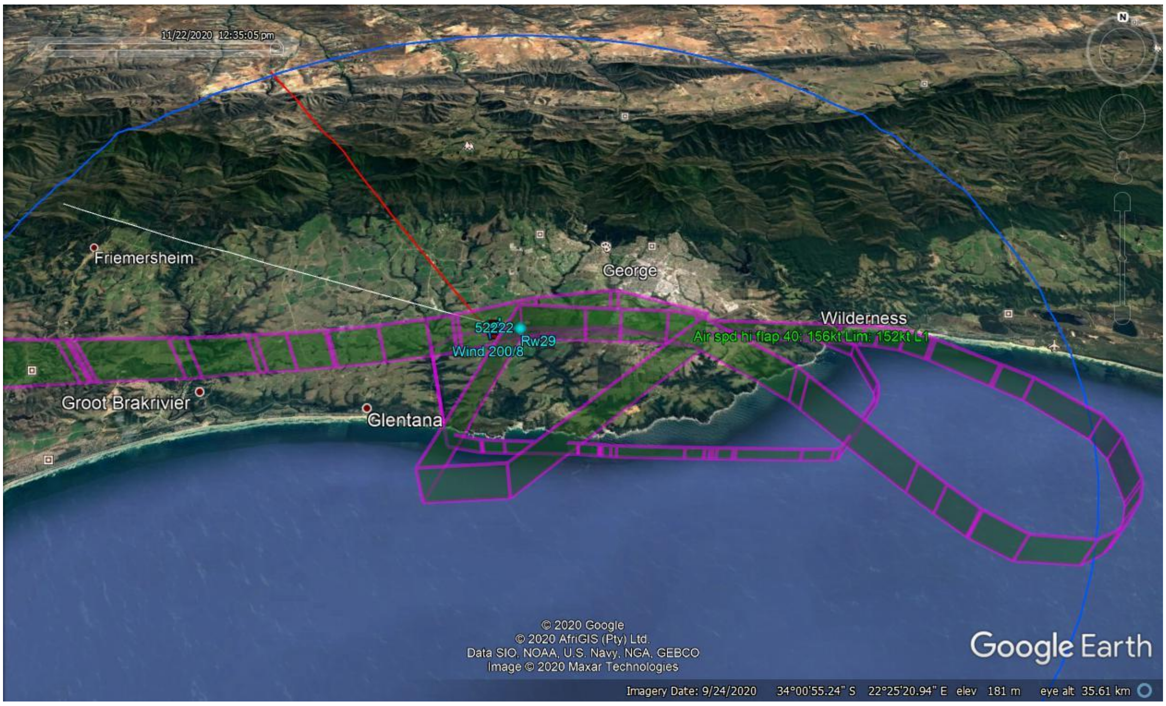


Figure 6: Google Earth overlay of the aircraft joining overhead FAGG (purple track) before landing.

1.2 Injuries to Persons

Injuries	Pilot	Crew	Pass.	Total On-Board	Other
Fatal	-	-	-	-	-
Serious	-	-	-	-	-
Minor	-	-	9	9	-
None	2	4	149	155	-
Total	**2**	**4**	**158**	**164**	**-**

Note: Other; means people on the ground.

1.2.1 After landing, one passenger required medical assistance, three passengers had nosebleed and five passengers indicated that they had severe ear pain.

1.3 Damage to Aircraft

1.3.1 There was no damage to the airframe of the aircraft. Damage was limited to the aircon bay compressor outlet duct with Part No. 65-51552-8 located on the left air-conditioning pack, and the aft cargo compartment door seal had to be replaced.

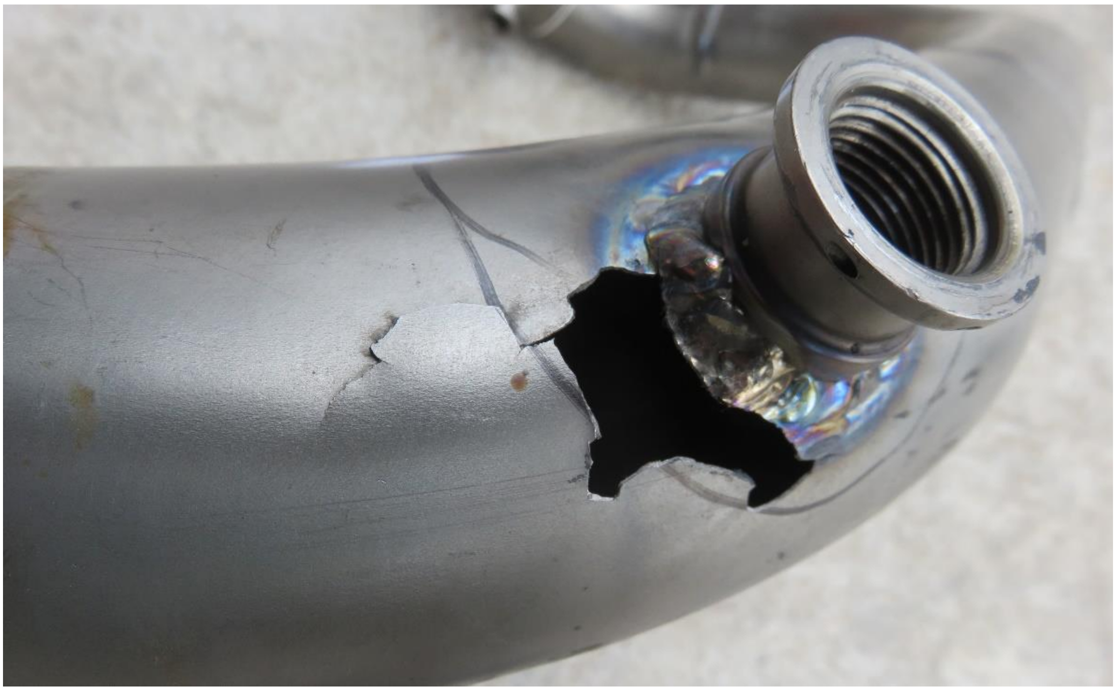


Figure 7: Damage to the aircon bay compressor outlet duct (left air-conditioning pack).

1.4 Other Damage

1.4.1 None.

1.5 Personnel Information

1.5.1 Pilot-in-command (PIC)

Nationality	South African	Gender	Male	Age	37
Licence Number	027 048 7242	Licence Type	Airline Transport Pilot Licence		
Licence Valid	Yes	Type Endorsed	Yes		
Ratings	Instrument, Flight Instructor Grade II				
Medical Expiry Date	31 January 2021				
Restrictions	None				
Previous Incidents	None				

Flying experience:

Total Hours	7 924.0
Total Past 90-Days	202.0
Total on Type Past 90-Days	194.0
Total on Type	3 383.0

1.5.2 First Officer (FO)

Nationality	South African	Gender	Male	Age	31
Licence Number	027 221 7977	Licence Type	Airline Transport Pilot Licence		
Licence Valid	Yes	Type Endorsed	Yes		
Ratings	Instrument, Flight Instructor Grade II				
Medical Expiry Date	31 January 2021				
Restrictions	Corrective lenses				
Previous Incidents	None				

Flying experience:

Total Hours	5 050.0
Total Past 90-Days	210.0
Total on Type Past 90-Days	210.0
Total on Type	2 000.0

1.6 Aircraft Information

1.6.1 The Boeing 737-400 is a short- to medium-range, narrow-body aircraft powered by two turbofan engines. It is a variant of the Boeing 737 family that has been in production since 1967. The normal crew is two pilots and four cabin crew. Depending on the cabin configuration, up to 188 passengers can be carried on-board.

Airframe:

Type	Boeing 737-4S3	
Serial Number	25116	
Manufacturer	Boeing Aircraft Company	
Year of Manufacture	1991	
Total Airframe Hours (at time of incident)	65 823.39	
Last Phase Inspection (hours & date)	65 664.47	27 October 2020
Hours Since Last Phase Inspection (C2)	158.92	
C of A (issue date)	4 April 2007	
C of A (expiry date)	30 April 2021	
C of R (Issue date) (Present owner)	3 November 2017	
Operating Category	Standard Transport (Aeroplane)	

Engine No. 1:

Type	CFM 56-3C-1
Serial Number	722436
Hours Since New	84 473.6
Cycles Since New	52 309

Engine No. 2:

Type	CFM 56-3C-1
Serial Number	723135
Hours Since New	82 960.6
Cycles Since New	61 873

1.7 Meteorological Information

1.7.1 At the time of the occurrence, visual meteorological conditions (VMC) at day time prevailed. The weather information (below) was obtained from the Meteorological Aerodrome Report (METAR) that was issued by the South African Weather Service (SAWS) for FAGG on 22 November 2020 at 0830Z.

FAGG 220830Z 21010KT 9999 SCT033 BKN046 19/14 Q1014=

Wind direction	210˚	Wind speed	10kts	Visibility	9999m
Temperature	19˚C	Cloud cover	3-4 octas	Cloud base	3 300ft
Dew point	14˚C	QNH	1014hPa		

1.8 Aids to Navigation

1.8.1 The aircraft was equipped with standard navigational equipment as approved by the Regulator (SACAA). There was no record indicating that the navigation system was unserviceable prior to or during the flight.

1.9 Communication

1.9.1 The aircraft was equipped with standard communication equipment as approved by the Regulator. There were no recorded defects prior to or during the serious incident.

1.9.2 The aircraft was in radio communication with the Cape Town tower on VHF 118.10MHz. Once the aircraft was airborne, it was handed over to area controller west (radar) on VHF 125.10MHz. The aircraft was not interrogated by SSR radar due to a transponder-related problem; the crew was advised accordingly, and the aircraft was tracked on primary surveillance radar. At 08:06:08Z, the crew advised that they have an Altitude Cabin Warning and requested to descent to FL100. This was followed by a MAYDAY broadcasted by the crew 25 seconds later.

1.9.3 At 08:16:08Z, the aircraft was handed over to the approach controller at FAGG on VHF 128.20MHz. At 08:37:50Z, the aircraft was again handed over to the George tower frequency on 118.90MHz.

1.10 Aerodrome Information

Aerodrome Location	George Aerodrome (FAGG)
Aerodrome Co-ordinates	34°00'24.13" South 022°22'27.41" East
Aerodrome Elevation	648 feet AMSL
Runway Designations	11/29
Runway Dimensions	2 000 m x 45 m
Runway Used	29
Runway Surface	Asphalt
Approach Facilities	DVOR/DME; ILS LOC; ILS GP CAT II; ILS/DME, Runway lights
Aerodrome Status	Licensed

The aerodrome chart is attached to this report as Appendix A.

1.11 Flight Recorders

1.11.1 The aircraft was equipped with a cockpit voice recorder (CVR). No information was obtained from the recorder as the unit was not quarantined by the operator prior to the ferry flight from FAGG to O.R. Tambo International Airport (FAOR) and, therefore, the data was overwritten.

1.11.2 The aircraft was equipped with a digital flight data recorder (DFDR). From the graph below, the yellow window indicates when the crew commenced with the descent (green line) after the Cabin Altitude Warning activated and both engines' N1 decayed to approximately 30% (grey line).

1.11.3 A quick-access recorder was also fitted which provided some data about the flight path.

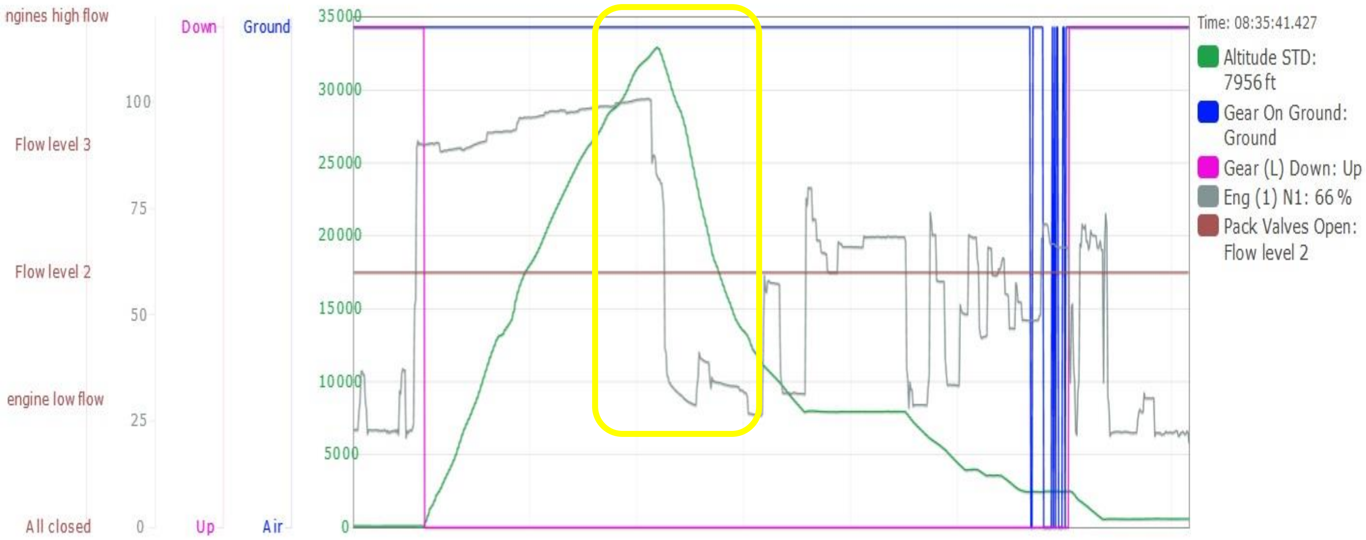


Figure 8: The graph of the serious incident flight with essential data captured. (Source: Safair)

1.12 Wreckage and Impact Information

1.12.1 The aircraft maintained flight and, following the Mayday call by the crew, they assessed the situation and informed the area controller that they will be diverting to FAGG.

1.13 Medical and Pathological Information

1.13.1 The pilot-in-command (PIC) had a valid Class 1 aviation medical certificate with an expiry date of 31 January 2021.

1.13.2 The first officer (FO) had a valid Class 1 aviation medical certificate with an expiry date of 31 January 2021.

1.14 Fire

1.14.1 There was no evidence of a pre- or post-impact fire.

1.15 Survival Aspects

1.15.1 The serious incident was considered survivable as no damage was caused to the cockpit or cabin structure of the aircraft. The cockpit crew had made the decision not to deploy the passengers oxygen masks. As per the QRH memory item procedure, the PIC and FO donned their oxygen masks.

1.16 Tests and Research

1.16.1 Metallurgical Examination

The Aircon Bay Pack/Machine Compressor Outlet Duct Assembly with Part No. 65-51552-8 that was installed on the left air-conditioning pack was found to have fractured in an area that was subjected to a welding repair previously (see Figure 6). The air duct was subjected to a metallurgical examination. An official report was obtained from the source, SGS MetLab:

"The aircraft was acquired from the previous owner in 2017 with 61 286 hours on the airframe. At the time of the incident, the total airframe hours were 65 823 hours (4 537 hours in service with the new owner). The AMO reported that no record of any previous repairs on the duct was provided upon ownership transfer on 3 November 2017 and the AMO did not perform any subsequent repairs on the component. It was reported that three inspections relevant to the failed component were conducted since acquisition – one pre-delivery and two subsequent inspections of which the last one was three months prior to the incident flight.

The limited design detail of the duct indicates that the nipple is attached to the primary duct by welding during manufacture. The primary duct is pre-shaped with a hole that have a protruding throat section of about 3mm above the tangent on the duct at the centre line of the threaded nipple to be attached. The welding is affected only on the external diameter and appears to be dressed as virtually no evidence of welding is visible on the unaffected nipple. It is significant to appreciate that no *welding is affected on the primary duct circumference as the welding is limited to the throat material. This means that the transition curve between nipple and duct consists of unwelded duct material formed in a curve. The original welding is thus affected on material above the stress concentration of the curved joint configuration between the nipple and the duct. This will have a significant positive impact on the fatigue life expectancy of the component.*

The following tests were performed on the sample:

(i) Visual inspection
(ii) Chemical analysis
(iii) Microstructure Evaluation
(iv) Scanning Electron Microscope (SEM) Evaluation

The duct was manufactured from thin-wall tubing. The nipple-to-duct joint contained a discoloured weldment around the circumference. The weld-cap (or bead crown) is very irregular with a qualified convex profile (see Figure 9).

Figure 9: Closer view of the discoloured welding around the circumference of the nipple.

The internal surface of the nipple-to-duct joint was not subjected to any welding but a flaky surface layer with various combinations of yellow, light and dark grey colouring was visible. The appearance and texture of the surface layer, especially the yellow areas were consistent with a solidified glassy substance comparable with non-metallic compounds that had been exposed to significant heat (see Figure 10). The presence of a circumferential crack of which the position correlates with the external toe crack was confirmed. Part of the crack is open and had propagated *through the material thickness (see Figure 10). The presence of another two cracks underneath the weld material and NOT related to the external toe cracks was also confirmed (see Figure 10). The location of these two cracks was in the middle of the external weld. Evidence of melting at one of the cracks and the presence of porosity inside the cracks are indicative that the welding was affected on top of the two cracks. The orientation and location of the cracks are significant with respect to the duct geometry. The cracks are on opposite sides of the nipple circumference on the transition curve between the nipple and duct and the cracks are almost parallel to the longitudinal axis of the duct – considering that the duct is curved at this location.*

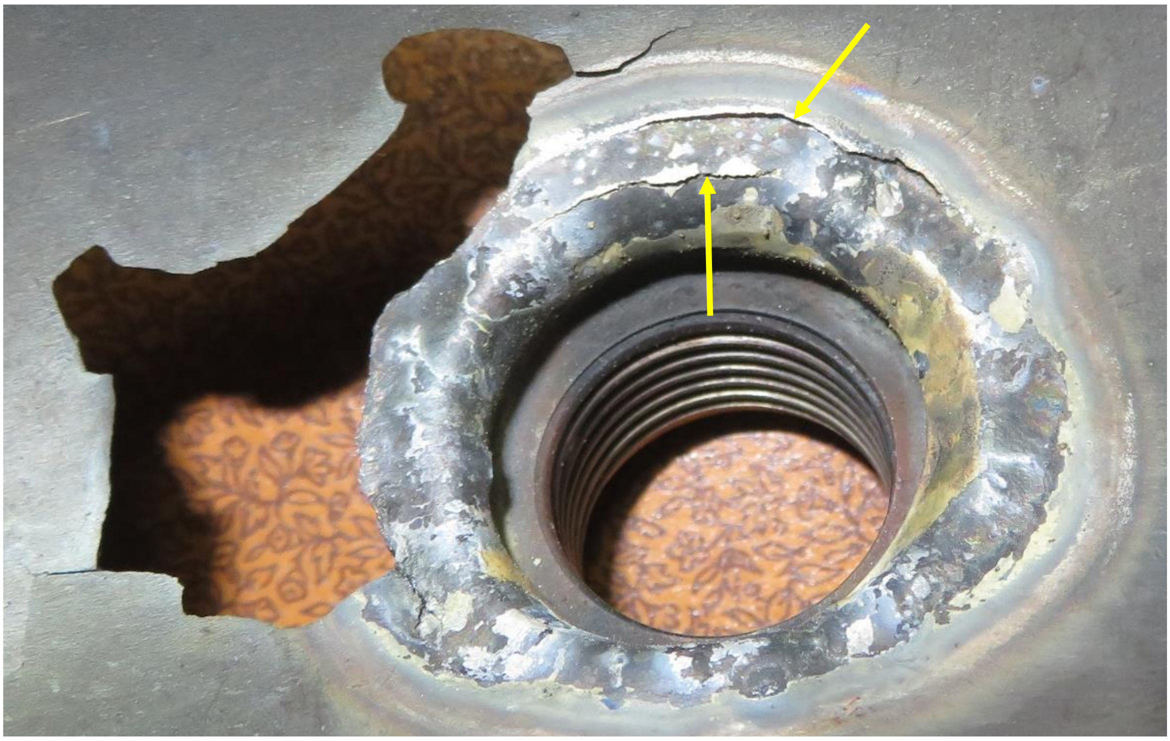


Figure 10: Closer view of the inside of the duct showing the multi-coloured flaky surface layer on the duct surface below the external weld. Note the open and through thickness crack associated with the toe of the weld as indicated by the top arrow. In addition, one of the original cracks that was weld-repaired is indicated by the bottom arrow. The second crack on the opposite side of the throat is not visible due to the angle of the image.

1. The weld discolouration due to in-adequate shield-gas protection as well as very irregular weld cap profile was confirmed (see Figure 11).
2. The detail of the external toe crack was confirmed (see Figure 12).
3. There are three distinct types of internal cracks at the nipple throat and adjacent duct material. The first type is the network of secondary cracks in the duct material that contributed to the rapture of the duct material. The second type is the crack associated with the stress concentration caused by the toe of the weld to the duct material and that had propagated through the thickness of the duct material. The

third type is the original crack that was the reason for the weld repair on the external surface (see Figure 12).

4. The internal toe crack showed evidence of a brittle nature with extensive branching and parallel micro-cracks (see Figures 11 & 12).

5. The presence of macro-porosity due to burn-through on the duct material combined with surface contamination of the internal surface and incorrect gas shielding of the internal volume of the duct was observed. This type of porosity is a common problem with the welding of titanium and usually associated with hydrogen contamination.

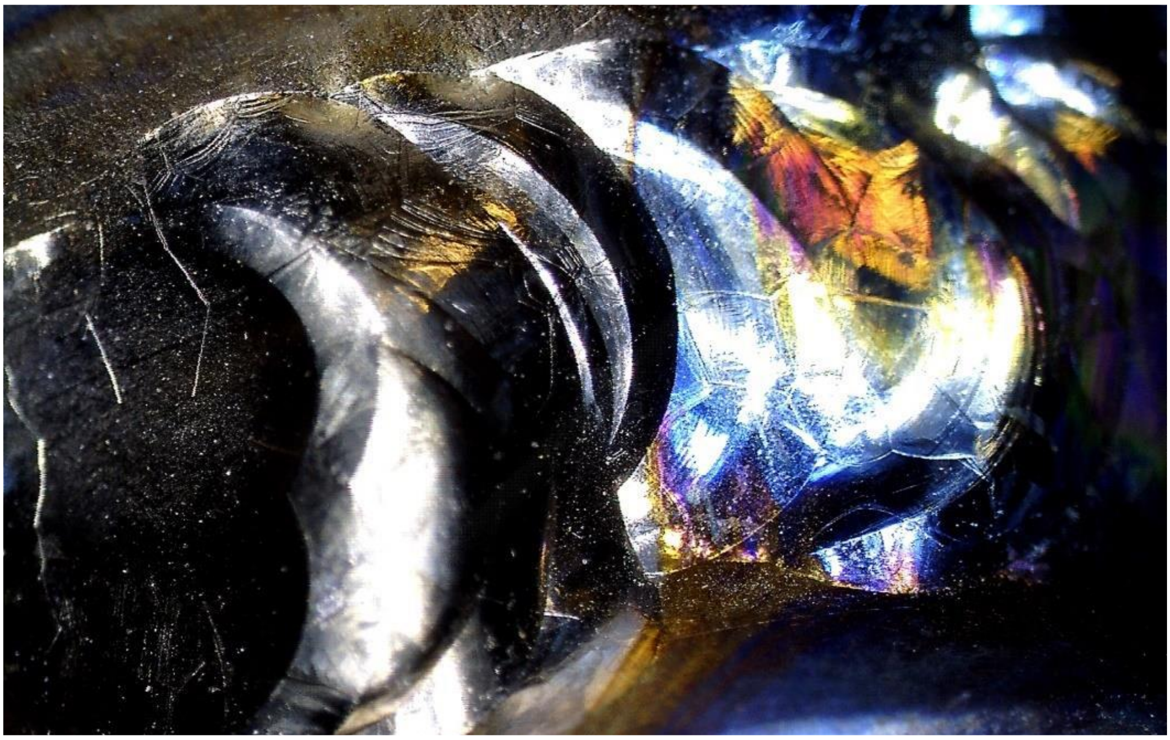


Figure 11: Magnified view of the weld surface showing the discolouration due to in-adequate shield-gas protection as well as a very irregular weld cap profile.

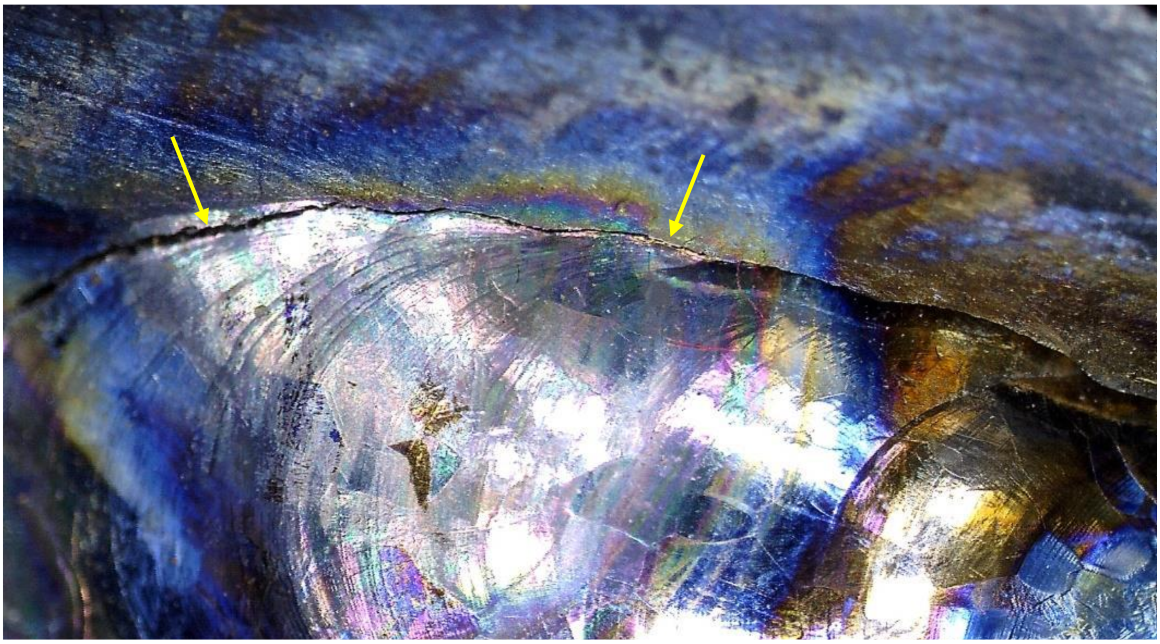


Figure 12: Magnified view of the toe area of the weld showing the toe crack following the weld profile. Note the extensive discolouration that extends well onto the duct material.

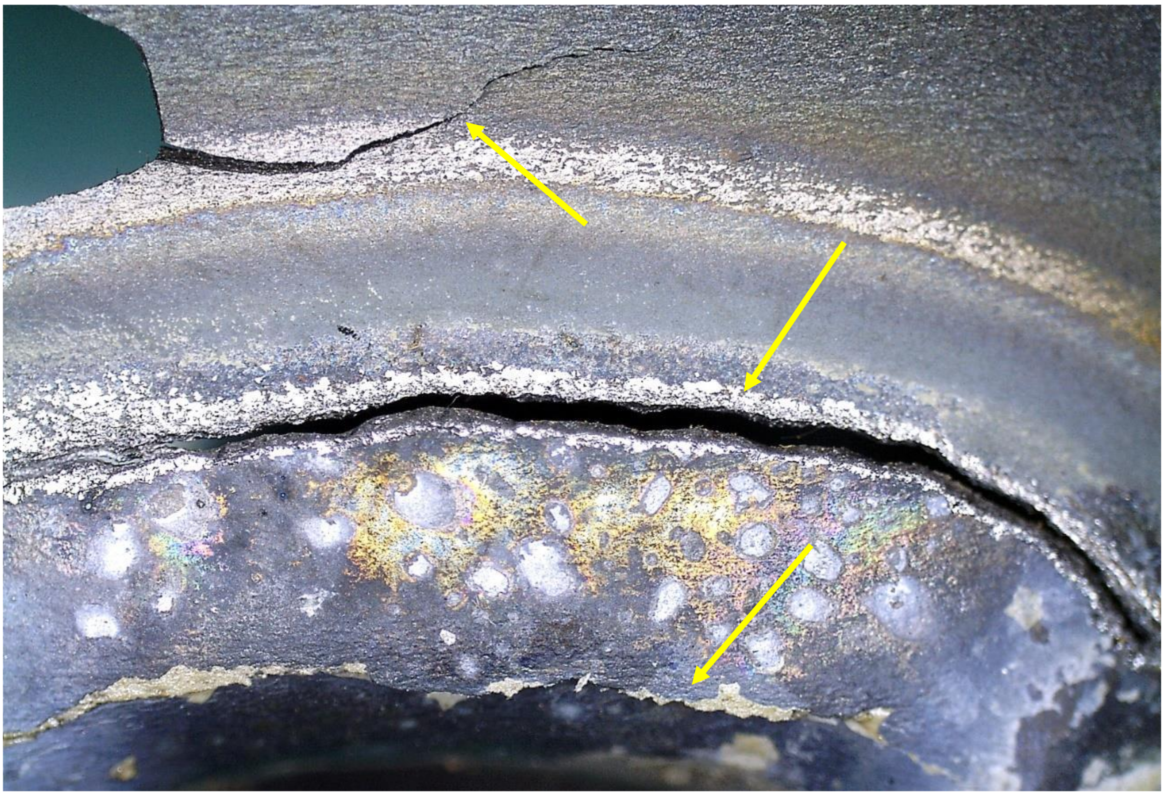


Figure 13: General magnified view of the three variations of cracks that were observed on the inside of the nipple. At top is a secondary crack that formed part of the rupture of the duct material and the association with the edge of the HAZ is quite obvious. The crack in the middle is directly related to the toe of the weld on the outside of the duct. The crack at the bottom is one of the original cracks that was the reason for the external weld repair.

Conclusion

(i) *Although extensive background information, maintenance and design details were provided, the actual weld repair information of the failed duct was not available.*

(ii) *The chemical analysis indicate that the material conforms to; Titanium Grade 2 or commercially pure titanium.*

(iii) *The visual examination confirmed the rapture of the duct, the character of the weld repair and the presence of various cracks, even the original cracks that were the subject of the weld repair.*

(iv) *Significant evidence of weld contamination due to incorrect shield gas application was visually confirmed. Reference is made to the quoted maintenance instructions from the manufacturer maintenance manual that explicitly require contamination-free welding on titanium on several occasions.*

(v) *The presence of classic weld-related cracking was confirmed.*

(vi) *The microstructural analysis of the samples confirmed the characteristics of titanium microstructures that prevail due to various thermo-mechanical treatments as well as the welding repair.*

(vii) *The occurrence of significant oxygen ingress into the titanium material due to incorrect weld procedures that allowed the development of unfavourable microstructures such as coarse oxygen-rich alpha-case structures as well as a thick brittle titanium oxide surface layer was confirmed.*

(viii) *SEM evaluation of the fracture surfaces of the duct material adjacent to the weld confirmed the brittle nature of the fracture mechanism. The nature of the surface layer on the inside of the nipple below the external weld was qualified as a very thick titanium oxide layer.*

(ix) ***The cause of the failure of the ducting was due to an incorrect welding procedure, resulting in material embrittlement as the result of oxygen***

contamination. The mechanism of failure was initial brittle fracture that continued with a fatigue mechanism.

1.17 Organisational and Management Information

1.17.1 This was a commercial flight conducted under the provisions of Part 121 of the Civil Aviation Regulations (CAR) 2011 as amended.

1.17.2 The operator was issued a Class 1 Air Service Licence on 26 March 2014 by the Department of Transport. The licence authorised the carrier to operate under categories: Type S1 – *transport of passengers between two or more specified points*, and Type S2 – *transport of cargo or mail between two or more specified points*. The aircraft utilised under this operation should meet category A1 provisions – *any aircraft, excluding a helicopter, with a maximum certificated mass exceeding 20 000 kilograms.*

1.17.3 The operator was in possession of a valid air operating certificate (AOC), which was issued on 28 April 2020 by the SACAA with an expiry date of 30 April 2021. The aircraft was duly authorised to operate under the AOC.

1.17.4 The aircraft maintenance organisation (AMO) that carried out the last maintenance inspection on this aircraft prior to the serious incident flight was in possession of a valid AMO-approval certificate.

1.18 Additional Information

1.18.1 Boeing 737 Air Conditioning & Pressurisation System
Source: www.studylib.net/doc/8362170/boeing-737-systems-review-air-conditioning, Copyright of the content: www.Smartcockpit.com

General

Conditioned air comes from either the aircraft air-conditioning system or a preconditioned ground source. (Engines, Auxiliary Power Unit (APU) or a ground cart)

Air from the preconditioned ground source enters the air-conditioning system through the mix manifold. The air-conditioning system provides temperature-controlled air by processing bleed air from the engines, APU or a pneumatic ground source through two air-conditioning packs.

Conditioned air from the left pack flows directly to the cockpit. Excess air from the left pack, air from the right pack and air from the recirculation system is mixed in the mix manifold. The mixed air is then distributed to the passenger cabin.

Recirculation Fan(s) control the recirculation system which maintains proper ventilation while economising the use of bleed air. It collects air from the aircraft cabin, filters it and returns it to the mix manifold to be mixed with fresh conditioned air supplied by the packs.

737-400/-800/-900

Pack temperature control is balanced. The outlet temperature of both packs is normally controlled at the same temperature by two electronic controllers.

The pack outlet temperature is determined by the zone that requires the most cooling (Control Cabin, Forward Cabin or Aft Cabin).

A three - zone trim air system provides individual zone temperature control by adding high temperature air from the pneumatic system to those zones that have a higher temperature demand than the pack outlet temperature. Any trim air failure will cause the packs to revert to independent operation.

Only in case of failure of the trim air system, pack temperature control will become unbalanced.

Main Components & Subsystems Bleed Air Supply

The pack valves control the flow of bleed air from the aircraft pneumatic system to the air-conditioning packs. A single pack is capable of maintaining pressurisation and acceptable temperature throughout the aircraft.

Two pack operation from a single engine bleed air source is not recommended due to excessive bleed requirements.

Pack and Zone Temperature Control 737-400/-800/-900

There are three zones: control cabin (cockpit), forward cabin and aft cabin.

Desired zone temperature is set by adjusting the individual Temperature Selectors.

The packs produce an air temperature, which will satisfy the zone which requires the most cooling.

Zone temperature is controlled by adding the proper amount of trim air to the air leaving the mix manifold through the zone supply ducts.

The quantity of trim air is regulated by individual trim air modulating valves.
If air in a zone supply duct overheats, the associated amber ZONE TEMP light illuminates, and the associated trim air modulating valve closes. The trim air modulating valve may be reopened after the duct has cooled by pushing the TRIP RESET Switch.

Electronic Controllers

Control is performed by two electronic controllers, the left and right electronic controller which have the following functions:

Left controller	*Right controller*
AFT CABIN zone	*FWD CABIN zone*
back up control of CTL CABIN zone	*primary control of CTL CABIN zone*
LH pack temp control valve	*RH pack temp control valve*
RH pack standby temp control valve	*LH pack standby temp control valve*
LH ram-air door	*RH ram-air door*

Pressurisation

The aircraft is pressurised by bleed air supplied to and distributed by the air-conditioning system. Pressurisation and ventilation are controlled by varying the opening of outflow valves. A proportional relationship is maintained between ambient and cabin pressure in climb or descent, and a maximum differential is normally maintained in cruise.

Cabin pressurisation is controlled by regulating the discharge of conditioned air through the outflow valves.

Pressurisation control is provided by the Electronic Cabin Pressure Controller, which controls the main outflow valve. The main outflow valve controls the air flow out of the airplane fuselage & it is actuated:

- *737 - 300/400: by an AC or a DC motor*

Pressurisation Control 737-300/-400/-500

Pressurisation control is provided automatically by a single pressurisation controller. The pressurisation system controls cabin altitude in anyone of four modes:

AUTO - Automatic; the normal mode of operation. Uses an Alternate Current (AC) motor.
STBY - Semi-automatic; a standby system in the event of AUTO failure. Uses a Direct Current (DC) motor.
MAN AC - Manual control of the system using AC motor.
MAN DC - Manual control of the system using DC motor.

In the automatic mode of operation, aircraft altitude is sensed directly from the static ports. In the standby mode, aircraft altitude is sensed electrically from the Air Data Computer (ADC). Barometric corrections to these pressures come from the Captain's altimeter in AUTO and the First Officer's altimeter in STBY. The controller receives additional information from the air/ground safety sensor and cabin pressure altitude sense port.

The main outflow valve can be actuated by either an AC or a DC motor. The AC motor is used during AUTO and MAN AC operation. The DC motor is used during STANDBY and MAN DC operation. The forward outflow valve closes automatically to assist in maintaining cabin pressure when the main outflow valve is almost closed or when the recirculation fan is operating.
On 737-400 aircraft, the system considers the operation of the right recirculation fan.

Pressurisation Outflow

737-300/-400/-500

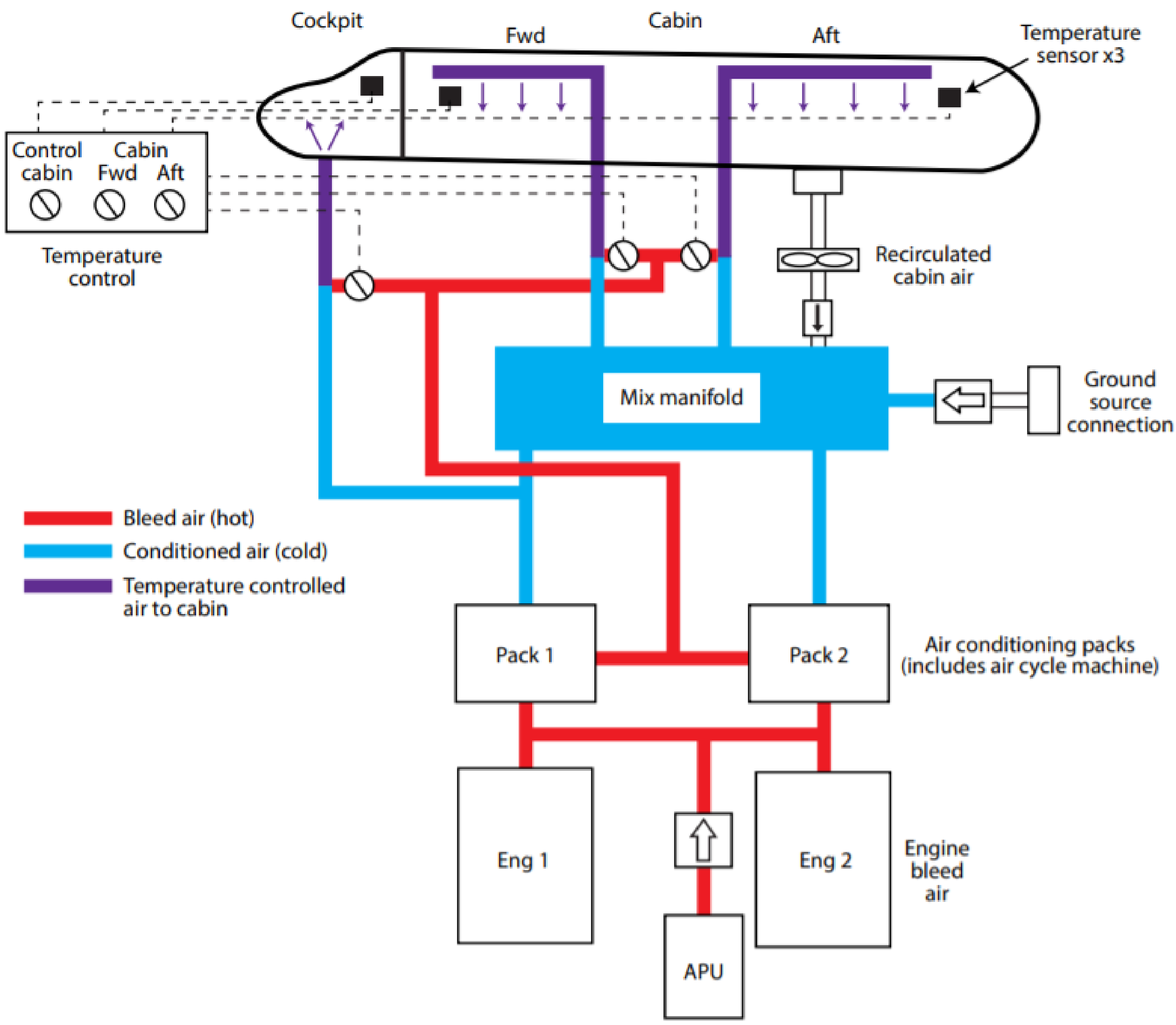
Cabin air outflow is controlled by the main outflow valve, the forward outflow valve, and the flow control valve. During pressurised flight, the flow control valve is closed, and the majority of the overboard exhaust is through the main outflow valve. Passenger cabin air is drawn through foot level grills, down around the aft cargo compartment, where it is heating, and is discharged overboard through the main outflow valve. A small amount is also exhausted through the toilet and galley vents, miscellaneous fixed vents, and by seal leakage.

The flow control valve opens to exhaust the cooling air from the E & E compartment overboard during ground operation, unpressurised flight, and pressurised flight below a cabin differential pressure of approximately 1.0 psi.

When the flow control valve closes, air is directed around the forward cargo compartment liner for inflight heating.

The forward outflow valve is the overboard discharge exit for air circulated around the forward cargo compartment (located approximately under first cabin window on left side of the aircraft). The valve is closed whenever the recirculation fan is operating. You can "refresh" the aircraft (for example with Full PAX load) by placing R pack to HI (RECIRC fan is then turned OFF & the forward outflow valve is opened adding more fresh air...)

On 737-400 aircraft, the valve is closed whenever the right recirculation fan is operating.



Simplified Schematic of the Air Conditioning System.

1.18.2 Post-incident Inspection/Testing

The investigator inspected the aircraft on 2 December 2020 once it was back at the maintenance base at FAOR. All four cabin doors were inspected, and no anomalies were found with the locking mechanisms, nor the door seals (see Figures 14 and 15). According to the AMO, the two front doors, 1L and 1R, were adjusted as per the aircraft maintenance manual (AMM) requirements after the serious incident to ensure the doors close and seal properly. When the aircraft was pressurised on the ground, it was found that air was leaking from the L2 door. Remedial action was taken and the defect has been rectified.

Figure 14: Door 1R in the open position, with no damage visible on the 'grey' door seal.

Figure 15: The right aft door (2R) in closed position.

1.18.3 The Air/Ground Sensor

Further inspections were carried out in accordance with the manufacturer's Fault Isolation Manual (FIM). The Air/Ground proximity sensor located in the right main landing gear wheel well was found to be defective and was replaced. The aircraft was then jacked up and several retractions were performed to confirm correct operation of the switches. A post-maintenance acceptance (confidence) flight was performed, and all operations were found to be normal. No adjustments were made to the Teleflex cable on the right main gear. This sensor was found to have caused numerous warnings the crew encountered in the cockpit during the flight. Attached to this report as Appendix B is a list of the Air/Ground Logic System Table.

The Air/Ground squat switch is only fitted to the right main gear and consists of a Teleflex cable, which will compress or extend as the weight of the aircraft comes on or off the right main gear. This Teleflex cable is connected to the Air/Ground sensor, which activates the switch by sensing if the aircraft is in air or ground mode.

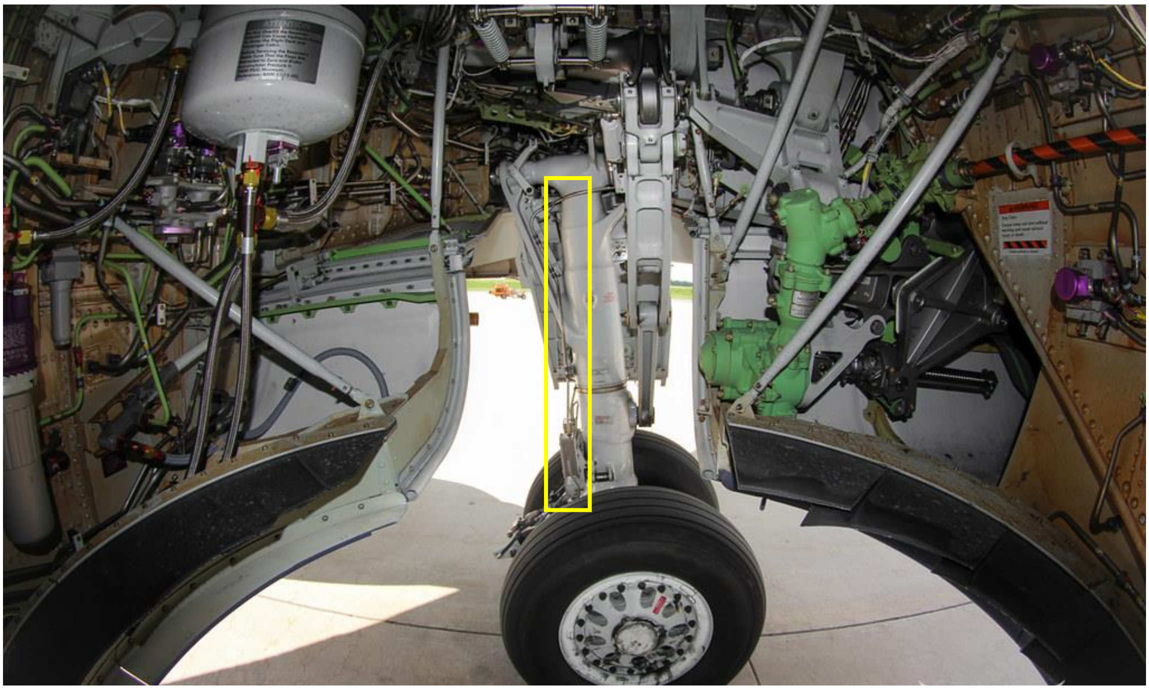


Figure 16: The photograph was taken from within the right main gear wheel well.

Air/Ground system in-flight and ground operation of various airplane systems are controlled by the air/ground system. The system receives air/ground logic signals from these sensors. These signals are used to configure the airplane systems to the appropriate air or ground status. The air/ground system supplies air/ground discrete signals to many aircraft systems. The proximity switch electronics unit (PSEU) is a component of the air/ground system. Many aircraft systems send signals to the PSEU through position sensors and switches. The PSEU also controls the air/ground relays.

The PSEU monitors the following systems: • take-off configuration warnings • landing configurations warnings • landing gear • air/ground sensing. The PSEU, its sensors and its input signals are monitored for internal faults. When designated faults are detected, a PSEU light on the aft overhead panel illuminates, and the OVERHEAD system annunciator light and MASTER CAUTION lights illuminate. The PSEU light, OVERHEAD system annunciator and Master Caution illuminate automatically for simple faults, but only after a landing. The PSEU light extinguishes when a parking brake is set or when both engines are turned off. The PSEU light is inhibited: in-flight when the thrust levers are advanced toward take-off power for 30 seconds after landing. In some aircraft, the PSEU light may illuminate during recall. In this case, with a simple fault, resetting the MASTER CAUTION system extinguishes the PSEU light.

Figure 17: Right main gear (view from the front) with the Teleflex cable visible in the yellow window.

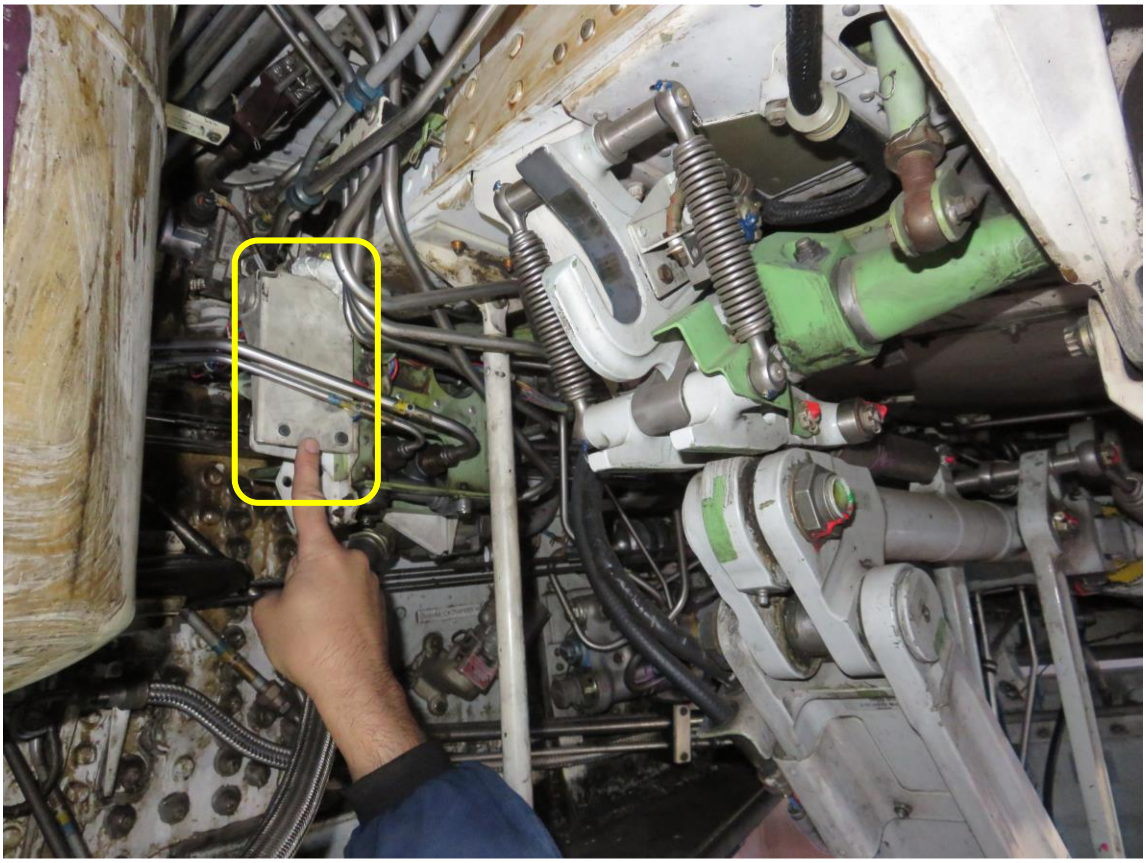


Figure 18: The Air/Ground proximity sensor is pointed out in the right main wheel well.

1.18.4 Pressurisation Outflow, Boeing 737-300/-400/-500

Cabin air outflow is controlled by the main outflow valve, the forward outflow valve and the flow control valve. During pressurised flight, the flow control valve is closed, and the majority of the overboard exhaust is through the main outflow valve. Passenger cabin air is drawn through foot level grills, down around the aft cargo compartment, where it provides heating, and is discharged overboard through the main outflow valve. A small amount is also exhausted through the toilet and galley vents, miscellaneous fixed vents and by seal leakage.

The flow control valve opens to exhaust the cooling air from the electronic equipment compartment overboard during ground operation, unpressurised flight and pressurised flight below a cabin differential pressure of approximately 1.0 psi.

When the flow control valve closes, air is directed around the forward cargo compartment liner for in-flight heating.

The forward outflow valve is the overboard discharge exit for air circulated around the forward cargo compartment (located approximately under first cabin window on left-side of the aircraft). The valve is closed whenever the recirculation fan is operating. The cockpit crew can "refresh" the aircraft (for example with full passenger load) by placing the right pack to HI (Recirculation fan is then turned OFF & the forward outflow valve is opened adding more fresh air). On the 737-400 aircraft, the valve is closed whenever the right recirculation fan is operating.

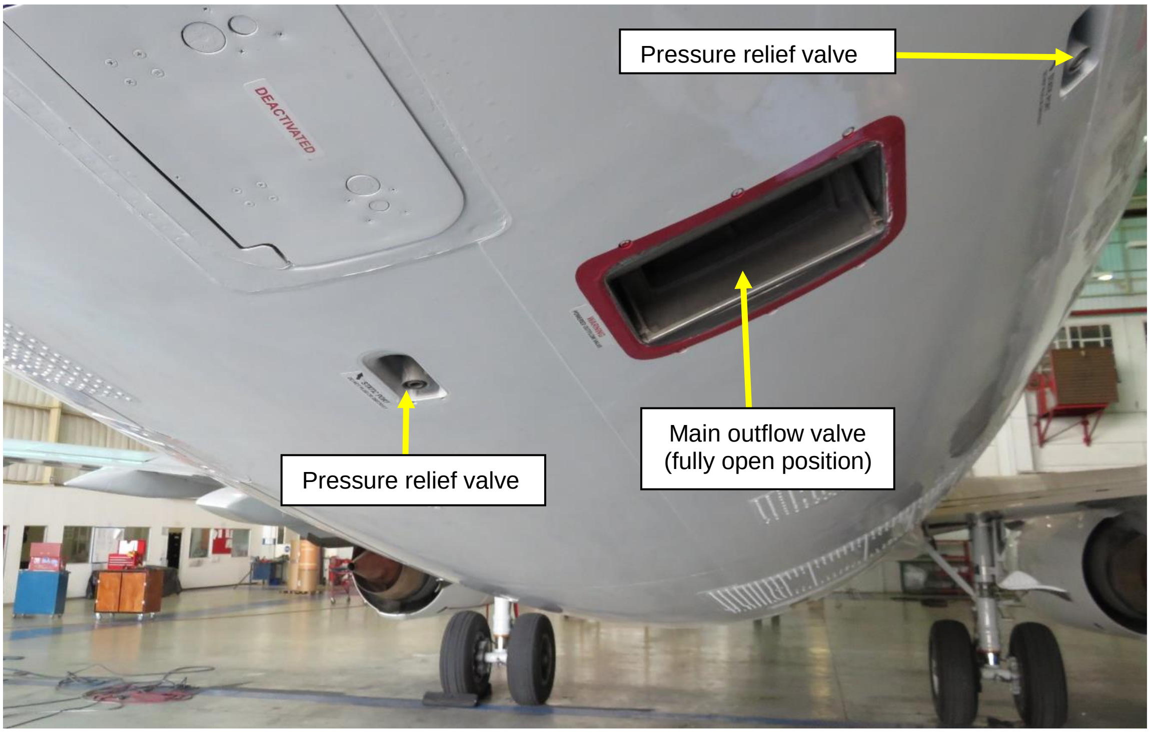


Figure 19: Main outflow valve and two pressure relief valves. (Not the incident aircraft)

1.18.5 Pressurisation Fault Finding

A bleed down check was performed on the aircraft and it was found that most of the bilge drains were not closing at 2.5 pounds per square inch (psi), which were subsequently replaced. *“A "bilge" valve, adapted to be mounted on the lowermost wall of an aircraft fuselage, is disclosed in which the valve has a normally open condition to drain accumulated condensate through a registering opening in the fuselage wall when the interior cabin is depressurised, and assumes a closed condition in response to a differentially higher cabin pressure relative to outside air pressure to seal off the interior of the fuselage.”*
Source: https://patents.google.com/patent/US4463774A/en

Figure 20: The bilge valves mounted at various places on the lower fuselage.

It was also found that the compressor outlet duct assembly with Part No. 65-51552-8 on the left air-conditioning pack had ruptured in the area where a repair was made previously. The compressor outlet duct was replaced, and the left air-conditioning pack efficiency improved radically. The aft cargo door seal was found to be worn out on the left aft lower corner; this seal was replaced.

1.18.6 Emergency Procedure for Cabin Altitude Warning / Rapid Depressurisation

Source: Boeing 737, Quick Reference Handbook (QRH)

The crew followed this QRH procedure in-flight as contained on pages 2.1 to 2.3.

CABIN ALTITUDE WARNING or Rapid Depressurization

CABIN ALTITUDE (As installed)

Condition: One or more of these occur:
- A cabin altitude exceedance
- In flight, the intermittent cabin altitude/configuration warning horn sounds or the CABIN ALTITUDE light (as installed) illuminates.

1 Don oxygen masks and set regulators to 100%.

2 Establish crew communications.

3 Pressurization mode selector . . . . MAN AC

4 Outflow VALVE switch . . . . Hold in CLOSE until the outflow VALVE indication shows fully closed

5 **If** cabin altitude is **uncontrollable**:

Passenger signs . . . . ON

PASS OXYGEN switch . . . . ON

►►Go to the Emergency Descent checklist on page 0.1

■ ■ ■ ■

▼ Continued on next page ▼

▼CABIN ALTITUDE WARNING or Rapid Depressurization continued▼

6 **If** cabin altitude is **controllable**:

Continue manual operation to maintain correct cabin altitude.

When the cabin altitude is at or below 10,000 feet:

Oxygen masks may be removed.

7 **Checklist Complete Except Deferred Items**

Deferred Items

Note: Use momentary actuation of the outflow valve switch to avoid large and rapid pressurization changes.

Descent Checklist

Pressurization . . . . **Move outflow VALVE switch to OPEN or CLOSE as needed to control cabin altitude and rate**

Recall . . . . Checked

Autobrake . . . . ___

Landing data . . . . VREF ___, Minimums ___

Approach briefing . . . . Completed

Approach Checklist

Altimeters . . . . ___

▼ Continued on next page ▼

▼CABIN ALTITUDE WARNING or Rapid Depressurization continued▼

At Pattern Altitude

Outflow VALVE switch . . . . Move to OPEN until the outflow VALVE indication shows fully open to depressurize the airplane

Landing Checklist

ENGINE START switches . . . . CONT

Speedbrake . . . . ARMED

Landing gear . . . . Down

Flaps . . . . ___, Green light

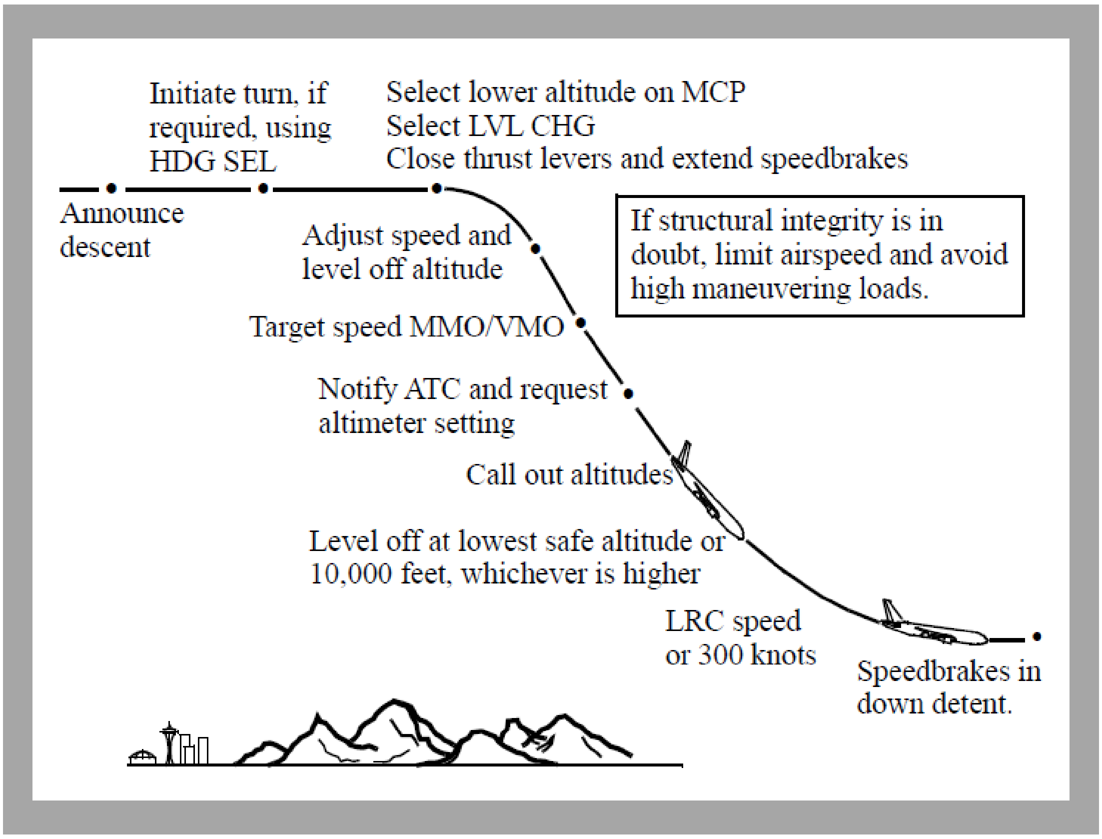
■ ■ ■ ■

1.18.7 Rapid Descent

Source: Boeing 737 Flight Crew Training Manual, Pg. 273 and 274

This section addresses basic techniques and procedures for a rapid descent. Some routes over mountainous terrain require careful operator planning to include carrying additional oxygen, special procedures, higher initial level off altitudes, and emergency routes in the event a depressurisation is experienced. These requirements are normally addressed in an approved company route manual or other documents that addresses route specific depressurisation procedures. This manoeuvre is designed to bring the airplane down smoothly to a safe altitude, in the minimum time, with the least possible passenger discomfort.

Note: *Use of the autopilot is recommended.*



If the descent is performed because of a rapid loss of cabin pressure, crewmembers should place oxygen masks on and establish communication at the first indication of a loss of cabin pressurisation. Verify cabin pressure is uncontrollable, and if so, begin descent. If structural damage exists or is suspected, limit airspeed to current speed or less. Avoid high manoeuvring loads.

Perform the manoeuvre deliberately and methodically. Do not be distracted from flying the airplane. If icing conditions are entered, use anti-ice and thrust as required.

Note: *Rapid descents are normally made with the landing gear up.*

The PM checks the lowest safe altitude, notifies ATC, and obtains an altimeter setting (QNH). Both pilots should verify that all memory items have been accomplished and call out any items not completed. The PM calls out 2 000 feet and 1 000 feet above the level off altitude.

Level off at the lowest safe altitude or 10 000 feet, whichever is higher. Lowest safe altitude is the Minimum Enroute Altitude (MEA), Minimum Off Route Altitude (MORA), or any other altitude based on terrain clearance, navigation aid reception, or other appropriate criteria.

1.19 Useful or Effective Investigation Techniques

1.19.1 No new methods were used.

2. ANALYSIS

2.1 General

From the available evidence, the following analysis was made with respect to this serious incident. This shall not be read as apportioning blame or liability to any particular organisation or individual.

2.2 Analysis

2.2.1 Crew

The crew was confronted with some ‘non-normal’ situations as they became aware of multiple alerts. It is possible that a single malfunction could result in multiple flight deck indications. Once the cabin altitude warning activated, the crew dealt with the emergency checklist and initiated an emergency descent as required to FL100. They also made the decision to divert to their nearest suitable aerodrome, which was FAGG, at which a safe landing was executed.

The injuries/medical treatment the passengers received after the occurrence are viewed as minor. The AIID classified the occurrence as a serious incident and conducted an investigation due to the rapid decompression in conjunction with the necessity to use oxygen masks by the crew.

According to the QAR data, the aircraft had nearly levelled off at its cruising altitude when the descent was initiated, and the crew stopped the descent in FL100. The aircraft was landed without further problems.

2.2.2 The Aircraft

What is concluded from an aircraft structure and aircraft systems is that the cabin altitude warning was triggered by multiple system failures and air leaking from the structure. In the summary below, the specific matters and how they were rectified after the aircraft was positioned from FAGG to its maintenance base at FAOR are highlighted:

1. A problem was encountered prior to departure where the two right doors 1R and 2R proved difficult to close; the assistance of a technician was required to close the doors. After several attempts, it was later confirmed that the doors 'looked closed' from the outside. According to the PIC, when he conducted a walk-around of the aircraft after landing at FAGG, he noted that the doors 1R and 2R were skew in their frames, with gaps at the top. With the doors not being in the correctly closed position, cabin air leaked from these door seals during flight, contributing to the cabin rate of climb rate of 600 to 700 ft/min.

   These doors were adjusted as per the aircraft maintenance manual (AMM) requirements.

2. After take-off the cockpit crew observed several redundancies:

   (i) No transponder, the unit remained in ground mode. It initially could not be determined if this was an aircraft problem or an SSR interrogation system error. It was later determined that this was indeed an aircraft system related occurrence.

   (ii) No N1 (low pressure rotor speed) engine indication.

   (iii) No LNAV or VNAV.

   (iv) The flight management computer (FMC) lost position but came back on later with no LNAV.

   (v) The auto throttle thrust stayed in the take-off configuration, and the crew disconnected auto throttle manually and continued with the flight with auto throttle disabled. It was determined that if the air/ground sensing system fails to "ground" mode the auto throttle cannot transition to the Throttle Arm position and it was, therefore, not possible to be armed.

   (vi) When the crew retarded the thrust levers as they commenced with the emergency descent, the LOW IDLE amber warning light along with the MASTER CAUTION ENG indication activated, which alerted the crew (see Figure 1) that the engines will be entering the sub-idle range which is associated with an N1 rpm of 32% or less when in-flight. A low idle condition is brought about by the system sensing that flight idle is not achieved and the system is still in ground idle, which is several % N1 lower than flight idle. The crew followed the correct procedure by disconnecting auto throttle and advancing the thrust levers until the light went out. The reason behind the LOW IDLE light is that there was a series of flame outs on these CFM56-3 engines earlier on in their service life, for which an Airworthiness Directive (AD) was issued.

In consultation with the aircraft manufacturer fault isolation maintenance procedure, it was determined that these multiple cockpit indications were as a result of a defective Air/Ground proximity switch, which was located in the right main wheel well. The proximity switch was replaced, and the problem did not present itself again during the confidence/post-maintenance acceptance flight.

3. Aircon Bay Pack Compressor Outlet Duct Fracture

The left Aircon Bay Pack/Machine Compressor Outlet Duct Assembly with Part No. 65-51552-8 was found to have ruptured in the same area where it was previously repaired. This component was removed and was metallurgically examined. *The cause of the failure of the ducting was due to an incorrect welding procedure, resulting in material embrittlement as the result of oxygen contamination. The mechanism of failure was initial brittle fracture that continued with a fatigue mechanism.*

It could not be determined when this outlet duct had fractured; however, the aircraft had no previous defects that could have been associated with such a failure and it could, therefore, not be ruled out to have occurred during this flight. The left and right packs are completely independent of each other and normally operate in parallel. The cockpit requires only a fraction of the air supply provided by the left pack, with the majority of the left pack supply being routed to the mix manifold. The output of the two packs is combined in the mix manifold. According to technical information, the cabin altitude can be maintained with only one pack operating; this was, however, not the case in this serious incident. The investigator noted that the cockpit crew fitted their oxygen masks, which was most probably related to the reduced air supply from the left pack following the failure of this outlet duct. The subsequent replacement of this component improved the efficiency of the left air-conditioning pack considerably as well as the entire system.

4. Aft Cargo Compartment Door Seal

   The door seal was found to be torn in the aft left corner. The seal was replaced.

5. Cabin Altitude Warning

   The cabin altitude warning horn sounds (actives) when the cabin altitude exceeds 10 000ft. The passenger oxygen masks will not deploy until 14 000ft cabin altitude although they can be downed manually at any time by the crew. In this flight, the cabin altitude stabilised at around 12 500ft. Due to the slow nature of the leak, the cockpit crew decision was not to deploy the cabin oxygen masks during the flight.

6. The Outflow Valve

   After landing at FAGG, the crew noticed a very high cabin pressure. It was not possible to open the doors, which could have delayed an evacuation if it were required. The outflow valve as illustrated in Figure 19 was in the closed position. This valve was then slowly opened manually by the crew to ensure the cabin was fully depressurised to allow the doors to be opened; if the air ground sensor was operational, the aircraft would have automatically dumped the excess cabin pressure on touchdown.

2.2.3 Factors that Affect Cabin Pressure

To pressurise the cabin, air is supplied continuously from the engines via the air-conditioning packs. The pressure is regulated by controlling the exit of air from the aft outflow valve. Therefore, the cabin pressure is affected by the following factors:

- the inflow or supply of air from the engines to the cabin
- the controlled (regulated) leakage of air from the cabin
- any uncontrolled leakage of air from the cabin.

2.2.4 Environment

The flight was conducted during day time with visual meteorological conditions (VMC) prevailing; fine weather conditions prevailed, which had no bearing on this flight.

2.2.5 Summary

No individual component of the cabin pressurisation system was identified as having caused the loss of cabin pressure. The outflow valve, selector panel and cabin pressure controller have internal built-in test functions that report any faults affecting the control of cabin pressure, whether intermittent or constant, to the controller, which records these faults to non-volatile memory. The non-volatile memory data for this incident was examined and no pressurisation system failures were recorded. The tear-down examination of those components revealed no faults. Experience has shown that older pressurisation system components could have intermittent faults that do not show during subsequent testing. A combination of components with low or marginal performance could have caused the incident, which include the failure of the left air-conditioning duct. It was identified that some uncontrolled air leakages occurred at several places, which were caused by the cabin doors on the right not being properly secured/latched prior to take-off as well as a worn aft cargo compartment door seal.

The effect of the failure of the Air/Ground proximity sensor resulted in the crew having to deal with a 'non-normal' situation. This sensor has a direct effect on twenty-seven (27) of the aircraft systems (see list in Appendix B), which include the pressurisation system. It was noted that not all systems on the list were affected by the failure of the sensor, for example, the crew was able to retract and extend the landing gear normally.

3. CONCLUSION

3.1 General

From the available evidence, the following findings, causes and contributing factors were made with respect to this serious incident. These shall not be read as apportioning blame or liability to any particular organisation or individual.

To serve the objective of this investigation, the following sections are included in the conclusion heading:

- **Findings —** are statements of all significant conditions, events or circumstances in this serious incident. The findings are significant steps in this incident sequence, but they are not always causal or indicate deficiencies.

- **Causes —** are actions, omissions, events, conditions or a combination thereof, which led to this serious incident.
- **Contributing factors —** are actions, omissions, events, conditions or a combination thereof, which, if eliminated, avoided or absent, would have reduced the probability of the serious incident occurring, or would have mitigated the severity of the consequences of the serious incident. The identification of contributing factors does not imply the assignment of fault or the determination of administrative, civil or criminal liability.

3.2 Findings

<u>The Crew</u>

3.2.1 The PIC was issued an Airline Transport Pilot Licence (ATPL), and the aircraft type was endorsed on his licence. He also had a Class 1 aviation medical certificate with an expiry date of 31 January 2021.

3.2.2 The FO was issued an ATPL, and the aircraft type was endorsed on his licence. He also had a Class 1 aviation medical certificate with an expiry date of 31 January 2021.

3.2.3 The crew declared a Mayday at 08:06:08Z on the Cape Town West sector frequency 125.10MHz.

3.2.4 Following the Mayday call, the crew diverted to FAGG, and the aircraft was granted permission to make a descent to FL100 by the radar controller as requested by the crew.

3.2.5 Both pilots fitted their oxygen masks immediately after they recognised loss of cabin pressure but decided not to deploy the oxygen masks in the cabin area.

3.2.6 The crew performed the sequence of actions provided in the QRH of the Boeing 737-400 aircraft for when the cabin altitude was exceeded.

3.2.7 The crew also had to deal with a non-normal situation (air/ground proximity sensor failure), which was not documented in any of the OEM guidance material.

The Aircraft

3.2.8 The aircraft was issued a Certificate of Airworthiness (C of A) on 4 April 2007 with an expiry date of 30 April 2021.

3.2.9 The last maintenance inspection (C2-check) that was carried out on the aircraft prior to the serious incident flight was certified on 27 October 2020 at 65 664.47 airframe hours. The aircraft had flown a total of 158.92 hours since then.

3.2.10 Prior to the flight from FACT to FAEL, the aircraft had no historic defects relating to the pressurisation system.

3.2.11 Following take-off from FACT, the aircraft was not interrogated by secondary surveillance radar due to a transponder-related activation malfunction on the aircraft.

3.2.12 The air duct with Part No. 65-51552-8 located on the left air-conditioning pack was found to have fractured in the area where a welding repair was undertaken previously (see Figure 7), which drastically reduced the efficiency of the left-side pack system.

3.2.13 The doors were adjusted as per the aircraft maintenance manual (AMM) requirements.

3.2.14 The aft cargo compartment door seal was replaced after it was found to have been torn in the aft left lower corner.

3.2.15 The Air/Ground proximity sensor located within the right wheel well was found defective and was replaced. This unit caused multiple cockpit redundancies and also contributed to the transponder being in operative while the landing gear was in the retracted position. It was only possible to interrogate the transponder after the landing gear was lowered for landing at FAGG.

3.2.16 Data from the QAR was downloaded by the operator for the purpose of this investigation.

3.2.17 Prior to the flight from FACT to FAEL, the aircraft had no historic defects relating to the pressurisation system or the Air/Ground proximity sensor.

3.2.18 The operator did not quarantine the aircraft and its flight recorders after landing at FAGG. The aircraft was ferried from FAGG to FAOR (its main maintenance base). The CVR data for the serious incident flight was overwritten (not available).

Weather Information

3.2.19 During the occurrence, no dangerous meteorological phenomena were observed that could have affected the flight.

The Operator

3.2.20 The operator had a valid Air Operating Certificate (AOC), which was issued on 28 April 2020 by the SACAA with an expiry date of 30 April 2021. The aircraft was duly authorised under the AOC.

3.2.21 No primary surveillance radar was available at FAGG. The aircraft was interrogated for the first time during the flight by SSR when the aircraft descended below 2 500ft AMSL (with the landing gear extended) while positioning for landing at FAGG.

3.2.22 The aircraft landed safely at FAGG on Runway 29 at 0840Z.

Passengers

3.2.23 The main risk to passengers and crew was barotrauma. One of the passengers required medical attention; three passengers complained of nose bleed and five passengers suffered from severe ear pain following the cabin altitude warning and emergency descent. These injuries/medical treatments were viewed as minor.

3.3 Probable Cause

3.3.1 It is likely that this serious incident occurred as a result of the following failures:

(i) The air/ground proximity sensor becoming defective, which rendered certain cues to remain in ground mode and causing certain warning lights to illuminate in the cockpit which required crew intervention, whilst certain cues functioned normally.

(ii) Loss of cabin pressure, which was attributed to air leaking from the fuselage, including the aft cargo compartment door seal that was worn out. This situation was further aggravated by the left air-conditioning pack outlet duct fracture in an area that was previously repaired, which resulted in reduced air supply to the system.

4. SAFETY RECOMMENDATIONS

4.1 General

The safety recommendations listed in this report are proposed according to paragraph 6.8 of Annex 13 to the Convention on International Civil Aviation and are based on the conclusions listed in heading 3 of this report. The AIID expects that all safety issues identified by the investigation are addressed by the receiving States and organisations.

4.2 Safety Recommendations/Actions

4.2.1 Action to be taken by the aircraft maintenance organisation to prevent a recurrence.

It is recommended that a fleet inspection be conducted to check the status of the air duct with Part No. 65-51552-8 located on the left air-conditioning pack that was found to have failed during operation (as seen in Figure 7). Such inspection should be conducted at the aircraft's next maintenance inspection despite the type of maintenance the aircraft is scheduled for.

4.2.2 Action to be taken by the operator to prevent a recurrence.

It is recommended that a crew notice be issued by the operator to cockpit/flight deck crew that the absence/unavailability of transponder data during flight renders the aircraft not to be interrogated by SSR. The aircraft was only visible on the primary surveillance radar reflected as a signal with no altitude or speed data available to the controller.

4.2.3 It is recommended to Boeing that this 'non-normal' condition that was experienced by the crew be included in the Boeing 737 Flight Crew Training Manual.

4.2.4 It is recommended to the operator that this 'non-normal' condition that was experienced during this flight by the crew be included in their evidence-based training procedures.

4.2.5 It is recommended that the operator reminds all pilots that power must be removed from the recorders after landing following a serious incident. No CVR data was available for this flight as the unit was not powered off/quarantined after landing at FAGG.

5. APPENDICES

5.1 Appendix A (George Aerodrome Chart)

5.2 Appendix B (Boeing 737 Air/Ground Systems)

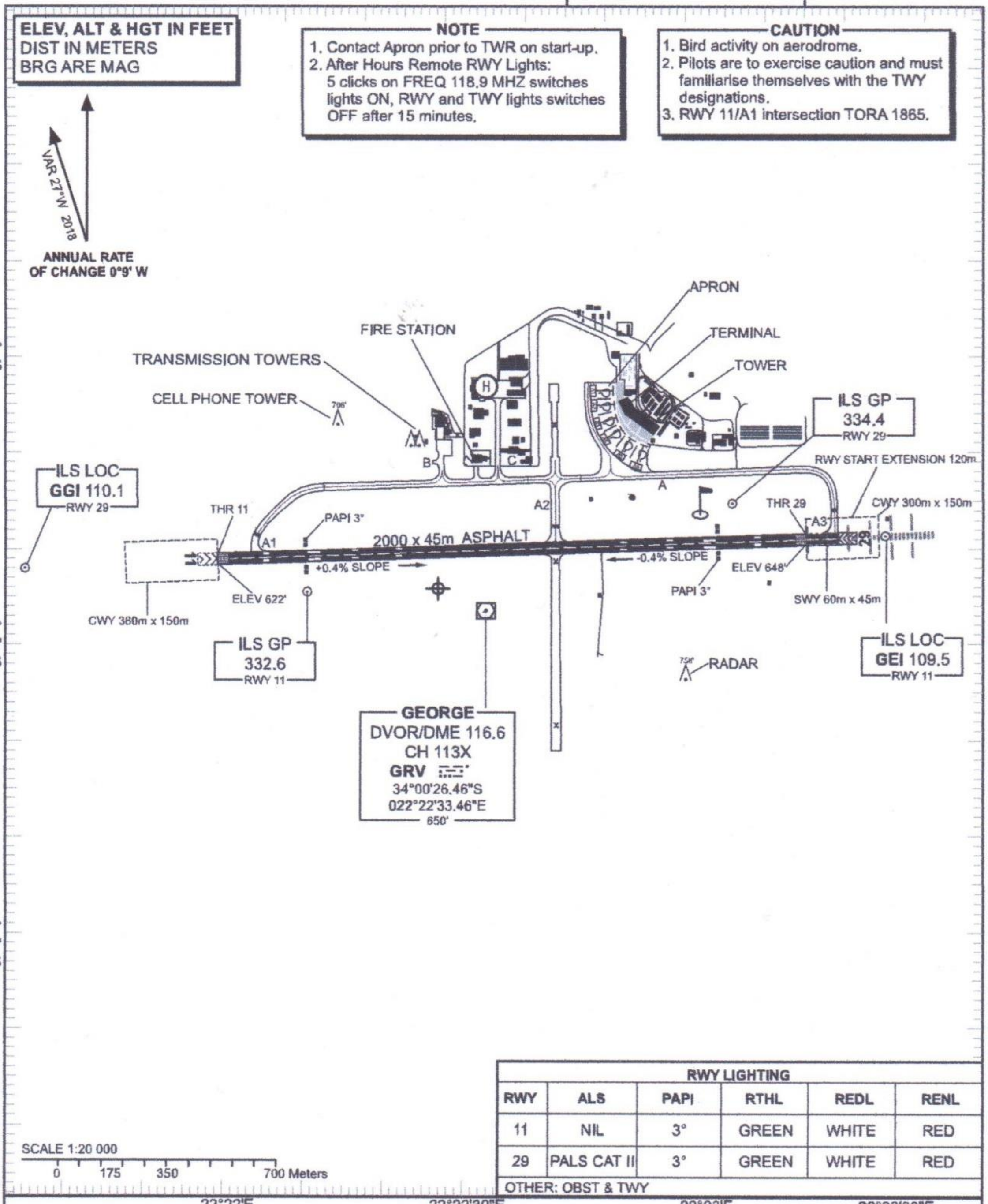
This report is issued by:
Accident and Incident Investigations Division
South African Civil Aviation Authority
Republic of South Africa

APPENDIX A

AERODROME/ HELIPORT CHART - ICAO | 34°00'24.13"S 022°22'27.41"E | **ELEV 648'** **GUND 104.1'**

GEORGE ATIS 126.225
ALPHA OSCAR (APN) 122.65
TWR 118.90
APP 128.20

GEORGE
FAGG



RWY LIGHTING

RWY	ALS	PAPI	RTHL	REDL	RENL
11	NIL	3°	GREEN	WHITE	RED
29	PALS CAT II	3°	GREEN	WHITE	RED
OTHER: OBST & TWY					

PHYSICAL CHARACTERISTICS

RWY	DIRECTION	THR COORDINATES	THR ELEVATION	TORA (m)	TODA (m)	ASDA (m)	LDA (m)	SWY	CWY	SLOPE	SURFACE	BEARING STRENGTH	CIRCUIT
11	088°(T)	34°00'21.30"S 022°21'59.01"E	622'	2000	2300	2060	2000	60m	300m	0.004 U	ASPH	PCN 49/F/B/Y/U	R/H
29	268°(T)	34°00'18.83"S 022°23'16.90"E	648'	2120	2500	2120	2000	0m	380m	0.004 D			L/H

CHANGE: True/ Magnetic Arrows and GUND

EFF: 11 OCT 18

SOUTH AFRICAN CIVIL AVIATION AUTHORITY

AD-01

Brake Temperature Indication

24165, 25116, 27168

Brake temperature for each main gear wheel is reflected on the BK TEMP indicator. The numerical scale of 0 to 10 is a relative value of brake energy. Values do not provide instantaneous readings of brake conditions, as brake temperature tends to rise for 10 to 15 minutes after brake application. The values tend to increase for 10 to 15 minutes after the brakes are used.

A BRAKE TEMP Light illuminates when any temperature value is 5 or above and extinguishes when all pointers drop below 4.

Air/Ground System

Inflight and ground operation of various airplane systems are controlled by the air/ground system.

The system receives air/ground logic signals from sensors located on the right main gear and the nose gear. These signals are used to configure the airplane systems to the appropriate air or ground status.

Air/Ground System Logic Table

SYSTEMS	NORMAL INFLIGHT OPERATION	NORMAL ON GROUND OPERATION	REFER TO CH
Drain Mast Heaters	115 volt AC operation.	28 volt AC operation.	1
Pack Valves	With one pack operating regulates to high flow with flaps up.	With one pack operating, regulates to high flow only when pack is operating from the APU and both engine bleed switches are OFF.	2
Pressurization (CPCS)	Allows programmed pressurization in the standby and automatic modes.	Allows pressurization as determined by the FLT/GRD switch.	2
Ram Air	Turbofans operate only when air conditioning packs operate and flaps are not up.	Turbofans operate whenever air conditioning packs operate. Deflectors are extended.	2

SYSTEMS	NORMAL INFLIGHT OPERATION	NORMAL ON GROUND OPERATION	REFER TO CH
Wing Anti–ice (Ground Operating System)	Control valves open when switch is ON. Thrust setting and duct temperature logic is bypassed.	With switch ON, valves cycle open and closed. Switch trips to OFF at lift–off.	3
Autothrottle	Enables go–around below 2000 ft radio altitude.	Disengaged 2 seconds after landing. Takeoff mode enabled.	4
TO/GA switch	Flight director engages go–around mode.	Flight director engages takeoff mode.	4

25095, 25096, 26961

ACARS	Sends out signal on strut extension for takeoff signal.	Sends out signal on strut compression for landing signal.	5

Voice Recorder	Prevents tape erasure.	Allows tape erasure when parking brake is set.	5
Standby Power	Standby busses automatically transferred to battery and inverter power when standby power switch is in AUTO	BAT position must be selected for transfer of standby busses	6
APU Control	APU operation possible with battery switch OFF.	APU shutdown if battery switch is positioned OFF.	7
APU Generator	May be connected to only one generator bus.	May be connected to two generator buses.	7
Engine Idle Control	Idle control and indication system is armed.	Maintains high idle until 4 seconds after landing.	7
Thrust Reverser	Thrust reverse disabled by gear sensors and radio altimeter.	Thrust reverse enabled.	7

SYSTEMS	NORMAL INFLIGHT OPERATION	NORMAL ON GROUND OPERATION	REFER TO CH
APU Fire Horn	Wheel well horn disabled.	Wheel well horn enabled.	8
Speed Brake Lever Actuator	Can be armed to raise ground spoilers for landing.	Activates SPEED BRAKE lever on landing if armed. Rejected take–off feature available. Drives to DOWN when thrust lever advanced.	9
Auto Slat	System enabled with flaps 1, 2, or 5 selected. PTU available if system B pressure is lost.	System disabled.	9
Flight Recorder	Operates when transfer bus No. 1 is powered	Operates when transfer bus No. 1 is powered and either engine is operating.	10

24165, 25116 - 28550

FMC	Position updated from DME or VOR/DME.	Does not update.	11

25095, 25096, 28890, 28891

FMC	FMC position updated from GPS, DME or VOR/DME.	FMC position updated from GPS.	11

Standby Hydraulic	Pump automatic operation with flaps extended and A or B pressure lost.	Wheel speed must be greater than 60 knots for automatic operation.	13
Antiskid	Releases normal brakes for touchdown protection.	Allows normal antiskid braking after wheel spin–up.	14
Autobrake	Allows selection of landing mode.	RTO mode available.	14
Landing Gear Lever Lock	Lever Lock solenoid released.	Lever Lock solenoid latched.	14

SYSTEMS	NORMAL INFLIGHT OPERATION	NORMAL ON GROUND OPERATION	REFER TO CH
Landing Gear Transfer Unit	Enabled.	Disabled.	14
Stall Warning	Enabled.	Disabled.	15
Takeoff Warning	Disabled.	Enabled.	15