



AIRCRAFT SERIOUS INCIDENT REPORT AND EXECUTIVE SUMMARY

		Reference:		CA18/3/2/1297	
Aircraft Registration	ZS-ZWT	Date of Serious Incident	16 December 2019	Time of Serious Incident	0536Z
Type of Aircraft	Boeing 737-800	Type of Operation	Air Transport Operation (Part 121)		
Pilot-in-Command Licence Type	Airline Transport Pilot Licence	Age	60	Licence Valid	Yes
Pilot-in-command Flying Experience	Total Flying Hours	16232.3	Hours on Type	11071.5	
Last Point of Departure	O.R. Tambo International Aerodrome (FAOR), Gauteng Province				
Next Point of Intended Landing	King Shaka International Aerodrome (FALE), Kwa-Zulu Natal Province				
Location of the serious incident site with reference to easily defined geographical points (GPS readings if possible)					
At or near the STV VOR in Standerton at the following GPS position (26°41'40.58" S 28°51'59.70" E					
Meteorological Information	Wind: Variable at 5kts, Temperature: 16°C, Dew Point: .4°C, Visibility: 9999m, QNH: 1023hPa				
Number of People On-board	2 + 4 + 183	No. of People Injured	0	No. of People Killed	0
Synopsis					
<p>On 16 December 2019 at approximately 0536Z, a B737-800 aircraft with registration marks ZS-ZWT departed O.R. Tambo International Aerodrome (FAOR) on a scheduled commercial flight to King Shaka International Aerodrome (FALE). On-board the aircraft were two flight crew, four cabin crew and 183 passengers.</p> <p>During the climb phase, the pilots noticed that the cabin altitude warning, which alerts the flight crew that the aircraft's cabin was not pressurising to the required cabin altitude setting, was activated whilst flying over Standerton area (Skhukhuza) in Mpumalanga province, and near the very high omnidirectional range (VOR) beacon STV.</p> <p>The crew notified the air traffic control (ATC) of the cabin's pressurisation problem. The flight path showed the aircraft performing two climbs over flight level 100 (FL100). The aircraft first climbed to FL150 and, later, made a descent to FL100 to address the cabin altitude warning. The pilots referenced the Quick Reference Handbook (QRH) to troubleshoot the cabin altitude warning alert. Thereafter, the aircraft climbed to FL130 before declaring an emergency by broadcasting a PAN-PAN-PAN and making a descent to FL100. At this point, the pilots requested an air turn-back to FAOR.</p> <p>The aircraft landed uneventfully on Runway 21R at FAOR and the passengers disembarked safely. There were no reported damages to the aircraft, and no injuries were reported as a result of this serious incident.</p> <p>The investigation revealed that during the climb phase, the air cycle machine failed, causing reduced air inflow from engine number 2 air conditioning pack, which resulted in cabin pressurisation failure.</p> <p>Contributing factor: Air leakage on the forward entry door hinges.</p>					
SRP Date	11 August 2020	Publication Date	12 August 2020		

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Abbreviation	Description
°	Degrees
°C	Degrees Celsius
ACAU	Air conditioning Accessory Unit
ACP	Air conditioning packs
AFT	Rear
AMM	Aircraft Maintenance Manual
AMSL	Above mean sea level
APU	Auxiliary power unit
ATC	Air Traffic Control
ATPL	Airline transport pilot licence
BAR	Bleed air regulator
BITE	Built-in test equipment
CAR	Civil Aviation Regulations, 2011, as amended
CAVOK	Ceiling and visibility OK
C of A	Certificate of airworthiness
C of R	Certificate of registration
CPC	Cabin Pressure Controller
CVR	Cockpit voice recorder
DCPCS	Digital Cabin Pressurisation Control System
DME	Distance measuring equipment
ECAM	Electronic Centralised Aircraft Monitor
EO	Engineering Order
FCV	Flow Control Valves (aka pack valve)
°F	Fahrenheit
FL	Flight Level (standard air pressure, expressed in hundreds of feet)
FALE	King Shaka International Aerodrome
FAOR	O.R. Tambo International Aerodrome
FCOM	Flight Crew Operations Manual
FO	First Officer
ft	Foot/feet
FWD	Forward
GPS	Global Positioning System Coordinates
hPa	Hectopascals
IFR	Instrument flight rules
kt	Knot
MPD	Maintenance Planning Document
MEL	Minimum Equipment List
OFV	Outflow valve
PAPI	Precision Approach Path Indicator
PIC	Pilot-in-command
PRSOV	Pressure Regulator and Shut-Off Valve
psig	Pounds per square in gauge
QNH	Query: Nautical height
QRH	Quick Reference Handbook
SACAR	South African Civil Aviation Regulations of 2011
VOR	Very High Frequency Omnidirectional Range
Z	Zulu (Term for Universal Co-ordinated Time - Zero Hours Greenwich)

DESCRIPTION OF SERIOUS INCIDENT

Reference number : CA18/3/2/1297
Name of owner : Comair (Pty) Ltd
Name of the operator : Comair (Pty) Ltd
Manufacturer : Boeing Aircraft Company
Model : B737-800
Nationality : South African
Registration markings : ZS-ZWT
Place : En route to King Shaka International Airport (FALE)
Date : 16 December 2019
Time : 0536Z

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.

Purpose of the Investigation:

*In terms of Regulation 12.03.1 of the South African Civil Aviation Regulations 2011, this report was compiled in the interest of the promotion of aviation safety and the reduction of the risk of aviation accidents or serious incidents and **not to establish blame or liability**. Any person who has information regarding this serious incident should contact the Accident and Incident Investigations Division (AIID) on AIIDinbox@caa.co.za*

Investigation process:

The AIID of the South African Civil Aviation Authority (SACAA) was informed of an aircraft serious incident involving a Boeing 737-800, which occurred during the climb phase after take-off from O.R. Tambo International Aerodrome (FAOR) en route to King Shaka International Aerodrome (FALE) on 16 December 2019. The serious incident was notified to the AIID investigator-on-call at 0544Z on the day of the serious incident. No investigator/s were dispatched for this serious incident.

The AIID has appointed an investigator-in-charge. Notifications were sent to the State of Registry, State of Operator, and State of Manufacture and Design (National Transportation Safety Board) that has assigned an Accredited Representative to the investigation. The AIID will lead the investigation and issue the final report.

Notes:

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

- Serious incident – this investigated serious incident*
- Aircraft – the B737-800 involved in this serious incident*
- Investigation – the investigation into the circumstances of this serious incident*
- Crew – the flying crew involved in this serious incident*
- Report – this serious incident report*

2. Photos and figures used in this report were obtained from different sources and may be 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 the addition of text boxes, arrows or lines.

Disclaimer:

This report is produced without prejudice to the rights of the SACAA, which are reserved.

FACTUAL INFORMATION

1.1. History of Flight

- 1.1.1. On 16 December 2019 at 0536Z, a B737-800 aircraft with the call sign MN601 and registration marks ZS-ZWT departed O.R. Tambo International Aerodrome (FAOR) on a scheduled commercial flight to King Shaka International Aerodrome (FALE). On-board the aircraft were two flight crew, four cabin crew and 183 passengers. The flight was conducted under the provisions of Part 121 of the South African Civil Aviation Regulations 2011 as amended.
- 1.1.2. During the climb phase, the pilots noticed that the cabin altitude warning, which alerts the flight crew that the aircraft's cabin was not pressurising to the required cabin altitude setting was activated whilst overhead Standerton area (Skhukhuza) in Mpumalanga province, and near the very high omnidirectional range (VOR) beacon STV.
- 1.1.3. The crew notified the air traffic control (ATC) of the cabin's pressurisation problem. The flight path showed the aircraft performing two climbs over flight level 100 (FL100). The aircraft first climbed to FL150 and, later, made a descent to FL100 to address the cabin altitude warning. The pilots referenced the Quick Reference Handbook (QRH) to troubleshoot the cabin altitude warning alert. Thereafter, the aircraft climbed to FL130 before declaring an emergency by broadcasting a PAN-PAN-PAN and making a descent to FL100. At this point, the pilots requested an air turn-back to FAOR.
- 1.1.4. The aircraft landed uneventfully on Runway 21R at FAOR and the passengers disembarked safely. The total flight time was 1 hour 10 minutes, which included time taken by the passengers to disembark the aircraft after landing.
- 1.1.5. There were no reported damages to the aircraft, and no injuries were reported as a result of this serious incident.
- 1.1.6. The flight was conducted under instrument flight rules (IFR) by day. The in-flight serious incident occurred overhead Standerton area at the following Global Positioning System (GPS) co-ordinates: 26°08'01.30" South 028°14'32.34" East before reaching FL130.



Figure 1: The flight path and elevation profile of ZS-ZWT from Flight Aware. (superimposed on Google Earth)

1.2. Injuries to Persons

Injuries	Pilot	Crew	Pass.	Other	Total
Fatal	-	-	-	-	
Serious	-	-	-	-	
Minor	-	-	-	-	
None	2	4	183	-	189

1.3. Damage to Aircraft

1.3.1. None.

1.4. Other Damage

1.4.1. None.

1.5. Personnel Information

1.5.1. Pilot-in-command (PIC) (Captain)

Nationality	South African	Gender	Male	Age	60
Licence Number	0270406135	Licence Type	Airline Transport Pilot Licence		
Licence Valid	Yes	Type Endorsed	Yes		
Ratings	Instrument Rating				
Medical Class & Expiry Date	Class 1, 31 May 2020				
Restrictions	Suitable corrective lenses				

Flying Experience of PIC:

Total Hours	16232.1
Total Past 90 Days	202.3
Total on Type Past 90 Days	202.3
Total on Type	11071.5

1.5.2. First Officer (FO)

Nationality	South African	Gender	Male	Age	41
Licence Number	0274464837	Licence Type	Airline Transport Pilot Licence		
Licence Valid	Yes	Type Endorsed	Yes		
Ratings	Instrument Rating, Grade 2 Flight Instructor				
Medical Class & Expiry Date	Class 1, 30 June 2020				
Restrictions	Suitable corrective lenses				

Flying Experience of FO:

Total Hours	7142.2
Total Past 90 Days	107
Total on Type Past 90 Days	104
Total on Type	1881.2

1.6. Aircraft Information

1.6.1. Aircraft Description

The Boeing 737-800 is a popular twin-engine, short- to medium-range aircraft. It is a single-aisle jet powered by two CFM56-7B engines.

Airframe

Type	B737-800	
Serial Number	27990	
Manufacturer	Boeing Aircraft Company	
Fuel Type	Jet-A1	
Date of Manufacture	27 March 1999	
Total Airframe Hours (at time of serious incident)	67646.02	
Last Scheduled A-check Inspection (Hours & Date)	67503.34	18 November 2019
Hours Since the Last A-check Inspection	142.68	
Last Scheduled C-check Inspection (Hours & Date)	64000.02	24 July 2018
Hours Since the Last C-check Inspection	3646	
C of A (Original Date of Issue)	25 April 2014	
C of A (Expiry Date)	30 April 2020	
C of R (Date of Issue) (Present Owner)	01 August 2016	
Operating Categories	Standard Part 121	

Engines

Engine Number	Engine 1	Engine 2
Type	CFM 56-7B26 turbofan engines	
Serial Number	PP 888796	PP 888792
Time Since New (Hours)	49233.82	57382.35
Hours since overhaul	Modular assembly	

1.6.2. Maintenance of the Forward (FWD) and Rear (AFT) Entry Door Seals

The AFT (rear) and FWD (forward) entry door seals are on condition items, which means that they are changed only when required (that is, when damaged or worn). According to the aircraft manufacturer, there were no Service Bulletins (SBs) or Airworthiness Directives (ADs) issued for unscheduled maintenance to be conducted on the FWD entry door seals prior to the serious incident.

1.6.3. Aircraft Systems Description according to the Boeing 737-600/700/800/900 Aircraft Maintenance Manual (AMM)

1.6.3.1. Description of the Bleed Air System (Refer to Figure 2)

Air for the bleed air system can be supplied by the engines, the auxiliary power unit (APU), or by an external air cart/source. The APU or external cart supplies air to the bleed air duct prior to engine start. After engine start, air for the bleed air system is normally supplied by the engines. Switches on the air conditioning "P5 forward overhead panel" operate the APU and engine bleed air supply system, are located on the pressurisation overhead panel. The following systems rely on the bleed air system for operation:

- *Air conditioning / pressurisation*
- *Wing and engine thermal anti-icing*
- *Engine starting*
- *Hydraulic reservoirs pressurisation*
- *Water tank pressurisation*

The aircraft's high-pressure bleed air from the engines is further regulated by the pneumatic

flow control valve (FCV) that control the air inflow to the two independent air conditioning packs' (ACP) which provide conditioned, pressurised air to the cabin. It should be noted that "FCV" is called "pack valve" in the Aircraft Operations Manual.

Engine bleed air is obtained from the mid (5th) compressor stage of each engine, through a check valve. When 5th-stage bleed air pressure is not high enough, high (9th) stage bleed air is used. Switching from mid to high stage bleed on each engine is controlled automatically by the high stage valve and regulator. The engine bleed air valve acts a pressure regulator and shutoff valve (PRSOV).

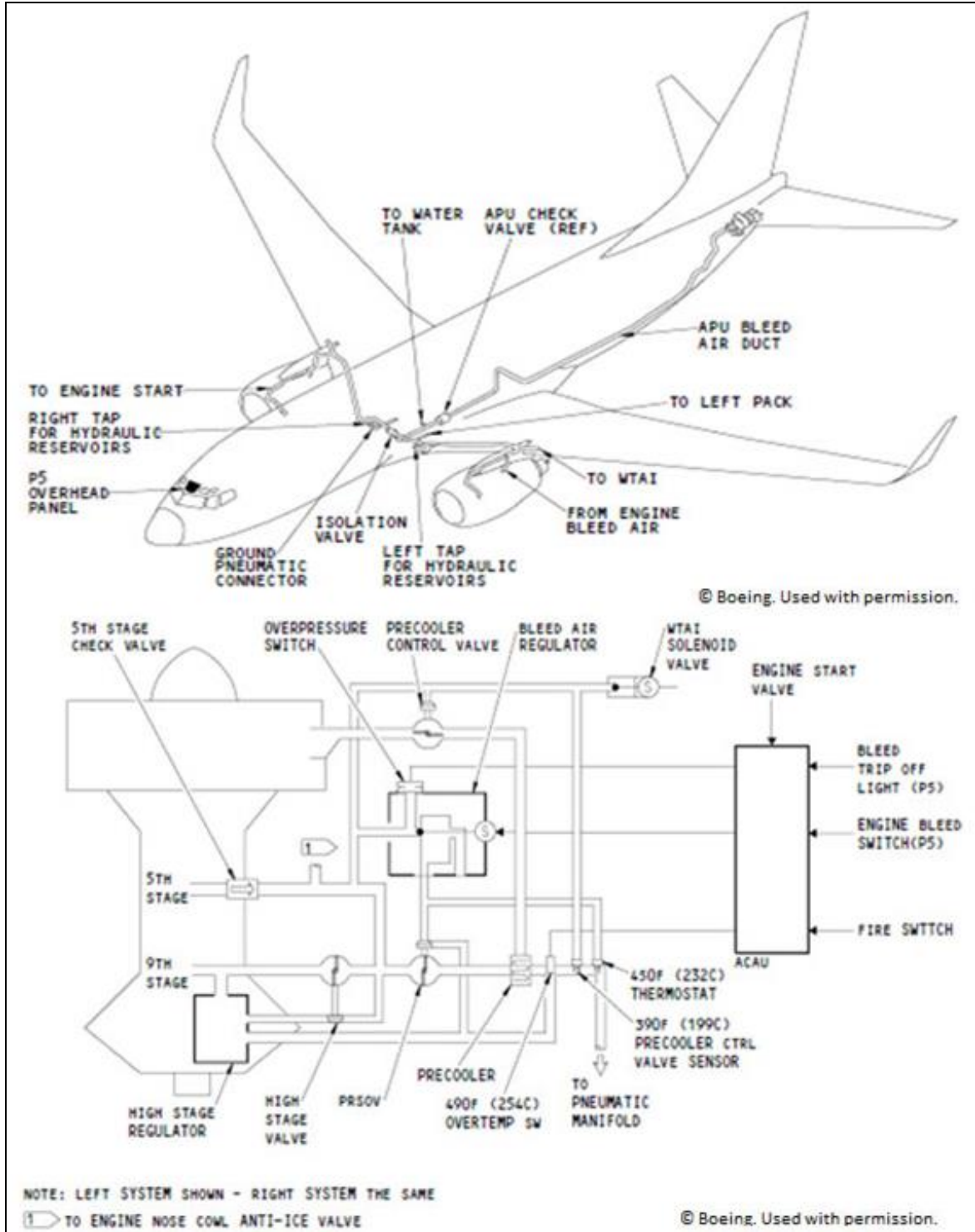


Figure 2: Bleed Air System schematic. (Source: Boeing)

The pressure regulator and shutoff valve (PRSOV) controls the flow of engine bleed air to the pneumatic manifold. The bleed air regulator (BAR) operates the PRSOV with control pressure which comes from the engine bleed inter stage duct. The BAR gets electrical control from a signal which comes from the air conditioning accessory unit (ACAU). When

the BAR solenoid valve opens electrically, it supplies control pressure to open the PRSOV against spring force. When the BAR closes electrically, it bleeds the control pressure from the PRSOV.

The air conditioning accessory unit (ACAU) is an interface between the air conditioning bleed air controls panel (switches and lights) and the PRSOV. The ACAU provides the outputs that enable or disable operation of the cooling pack and the temperature control system components.

The PRSOV controls the pressure of air supplied to the precooler within the range of 34 and 50 pounds per square in gauge (psig). Air from either stage is routed through a precooler on each engine before entering the pneumatic manifold.

A precooler system is an automatic system that cools engine bleed air, keeping the engine bleed air temperatures between 390°F (199°C) and 440°F (229°C). The precooler is a cross flow heat exchanger. It uses engine fan air to cool the engine bleed air.

The precooler control valve controls fan air flow to the precooler. The precooler control valve modulates the fan air flow in response to the precooler control valve sensor and the wing thermal anti-ice solenoid valve.

The 450°F (232°C) thermostat bleeds control pressure from the PRSOV if engine bleed air downstream of the precooler is 450°F (232°C) or higher. This causes the PRSOV to modulate toward closed. The reduced airflow through the PRSOV has these effects:

- *Prevents bleed trip off conditions, and*
- *A drop in pneumatic manifold pressure.*

1.6.3.2. Description of the Air Conditioning System

Conditioned air for the cabin comes from either the aircraft air conditioning system or an external ground source. The air conditioning system provides temperature-controlled air by processing bleed air from the engines, APU, or a ground air source, in the air conditioning packs.

The flow of bleed air from the main bleed air duct through each air conditioning pack is controlled by the respective pack valve. Normally the left pack uses bleed air from engine No. 1 (left engine) and the right pack uses bleed air from engine No. 2 (right engine).

A single pack can maintain pressurisation and an acceptable temperature throughout the aircraft up to the maximum certified ceiling.

1.6.3.3. Description of the Pressurisation System (Refer to Figure 3)

The purpose of the pressurisation system is to provide a safe comfortable cabin altitude at all aircraft altitudes. The air conditioning system provides a constant flow of pressurised, conditioned air to the cabin. Normally, a small amount of the air leaks overboard through door seals and other openings.

The pressurisation system meters the amount of air exhausted from the aft outflow valve (OFV) to control pressurisation to a prescribed schedule depending on the aircraft altitude, cruise altitude, and the altitude of the destination.

Cabin pressurisation is controlled during all phases of aircraft operation by the Digital Cabin Pressurisation Control System (DCPCS). The system uses bleed air supplied by the engines and distributed to the air conditioning system. Pressurisation and ventilation are controlled by modulating the OFV and the overboard exhaust valve (Refer to Figure 3).

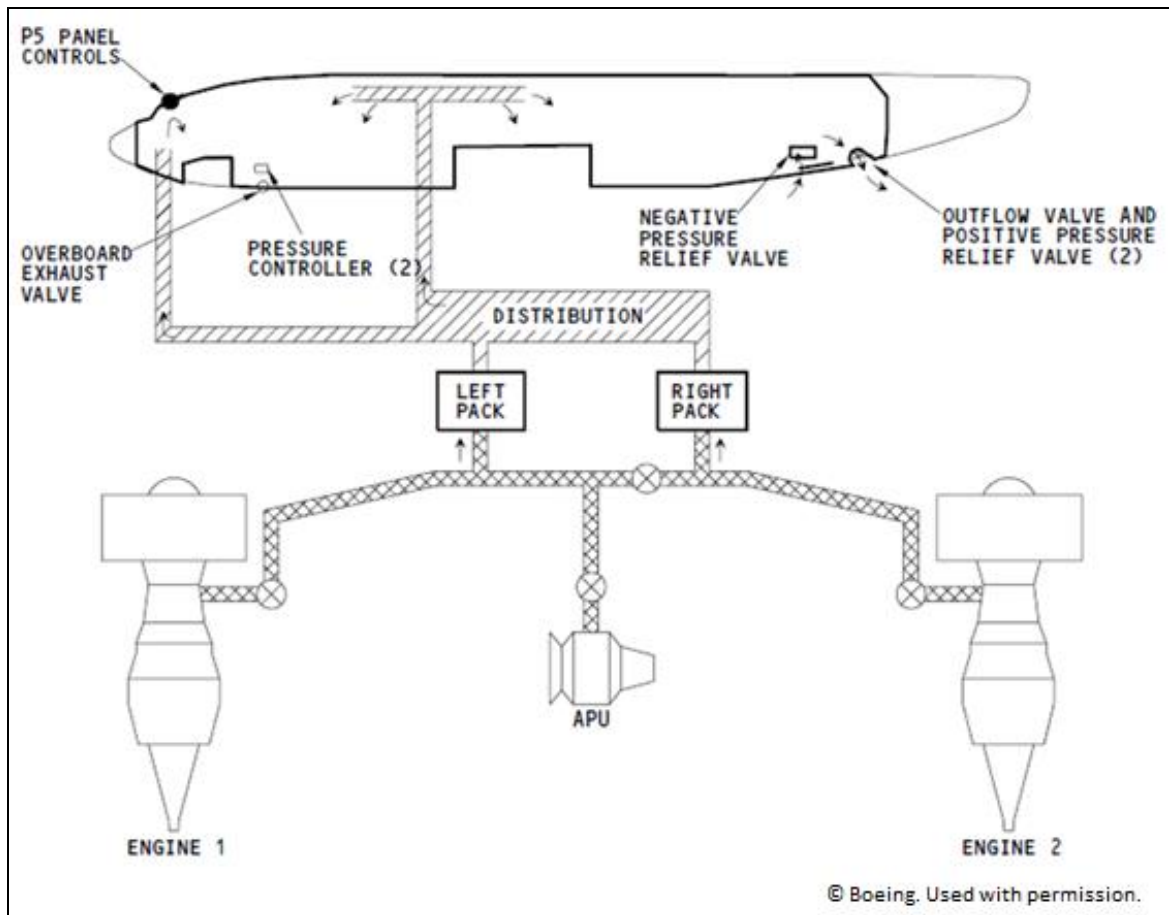


Figure 3: Air Conditioning and Pressurisation System – General Schematic. (Source: Boeing)

1.6.3.4. Operation of the Cabin Pressure Controller (CPC)

The pressurisation system on the Boeing 737-800 is controlled during all phases of flight by two digital Cabin Pressure Controllers (DCPCs). Cabin altitude is normally rate-controlled by the digital CPCs up to a cabin altitude of 8 000 ft at the aircraft maximum certified ceiling of 41 000ft.

Keeping the cabin altitude below 8 000ft generally avoids significant hypoxia, altitude sickness, decompression sickness, and barotrauma, and Federal Aviation Administration (FAA) regulations in the U.S. mandate that the cabin altitude may not exceed this at the maximum operating altitude of the aircraft under normal operating conditions.

During normal operation under the AUTO pressurisation mode, the cabin altitude is automatically controlled by adjusting the amount of air released outside of the aircraft, primarily through opening or closing of the OFV by the CPC.

In automatic mode, one pressure controller is operating, while the other controller is in standby mode. The DCPCS operates in the automatic mode using commands from the operational pressure controller to increase or decrease the aft OFV's exhaust areas as required during the flight to maintain the cabin pressure schedule.

The DCPCS operates in two main modes, automatic and manual, which are selected in the flight deck using the selector switch on the pressure control overhead panel. There are three allowable selector switch positions: AUTO, ALTN and MAN. The AUTO and ALTN positions will provide automatic cabin pressure control, and the MAN position will allow manual control.

There are two identical CPCs, one CPC operates as the active controller and the other is constantly in a state in which it can be used as a backup. The CPC's switch control with each flight or when there is an AUTOFAIL event.

When, during flight, the CPC detects a failure in the automatic system on the operating side and switches to the backup CPC, the pressurisation mode switches to the alternate (ALTN)

mode. Additionally, it is possible to switch to the ALTN mode using the Pressurisation Mode Selector switch.

Switching the Pressurisation Mode Selector switch to MAN and operating the system manually by monitoring the OFV's position indicator, without relying on the CPC, is called the "manual mode".

The cabin altitude warning switches activates a flight deck horn and light to warn the flight crew when cabin altitude is above 10 000 feet. Two switches provide redundancy in the cabin altitude warning indication system if one of the switches fails.

1.7. Meteorological Information

- 1.7.1. The weather information on the table (below) was obtained from the Meteorological Aeronautical Report (METAR) that was provided by the South African Weather Service (SAWS) recorded at FAOR on 16 December 2019 at 0500Z.

Wind direction	Variable	Wind speed	5kt	Visibility	9999m
Temperature	16°C	Cloud cover	Nil	Cloud base	Nil
Dew point	4°C	QNH	1023hPa		

1.8. Aids to Navigation

- 1.8.1. The aircraft was equipped with standard navigational equipment as approved by the Regulator (SACAA) for the aircraft type. There were no recorded defects with the navigation system prior to the serious incident.

1.9. Communication

- 1.9.1. The aircraft was equipped with standard communication equipment as per the minimum equipment list (MEL) approved by the Regulator for the aircraft type. There were no recorded defects with the communication system prior to the serious incident.
- 1.9.2. The aircraft was in radio communication with FAOR's ATC on the very high frequency (VHF) 124.50 megahertz (MHz) when the crew declared a PAN-PAN-PAN.

1.10. Aerodrome Information

Aerodrome Location	Johannesburg, South Africa	
Aerodrome Co-ordinates	South 26°08'01.30" East 028°14'32.34"	
Aerodrome Elevation	5550ft AMSL	
Runway Designations	03L/21R	03R/21L
Runway Dimensions	14504ft x 197ft	11171ft x 197ft
Runway Used	21R	
Runway Surface	Asphalt	
Approach Facilities	DVOR; UHF DME; ILS LOC; ILS GP CAT II; ILS/DME, Runway lights	
Aerodrome Status	Licensed	

1.11. Flight Recorders

- 1.11.1. The aircraft was equipped with a flight data recorder (FDR) and a cockpit voice recorder (CVR). No information was downloaded from either device as it was considered not necessary for this investigation.

1.12. Wreckage and Impact Information

- 1.12.1. While the aircraft was climbing to FL130, the crew declared an emergency by broadcasting a PAN-PAN-PAN followed by an emergency descent to FL100. The crew continued to maintain the aircraft's altitude at FL100 after the declaration of a PAN-PAN-PAN. The crew then requested clearance from ATC to allow them to execute an air-turn back to FAOR. The aircraft landed uneventfully on Runway 21R and the passengers disembarked normally.

1.13. Medical and Pathological Information

- 1.13.1. None.

1.14. Fire

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

1.15. Survival Aspects

- 1.15.1. Not applicable.

1.16. Tests and Research

1.16.1. Troubleshooting Action Steps

Following the reported cabin pressurisation failure on 16 December 2019; troubleshooting was undertaken by the operator to rectify the failure (refer to APPENDIX A). The troubleshooting history of ZS-ZWT was as follows:

- 1.16.1.1. Between 2 December 2019 and 9 December 2019.

The following faults occurred:

- Several snags regarding the cockpit temperature controllers being uncontrollable.
- Duct-pressure split clamp was reported as leaking, with pressures of 28psig on the No.1 engine and 15psig on the No.2 engine, respectively, during take-off and climb.

Actions taken:

- Cockpit temperature sensor cleaned. No. 1 zone temperature controllers tested and passed test. Filter found clean.
- Duct split was found to be in limits. According to the AMM *pneumatic duct pressure must be a minimum of 18psig to supply enough air for cabin pressurisation.*
- Air conditioner precooler control sensor replaced.

Notes:

- Pilots to give more report on all phases of flight.

- 1.16.1.2. On 10 December 2019, numerous passengers complained that the cabin temperature was too hot.

Actions taken:

- On 11 December 2019, fault isolation was continued, with the following components being replaced:
 - Right pack temperature control valve.
 - No.2 engine bleed air regulator (BAR). Bleed test carried out at 80% N1 with packs on and duct pressure was 26psig. According to the AMM *at 80% N1 duct pressure should be 34-50psig during the take-off and climb phases.*
 - 232°C (450°F) precooler control sensors.

Notes:

- No.2 pack was inoperative and that the cabin temperature would be difficult to control due to the No.2 pack being inoperative.
- No. 2 pack temperature control valve inoperative and deactivated.
- Aircraft dispatched in accordance with (IAW) the minimum equipment list (MEL) limitations.

1.16.1.3. Between 13 December 2019 and 15 December 2019.

The following faults occurred:

- No.2 engine duct pressure only 16psig and AFT cabin temperature remains hot during take-off and climb.

Actions taken (replacement of the following components):

- Recirculating fans filters.
- No.1 engine pack replaced with a standby temperature control valve.
- No. 2 engine BAR + high stage valve + Pressure Regulator and Shut-Off Valve (PRSOV)
- 198°C (390°F) and 232°C (450°F) precooler control valve sensors

Notes:

- Snag persisted. No.2 engine duct pressure snag was resolved.
- All components returned to their original positions.

1.16.1.4. On 16 December 2019 cabin altitude warning on climb out passing FL100 was reported.

The following faults occurred:

- Leak found around FWD entry door hinges.
- Upper and lower hinge fillers missing.
- Refit FWD entry door lining.
- Sealant not curing on filler plates pressurisation.

Actions taken after completion of incident flight:

- New fillers replace.
- Flapper seals replaced (but seals were still leaking around the same place).
- FWD entry door lining removed and installed.
- FWD entry door upper and lower seal replaced.
- Old sealant removed, and fresh sealant reapplied at filler plates.

Notes:

- Aircraft pressurised; no leaks evident at the door hinges.

1.16.1.5. On 17 December 2019, the operator requested that engine bleed air system health checks be carried out on the No.1 and No.2 engines.

Actions taken:

- Both No.1 and No.2 engines temperature control valves replaced.

Notes:

- Snag persisted during ground run. Troubleshooting to continue.

1.16.1.6. On 18 December 2019, the operator requested that the Air Conditioning Accessory Unit (ACAU) be replaced – inspection of condition and pressure check of the sense lines from the BAR to the PRSOV of both engines due to suspected damage introduced during interchanging of components between engines that took place on 13 December 2019.

The following faults occurred:

- No.1 engine duct-pressure split clamp between PRSOV and the precooler intake was removed and the seal was found damaged.

Actions taken:

- No.1 engine ACAU replaced.
- Sense lines checked on No. 2 engine from pre-cooler to PRSOV. No damage found. Nil leaks evident.
- New No.1 engine duct-pressure split clamp seal fitted. Same clamp refitted and secured.
- Bleed air supplied, and nil leaks were found.

Notes:

- No.2 engine's BAR and fan air valve ordered, and aircraft was on ground during this period.

1.16.1.7. Between 19 December 2019 and 22 December 2019, fitting and troubleshooting of the ordered No. 2 engine's BAR and fan air valve. A flight test was carried out during which the bleed and pressurisation systems were normal, however, the AFT cabin temperature was still high.

The following faults occurred:

- A No.2 engine BAR and fan air valve were removed from another aircraft, and the fault was not rectified. The parts were removed and returned to original engine.
- During a high-power ground run with configuration: *both packs AUTO, isolation valve CLOSED, APU bleed valve CLOSED, both ENG bleed valves OPEN*; Duct-pressures of

- 16psig was reported for both the No.1 and No.2 engines at 80% N1.
- No.2 engine fan air valve butterfly was found loose.

Actions taken:

- Ground run carried out and defects persisted at 80% N1 both bleed air pressures dropped from 48psig to 18psig with *packs on AUTO*, respectively.

Notes:

- Fan air valve to be changed when a spare becomes available.
- Fan air valve was removed from another aircraft and faults were rectified. Fan air valve was removed and returned to original engine.

1.16.1.8. On 23 December 2019, the No.1 and No.2 engines duct pressure was still low when packs are ON at high speed, the No.1 engine was found to be leaking. The Digital Cabin Pressurisation Control (DCPC) built-in test equipment (BITE) showed low air inflow OR high leakage (Cabin Pressure Controller indicates low inflow or high fuselage leakage and not a problem with the Cabin Pressure Controller).

Actions taken:

- No.1 and No.2 engines pre-cooler control valves were replaced.
- No.1 and No.2 engines 232°C (450°F) thermostat sensors were replaced.
- No.1 and No.2 engines valve-zone temperature controls were replaced.
- No. 2 engine ACAU was replaced.

Notes:

- Ground run performed, and bleed air pressure operated normally.
- Nil leaks were evident.
- Duct pressures recorded during ground run at 80% N1 both bleed air pressures dropped from 44psig to 44psig with packs on AUTO, respectively.

1.16.1.9. On 25 December 2019, a test flight was conducted to establish if the hot cabin temperature fault was resolved by the troubleshooting and component replacements done on 23 December 2019.

The following faults occurred:

- The AFT cabin temperature was still hot.

Actions taken:

- No.2 engine Pack Primary and Secondary Heat Exchangers replaced.
- Air Cycle Machine (ACM) had ceased and was replaced.
- Leak check carried out. All operations found to be normal.

1.16.1.10. According to Flight and Defect Folio Records (submitted in the later stages of the investigation), on 26 December 2019, ZS-ZWT experienced a No.1 engine pack light during climb, with the crew reporting a grinding sound and smell before the light illuminated.

Actions taken:

- ACM replaced.
- Leak check carried out – Nil leak evident. All operations normal.

1.16.1.11. According to Flight and Defect Folio Records, from 27 December 2019 until 28 January 2020, the faults associated with the No.1 engine pack and temperature control valve were still occurring, and the aircraft had been dispatched IAW MEL 21-33B.

1.16.2. Inspection of the bleed air system and associated components

1.16.2.1. According to the Maintenance Planning Document (MPD) provided by the operator, the bleed air system and associated components are required to be subjected to an internal and external zonal inspection at 16000 FH; the inspections in the form of functional checks are required to be performed as per the Boeing zonal inspection programme (see Table 1).

Table 1: Boeing 737-800 zonal inspection programme sheet.

MPD ITEM NUMBER	ZONE	ACC	INTERVAL	APPLIC	MAN-HOURS	TASK DESCRIPTION
36-020-01	36-12-00-710	FNC	16000 FH	16000 FH	411	Functionally check the left precooler control valve and wing TAI solenoid.
36-020-02	36-12-00-710	FNC	16000 FH	16000 FH	421	Functionally check the right precooler control valve and wing TAI solenoid.
36-030-01	36-12-03-000 36-12-03-400	FNC	16000 FH	16000 FH	433	Functionally check (off-airplane) the left precooler control valve sensor per vendor's CMM.
36-030-02	36-12-03-000 36-12-03-400	FNC	16000 FH	16000 FH	443	Functionally check (off-airplane) the right precooler control valve sensor per vendor's CMM.

1.16.2.2. In addition to the above MPD tasks, the operator took an initiative to develop an Engineering Order (EO) to perform additional preventative maintenance tasks (health checks) on the bleed air system and associated components at every C-check.

1.16.2.3. The EO was performed during the last C-check in 2018. Table 2 details all the bleed air system components that were defective and were replaced during the last C-check:

Table 2: Bleed air components replaced during the last C-check.

ITEM NUMBER	DESCRIPTION	PART NUMBER OFF	SERIAL NO. OFF	DATE	POSITION	PART NUMBER ON	SERIAL NO. ON	REASON FOR REMOVAL
#14	SENSOR ASSY	129694-2	5126	2018/07/13	PYLON#2	129694-3	4798	Broken
#15	PRSOV	3214552-5	1276C	2018/07/13	ENGINE#2	3214552-5	2637C	Broken
#21	HIGH STAGE REGULATOR	107484-7	3362	2018/07/17	ENG#1	107484-7	9551	Inoperative
#22	PRECOOLER CONTROL VALVE (CL&NG)	3289562-5	6085	2018/07/17	ENG#1	63292146-1	4479	Inoperative
#27	PRSOV	3214552-5	6394	2018/07/24	ENG#1	3214552-5	9689	Inoperative
#28	REGULATOR HIGH STAGE	107484-6	3936	2018/07/24	ENG#2	107484-7	13521	New installation
#29	PRECOOLER CONTROL VALVE (CL&NG)	3289562-5	11516	2018/07/24	ENG#2	3289562-5	5640	Inoperative
#30	SENSOR ASSY	129694-2	5572	2018/07/24	ENG#1	129694-2	8798	Inoperative
#31	VALVE HIGH STAGE	3214446-4	9325	2018/07/24	ENG#2	3214446-4	11004	Inoperative
#32	BLEED AIR REGULATOR	107492-6	6943	2018/07/24	ENG#1	107492-6	13834	Inoperative

1.16.2.4. Both the No.1 and No.2 engines PRSOVs were replaced during the last C-check inspection, which occurs every 16 000 flight hours.

1.17. Organisational and Management Information

1.17.1. The flight was conducted in accordance with the provisions of Part 121 of the South African Civil Aviation Regulations 2011 as amended.

1.17.2. The operator was in possession of an approved Class 1 Air Service Licence No. S066D for domestic schedule, which was issued on 12 August 2015 by the Department of Transport. The licence authorised the carrier to operate under the following 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 used 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 an Air Operating Certificate (AOC) No. CAA/N067D, which was issued on 30 April 2019 by the SACAA with an expiry date of 30 April 2020. The aircraft was duly authorised to operate under the AOC.

1.17.4. The Aircraft Maintenance Organisation (AMO) which carried out the last maintenance inspection (A-check) prior to the serious incident flight was in possession of an approved AMO certificate number 0001 that was issued by the SACAA on 30 September 2019 with an expiry date of 30 October 2020.

1.18. Additional Information

1.18.1. Forward Entry Door Inspection

- 1.18.1.1. The forward entry door is an inward-outward opening plug-type door at the forward end of the fuselage on the left side (Figure 1). An upper and a lower hinge assembly support the door on the forward edge in the door opening. The door may be closed or opened from inside or outside the airplane.
- 1.18.1.2. When the door is in the closed position and the passenger cabin is pressurised, doorstops mounted on the forward and aft frames of the door opening are contacted by adjustable door stop pins attached to the forward and aft edges of the door. The doorstops transmit pressurisation loads on the door to the fuselage structure surrounding the door and prevent excessive deflection of the seal attached around the entire edge of the door.
- 1.18.1.3. A flap is located at both the upper and lower hinges between cut-outs in the door reveal and is attached by a hinge to the forward frame of the door opening. The flap provides a continuous contact surface for the seal around the hinge cut-outs when the door is in the closed position.
- 1.18.1.4. According to the AMM, the FWD entry door is subject to schedule external and internal zonal inspections, which includes checking for evidence of degradation such as chafing of tubing, loose duct support, worn or loose linkage, wiring damage, cable and pulley wear, fluid leaks, inadequate drainage, and for other conditions which could lead to corrosion or other damage. The internal zonal inspection of the FWD entry door, however, requires the removal of the liner and internal panels for hinges, torque tube and handle box for an internal inspection.
- 1.18.1.5. According to the *Boeing 737-800 Maintenance Planning Document for Zonal Inspection Program*:
- *External Zonal* inspections of the entry doors should be carried out every 120 days; 2000 flying cycles/240 days; 3500 flying cycles/730 days; and 6600 flying cycles/36 months.
 - *Internal Zonal* inspections of the entry doors should be carried out every 36000 flying cycles/9 years.
- 1.18.1.6. According to the operator's logbooks, both the last external and internal zonal inspections on the FWD entry door were carried out on 3 August 2018. The inspection does not include inspecting the condition of the seals.



Table 3
737-600/700/800/900/900ER MAINTENANCE PLANNING DOCUMENT
ZONAL INSPECTION PROGRAM

MPD ITEM NUMBER	AMM REFERENCE	ZONE	ACCESS	INTERVAL		APPLICABILITY		MAN-HOURS	TASK DESCRIPTION
				THRESH	REPEAT	APL	ENG		
52-800-00	05-41-08-210	820 830 840	NOTE	120 DY	120 DY	ALL NOTE	ALL	0.10	ATA 52: DOORS EXTERNAL - ZONAL (GV): Entry Doors, Service Doors, Automatic Overwing Exits, Mid-Exit Doors, and Cargo Doors Perform an external zonal inspection (GV) of the doors. Inspection is accomplished from the ground, without the use of stands or ladders. No additional access panel is required. AIRPLANE NOTE: Mid-Exit Doors only on 900ER. ACCESS NOTE: Door closed.
53-864-00	05-41-02-210	221 222		6600 FC 36 MO NOTE	6600 FC 36 MO NOTE	ALL	ALL	0.50	EXTERNAL - ZONAL (GV): Passenger Compartment - Aft of Control Compartment to Fwd Entry Door Perform an external zonal inspection (GV) of the passenger compartment - aft of the control compartment to forward entry door - left and right - section 41, sta 259.5 to sta 360. INTERVAL NOTE: Whichever comes first.
52-810-01	05-41-08-210	831	831	3500 FC 730 DY NOTE	3500 FC 730 DY NOTE	ALL	ALL	0.03	EXTERNAL - ZONAL (GV): Forward Passenger Door Perform an external zonal inspection (GV) of the forward passenger door - section 41, sta 345. INTERVAL NOTE: Whichever comes first.

MPD ITEM NUMBER	AMM REFERENCE	ZONE	ACCESS	INTERVAL		APPLICABILITY		MAN-HOURS	TASK DESCRIPTION
				THRESH	REPEAT	APL	ENG		
53-870-00	05-41-02-210	221	831	2000 FC 240 DY NOTE	2000 FC 240 DY NOTE	ALL	ALL	0.17	EXTERNAL - ZONAL (GV): Forward Passenger Entry Door Stops, Latches and Hinges Perform an external zonal inspection (GV) of the forward passenger entry door stops, latches and hinges - section 41, sta 345. INTERVAL NOTE: Whichever comes first.
53-868-00	05-41-02-210	221 222	NOTE	36000 FC 9 YR NOTE	36000 FC 8 YR NOTE	ALL	ALL	1.50	INTERNAL - ZONAL (GV): Passenger Compartment - Aft of Control Compartment to Fwd Entry Door Perform an internal zonal inspection (GV) of the passenger compartment - aft of the control compartment to forward entry door - left and right - Section 41, Sta 270 to Sta 360. (EZAP) INTERVAL NOTE: Whichever comes first. The EZAP inspection requirement with interval 36000 FC/12 YR is satisfied by this zonal inspection. ACCESS NOTE: With access provided. Galleys and lavs removed. Floor panels, sidewall panels, and ceiling panels removal required.

1.18.2. Procedure When the CABIN ALTITUDE WARNING Activates

1.18.2.1. According to the Boeing 737 Flight Crew Operations Manual, the procedure to follow when the "CABIN ALTITUDE WARNING or Rapid Depressurisation" occurs is as follows:

Condition: When at least one of the following conditions occurs:

- A cabin altitude exceedance
- In flight, the intermittent cabin altitude/configuration warning horn sounds or a CABIN ALTITUDE light (if installed and operative) illuminates

- 1 Don oxygen masks and set regulators to 100%.
- 2 Establish crew communications.
- 3 Pressurisation mode selector MAN
- 4 Outflow VALVE switch Hold in CLOSE until the outflow VALVE indications show fully closed
- 5 **If cabin altitude is uncontrollable:**
 Passenger signs ON
 PASS OXYGEN switch ON
▶▶ Go to the Emergency Descent checklist

- 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.

1.18.3. Procedure When the AUTO FAIL Activates

1.18.3.1. According to the Boeing 737 Flight Crew Operations Manual, the procedure to follow when the "AUTO FAIL or Unscheduled Pressurisation Change" occurs is as follows:

Condition: When one or more of these occur:

- Automatic pressurisation mode has failed.
- The cabin altitude is uncontrollable.

Objective: Is to maintain control of cabin altitude

- 1 Increasing thrust may ensure enough air supply to control cabin altitude.
- 2 Pressurisation mode selector ALTN
- 3 Choose one:
 - ◆ AUTO FAIL light is **extinguished, and** cabin altitude is **controllable**:
Continue normal operation
■ ■ ■ ■
 - ◆ AUTO FAIL light is **illuminated, or** cabin altitude is **uncontrollable**:
▶▶ Go to step 4
- 4 Pressurisation mode selector MAN
- 5 Outflow VALVE switch Move to OPEN or CLOSE as needed to control cabin altitude and rate
- 6 Choose one:
 - ◆ Cabin altitude is **controllable**:
▶▶ Go to step 11
 - ◆ Cabin altitude is **uncontrollable**:
▶▶ Go to step 7
- 7 Don oxygen masks and set regulators to 100%.
- 8 Establish crew communications.
- 9 Passenger signs ON
- 10 PASS OXYGEN switch ON
- ▶▶ Go to the **Emergency Descent checklist**
■ ■ ■ ■
- 11 **Checklist Complete Except Deferred Items**

1.18.4. Similar Occurrences/Research

1.18.4.1. According to Boeing, there were 12 events between 1 January 2018 and 31 December 2019 where 737NG or 737MAX aircraft failed to pressurise during climb. 737NG/MAX aircraft operated approximately 18 million flights during that timeframe.

1.19. Useful or Effective Investigation Techniques

1.19.1. None.

2. ANALYSIS

2.1. General

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

2.2. Aircraft

2.2.1. The aircraft was issued a Certificate of Airworthiness on 29 April 2019 with an expiry date of 30 April 2020. The aircraft was also issued a Certificate of Registration (CoR) for the current owner since 1 August 2016.

2.2.2. The last maintenance inspection that was carried out on the aircraft prior to the serious incident flight was an A-check inspection on 18 November 2019 at 67 503.034 airframe hours. At the time of the serious incident, the aircraft had flown 142.68 hours. The A-check inspection does not cover inspection of the bleed air system and associated components.

2.2.3. Additional preventative maintenance tasks (health checks) on the bleed air system and associated components were performed during the last C-check carried out on 24 July 2018. The aircraft had accumulated approximately 3646 flying hours at the time of the serious incident, after the last C-check inspection.

2.2.4. Although both the last external and internal zonal inspections on the FWD entry door were carried out on 3 August 2018, this inspection does not require inspection of the condition of the doors' seal. This is because seals are 'on condition' items, which means that they are changed only when required (that is, when damaged or worn).

- 2.2.5. According to the workpack information, provided records of snags (faults) relating to the air conditioning and pressurisation systems on ZS-ZWT had been logged since 3 December 2019 (13 days) prior to the day of the cabin altitude serious incident flight on 16 December 2019.
- 2.2.6. According to the AMM, pressurisation requires proper operation of the pneumatic (engine bleed) system, the air conditioning packs and the cabin pressure control system. The pneumatic system supplies air to the air conditioning packs. The air conditioning packs regulate the air flow into the fuselage. The cabin pressure control system regulates air escaping from the fuselage to control cabin pressure. Air leaking from the fuselage must be within specified limits for the packs to operate efficiently. Unusual pressurisation occurrences are typically associated with low air inflow, high fuselage leakage, or a combination of the two.
- 2.2.7. Although correct fault isolation procedures were followed for troubleshooting the air conditioning and pressurisation systems, the faults found during the troubleshooting were pre-existing faults which were identified prior to the cabin altitude serious incident flight on 16 December 2019. Attempts to resolve all faults on ZS-ZWT prior to and after the serious incident had been unsuccessful despite carrying out correct fault isolation procedures during troubleshooting maintenance due to lack of availability of serviceable spares as indicated by robbing of components from other aircraft, in paragraph 1.16.1.7.
- 2.2.8. From the troubleshooting described in paragraph 1.16, the primary cause of the cabin pressurisation failure during climb on 16 December 2019 was likely due to a reduced air inflow from the No.2 engine's air conditioning pack, which was caused by failure of the air cycle machine. This was exacerbated by a high fuselage leakage through the forward entry door hinges, as a result, the aircraft's pressurisation system could not maintain a safe environment for the passengers and the cabin crew members.
- 2.2.9. According to Flight and Defect Folio records, from 27 December 2019 until 28 January 2020 the faults associated with the No.1 engine pack and TCV were still occurring and the aircraft had been dispatched IAW MEL 21-33B. This is an indication that troubleshooting maintenance was unsuccessful in resolving ZS-ZWT's air conditioning system failures.

2.3. Crew

- 2.3.1. The pilot-in-command (PIC) was initially issued an Air Transport Pilot Licence (ATPL) on 5 February 2009 with an expiry date of 29 February 2020. The PIC's last skills test was carried out on 27 January 2019. The PIC had flown a total 11071.5 hours on type and was issued a Class 1 aviation medical certificate on 20 November 2019 with an expiry date of 31 May 2020.
- 2.3.2. The first officer (FO) was initially issued an ATPL on 23 May 2010 with an expiry date of 30 April 2020. The FO's last skills test was carried out on 12 April 2019. The FO had flown a total 1881.2 hours on type and was issued a Class 1 aviation medical certificate on 3 June 2019 with an expiry date of 30 June 2020.

2.4. Flight Operations

- 2.4.1. During the climb-out phase from FAOR and while the aircraft was climbing to FL150, the "cabin alt" warning light illuminated, alerting the flight crew of the cabin pressurisation fault. According to the flight path and elevation profile diagram, the PIC stabilised the aircraft by making a descent to FL100 in accordance with the Non-Normal Checklist in the Quick Reference Handbook (QRH), while the FO carried out the CABING ALTITUDE WARNING checklist procedures to troubleshoot the snag. Oxygen masks were not deployed during the serious incident sequence.
- 2.4.2. It is likely that the flight crew's actions temporarily resolved the cabin altitude fault as the aircraft began to climb again, shown by the second peak on the flight path and elevation profile diagram. The profile shows the aircraft reaching FL130. It is most likely that the cabin altitude fault warning came on again. It is highly probable that the flight crew executed the AUTO FAIL checklist procedures and were not able to restore the aircraft's standard cabin pressure when the emergency was declared by broadcasting a PAN-PAN-PAN, followed by the second emergency descent to FL100. The crew requested clearance from ATC to allow them to execute an air-turn back to FAOR.

- 2.4.3. Although the flight crew executed the applicable QRH procedures to resolve the cabin altitude warning mentioned in paragraph 1.18.2/3 and operated the switch to close the outflow valve (OFV) by switching the pressurisation mode to Manual (MAN), the OFV was already in a fully closed position. The crew was unable to restore the aircraft's standard cabin pressure in all modes as a result of high fuselage leakage, as well as the loss of air inflow as identified by subsequent troubleshooting mentioned in paragraph 2.2.8.
- 2.4.4. The aircraft landed uneventfully on Runway 21R at FAOR and the passengers disembarked normally. There were no reported damages to the aircraft, as well as no injuries as a result of this serious incident.
- 2.4.5. The flight was conducted under IFR in daylight with fine weather conditions prevailing. The weather did not play a role in this serious incident.

2.5. Operator

- 2.5.1. The operator was issued an Air Operating Certificate (AOC) No. CAA/N067D on 30 April 2019 by the SACAA with an expiry date of 30 April 2020. The aircraft was duly authorised under the AOC in line with the provisions of Part 121 of the South African Civil Aviation Regulations 2011 as amended.
- 2.5.2. The aircraft maintenance organisation (AMO) which carried out the last maintenance inspection (A-check) prior to the serious incident flight was issued an approved AMO certificate number 0001 by the SACAA on 30 September 2019 with an expiry date of 31 October 2020 in line with the provisions of Part 145 of the South African Civil Aviation Regulations 2011 as amended.

3. CONCLUSION

3.1. Findings

3.1.1. Aircraft

- 3.1.1.1. The aircraft was certified, equipped and maintained in line with existing regulations and approved maintenance procedures.
- 3.1.1.2. The aircraft was issued a Certificate of Airworthiness (C of A) and was maintained in line with regulations.
- 3.1.1.3. Although the aircraft was release to service in accordance to the MEL which allows the aircraft to fly with only one operational air conditioning pack, the aircraft was airworthy when dispatched for the flight.
- 3.1.1.4. No data from the FDR or CVR was downloaded as it was considered not necessary for this investigation.
- 3.1.1.5. Malfunctions in the air conditioning and pressurisation systems that contributed to the failure of pressurisation of the cabin on 16 December 2019 were pre-existing issues that were recorded, however, not resolved.
- 3.1.1.6. There were no reported damages to the aircraft and none of the occupants sustained any injuries as a result of this serious incident.
- 3.1.1.7. Although the last maintenance inspection was carried out 142.68 hours prior to the serious incident flight, it did not include inspection of the bleed air system and associated components; therefore, the faults leading to the cabin altitude warning would not have been prevented by a scheduled maintenance.
- 3.1.1.8. The cabin pressurisation failure on 16 December 2019 was due to a reduced air inflow from the No.2 engine's air conditioning pack due to failure of the air cycle machine. This was exacerbated by a high fuselage leakage through the forward entry door hinges.

3.1.2. Crew

3.1.2.1. Both the PIC and the FO were appropriately licenced and qualified for the flight in accordance with ICAO and the provisions of Part 61 of the South African Civil Aviation Regulations 2011 as amended.

3.1.2.2. Both the PIC and FO were medically fit with valid medical certificates to operate the flight in line with the provisions of Part 67 of the South African Civil Aviation Regulations 2011 as amended.

3.1.2.3. The crew's actions indicated that their knowledge and understanding of the aircraft's air conditioning and pressurisation system was adequate.

3.1.3. Flight Operations

3.1.3.1. The flight was conducted in line with the procedures in the operator's operations manual.

3.1.3.2. The flight crew carried out normal radio communication with the relevant ATC at FAOR.

3.1.3.3. The PIC climbed to FL150 and FL130 before contacting the ATC at FAOR to declare an emergency.

3.1.3.4. Although the flight crew executed the applicable QRH procedures to resolve the cabin altitude warning, they were unable to restore the aircraft's standard cabin pressure as a result of high fuselage leakage as well as the loss of air inflow, which resulted in the crew deciding not to continue with the flight.

3.1.3.5. The flight was conducted under IFR in daylight with fine weather conditions prevailing. The weather did not play a role in this serious incident.

3.1.4. Operator

3.1.4.1. The operator had an AOC with ZS-ZWT duly authorised under the AOC in line with the provisions of Part 121 of the South African Civil Aviation Regulations 2011 as amended.

3.1.4.2. The AMO which carried out the last maintenance inspection on ZS-ZWT prior to the serious incident flight had an approved AMO certificate that was issued by the SACAA in line with the provisions of Part 145 of the South African Civil Aviation Regulations 2011 as amended.

3.2. Probable Cause/s

3.2.1. During the climb phase, the air cycle machine failed, causing reduced air inflow from engine number 2 air conditioning pack, which resulted in cabin pressurisation system being unable to maintain the required pressure level for a safe environment of the passengers and the crew members.

3.3. Contributory Factors

3.3.1. The lack of availability of serviceable spares contributed to the inability to rectify the previously identified faults in the aircraft air conditioning and pressurisation system prior to the serious incident.

3.3.2. High fuselage leakage on forward entry door hinges.

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 Recommendation/s

- 4.2.1 **Safety Message:** The operator and aircraft maintenance organisation to ensure that they have adequate spares required to support the operation of the aircraft. At times, the aircraft could remain in operation with defects in accordance with MEL limitations (which permits operating on only one air conditioning pack); reason cited was lack of spares.

5. APPENDICES

- 5.1. Appendix A – ZS-ZWT Troubleshooting Analysis.

This Report is issued by:

**Accident and Incident Investigations Division
South African Civil Aviation Authority
Republic of South Africa**

APPENDIX A ZS-ZWT Troubleshooting Analysis

FAULT DESCRIPTION	ACTION STEPS	CONTINUED FAULT DESCRIPTION	CONTINUED ACTION STEPS
<p>02 12 2019 SNAG RECURRING. TEMP CONTROLLERS STILL NOT WORKING PROPERLY (CAB TEMPERATURE WARMS WITH TRIM AIR IN OFF POSITION)</p>	<p>INFO NOTED RECOMMEND TO MCC</p>	<p>13 12 2019 R/H DUCT PRESS ONLY 16PSI & CABIN VERY HOT DURING T/O AND CLIMB.</p>	<p>PRECOOLER INSPECTION. FAN AIR INLET INSPECTED. NIL BLOCKAGE OR DAMAGE FOUND. BLEED AIR INLET FROM ENG INSPECTED. NIL BLOCKAGE OR DAMAGE FOUND. PRECOOLER ACCESS RESTORED. RECIRC FANS FILTERS REPLACED & AIRFLOW INSPECTED. ALL OPS NORMAL.</p>
<p>03 12 2019 DUCT SPLIT: L43/R21PSI CABIN AIR COND UNRESPONSIVE</p>	<p>DUCT SPLIT WITHIN LIMITS. MIN REQUIRED FOR OPS IS 15PSI. CREW TO PLEASE SUPPLY THE FIGURES ON ALL PHASES OF FLIGHT FOR T/SHOOTING PURPOSES. CHECKED ON GRND. OPS FOUND NORMAL.</p>	<p>14 12 2019 R/H DUCT PRESS ONLY 16PSI & AFT CABIN TEMP REMAINS HOT DURING T/O AND CLIMB.</p>	<p>TASK CARRIED OUT NIL FAULT FOUND. SNAG STILL PERSIST. FURTHER T/SHOOTING TO BE CARRIED OUT. L/H PACK STANDBY TCV REPLACED. WITH STANDBY TCV. TASK CARRIED OUT. SNAG STILL PERSISTS.</p>
<p>04 12 2019 COCKPIT TEMP CONTROL U/S</p>	<p>COCKPIT TEMP SENSOR CLEANED. TEST RAN ON #1 ZONE TEMP CONTROLLER-TEST PASSED FOR FURTHER REPORT. FILTER FOUND CLEAN AND NIL FAULT MESSAGES ON CONTROLLERS. SUSPECT TEMP SENSOR IN COCKPIT. MCC NOTIFIED TO T/SHOOT AND RECTIFY.</p>	<p>15 12 2019</p>	<p>THE FOLLOWING COMPONENTS INTERCHANGED ON # 2 ENG IN ELIMINATION OF BLEED DEFECT: BLEED AIR REGULATOR + HIGH STAGE VALVE + PRSOV. ALL SENSE LINES CHECKED AGAIN. NOSE COWL ANTI ICE VALVE CHECKED. PRECOOLER CHECKED FOR LEAKS. NIL LEAKS EVIDENT. NOTE: ALL COMPONENTS REFITTED IN ORIGINAL POSITIONS. SNAG PERSISTS.</p>
<p>05 12 2019 CONTROL CABIN DUCT SUPPLY BELOW 0 DEG C COCKPIT TEMP UNCONTROLABLE</p>	<p>A/C TO FLY IAW MEL. CAT C. PC 1&2 RESET. VARIOUS SETTINGS TRIED WITH FULL CONTROL ON FULL RANGE</p>		<p>INTERCHANGING HIGH STAGE VALVES NOT NECESSARY. PRECOOLER CONTROL VALVE SENSOR (390F) AND THERMOSTAT (450F) INTERCHANGED BETWEEN #1 AND #2 ENG. GROUND RUN CARRIED OUT. R/H DUCT PRESSURE SNAG FIXED. NIL LEAKS FOUND. GROUND RUN CARRIED OUT. NIL LEAKS FOUND. DUCT PRESSURES BACK TO NORMAL OPERATION.</p>
<p>06 12 2019 RECORD DUCT PRESSURE INFO: IDLE - 25 L/H 25 R/H. T/O - 26 L/H 22 R/H. CLMB - 28 L/H 15 R/H. CRZ - 38L/H 22 R/H. DSC - 27 L/H 27 R/H.</p>	<p>06 12 2019: INFO NOTED&FORWARDED TO MCC . D/A TO REMAIN OPEN. 08 12 2019: PRECOOLER CONTROL VALVE SENSOR REPLACED.</p>		<p>GROUND RUN CARRIED OUT. R/H DUCT PRESSURE SNAG FIXED. NIL LEAKS FOUND. GROUND RUN CARRIED OUT. NIL LEAKS FOUND. DUCT PRESSURES BACK TO NORMAL OPERATION.</p>
<p>08 12 2019 AIR COND PRECOOLER CONTROL SENSOR REPLACEMENT #2 ENG GROUND RUN</p>	<p>TEMP CONTROLLER REPLACED, PACKS OPERATED, ALL FOUND NORMAL. #2 ENG GROUND RUN CARRIED OUT. DUCT SPLIT LEAK EVIDENT BUT OK FOR FLIGHT. BAR TO BE REPLACED. PILOTS TO GIVE MORE REPORT ON ALL PHASES OF FLIGHT.</p>	<p>16 12 2019 CABIN ALTITUDE WARNING ON CLIMB OUT PASSING FL100.</p>	<p>T/SHOOTING REQUIRED. CABIN PRESSURIZATION CARRIED OUT. LEAK FOUND AROUND FWD ENTRY DOOR HINGES. INSPECTION CARRIED OUT & FOUND THAT UPPER & LOWER HINGE FILLERS MISSING. NEW FILLERS FITTED WITH SEALANT. FLAPPER SEALS CHANGED, BUT STILL LEAKING AROUND THE SAME PLACE. FWD ENTRY DOOR LINING REMOVED. PLS REFER STEP 4 FOR FURTHER ACTION. UPPER SEAL AND LOWER SEAL REPLACED.</p>
<p>09 12 2019 DUCT SPLIT LEAK #2 ENG. RIGHT PACK FAILED - CORRECTED WITH QRH ACTIONS.</p>	<p>10 12 2019 #2 PACK INOP. CABIN TEMP WILL BE DIFFICULT TO CONTROL DUE TO #2 PACK INOP.</p>		<p>FWD ENTRY DOOR LINING INSTALLED. OLD SEALANT REMOVED & SEALANT RE-APPLIED AT FILLER PLATES. AIRCRAFT PRESSURISED. NIL LEAKS EVIDENT AT DOOR HINGES.</p>
<p>11 12 2019 CONTINUE FAULT ISOLATION</p>	<p>RIGHT PACK TCV REPLACED. BLEED AIR REGULATOR REPLACED. BLEED TEST CARRIED OUT. TEST OK. BAR ON #2 ENG CHANGED. GROUND RUN CARRIED OUT. NO DUCT SPLIT LEAK EVIDENT. BLEED TEST CARRIED OUT AT 80% N1 WITH PACKS ON. DUCT 26PSI, SHOULD BE 34-50PSI. 450 DEG F THERMOSTAT REPLACED. #2 PACK TCV INOP. TCV DEACTIVATED. A/C DISPATCHED IAW MEL.</p>	<p>17 12 2019 REFIT DOOR LINING. SEALANT NOT CURING ON FILLER PLATES PRESSURIZATION.</p>	<p>PLEASE CARRY OUT ENG BLEED AIR SYSTEM HEALTH CHECK.</p>
		<p>18 12 2019</p>	<p>BLEED AIR HEALTH CHECK CARRIED OUT ON #1 AND #2 ENG.</p>

CONTINUED
FAULT DESCRIPTION ACTION STEPS

17 12 2019
 CUSTOMER REQUEST

BOTH L/H & R/H TCV CHANGED.
 GROUND RUN CARRIED OUT.
 SNAG STILL PERSISTS

18 12 2019

ENGs HEALTH CHECK.
 CUSTOMER REQUESTED TO CHANGE ACAU.
 INSPECT CONDITION AND PRESS CHECK
 SENSE LINES FROM BAR TO PRSOV ON #1 & #2
 ENGS DUE TO POSSIBLE DAMAGE DURING
 INTERCHANGING OF COMPONENTS BETWEEN
 ENGS.

#2 ENG BAR & FAN AIR VALVE ORDERED
 AOG.
 #1 ENG LEAKING.
 #1 ACAU CHANGED AS REQUESTED &
 INSTALLATION TEST CARRIED OUT.
 SENSE LINES CHECK ON #2 ENG FROM
 PRE-COOLER TO THERMOSTAT.
 NIL LEAKS EVIDENT.
 SENSE LINES TO THE BAR-PRSOV
 CHECKED ON #1 & #2 ENGS. NO
 DAMAGE FOUND.
 CLAMP REMOVE & FOUND THAT SEAL
 CRUSHED. NEW SEAL FITTED, SAME
 CLAMP RE-FITTED & SECURED.
 BLEED AIR SUPPLIED.
 NIL LEAKS EVIDENT.

19 12 2019

T/SHOOTING OF #2 ENG BAR. #2 ENG FAN AIR
 VALVE INFO RECORDED.
 THE FOLLOWING VALUES WERE RECORDED
 DURING A HIGH-POWER GROUND RUN.
 CONFIG: **BOTH PACKS AUTO, ISOLATION
 VALVE CLOSED, APU BLEED VALVE**

#2 ENG BAR FROM ZS-OAO INSTALLED
 FOR T/SHOOTING. DEFECT NOT
 RECTIFIED, PART TO BE RETURNED TO
 ORIGINAL ENG.
 #2 ENG BAR INSPECTION CARRIED OUT
 NIL DEFECTS FOUND.
 #2 ENG FAN AIR VALVE REMOVED FROM
 ZS-OAO INSTALLED ON ZS-ZWT FOR
 TROUBLE SHOOTING PURPOSE. DEFECT
 NOT RECTIFIED PART TO BE RETURNED
 TO ITS ORIGINAL ENG.
 #2 ENG BAR INSPECTION CARRIED OUT
 NIL DEFECTS FOUND.
 #2 ENG FAN AIR VALVE BUTTERFLY
 LOOSE.PLS CHANGE FAN AIR VALVE
 WHEN AVAIL.
 GROUND RUN CARRIED OUT DEFECTS
 PERSIST AT 80% N1 BOTH BLEEDS
 DROPS FROM 48PSI TO 18 PSI WITH
 PACTS ON AUTO FURTHER.
 ORIGINAL BLEED AIR REGULATOR &
 ORIGINAL FAN AIR VALVE REFITTED BACK
 ON TO #2 ENG
 ENG RESTORED TO NORMAL.
 BOTH #1 & #2 ENG 390 DEG F SENSORS &
 450 DEG F SENSORS VERIFIED AS
 CORRECT IAW IPC.
 STRUT PANELS RESTORED TO NORMAL.

20 12 2019

BLEED T/SHOOTING.
 CHANGE ACAU #2.

GROUND RUN CARRIED OUT & SNAG
 STILL PERSISTS.
 BOTH AIRCRAFT HIGH STAGE VALVES
 RETURNED TO ORIGINAL POSITIONS.

N1 VALUE	LEFT DUCT	RIGHT DUCT	PRESSURE (PSI)
IDLE	25	22	
30 %	26	25	
40%	27	27	
50%	27	27	
60%	35	35	
70%	21	21	
80%	16	16	
VALUE RECORDED FROM 80% TO IDLE			
80%	15	15	
70%	14	14	
60%	14	14	
50%	25	25	
40%	10	10	
30%	9	10	
IDLE	9	11	

CONTINUED
FAULT DESCRIPTION ACTION STEPS

21 12 2019
 CARRY OUT PRECOOLER CONTROL VALVE
 HEALTH CHECK AS PER BOEING E-MAIL

#1 & #2 ENG 390F SENSE LINES, FROM
 390F SENSOR TO FAN AIR CONTROL
 VALVE CHECKED FOR OBSTRUCTION.
 NIL OBSTRUCTION FOUND. SENSE LINES
 CHECKED FOR LEAKS & NIL LEAKS
 FOUND. SENSE LINES RE-SECURED.
 FAN AIR VALVE HEALTH CHECK CARRIED
 OUT ON #1 ENG. WITH REGULATED
 PRESSURE OF 75 PSI. CONTROL
 PRESSURE WAS 11 PSIG FOR PCCV AND
 PRECOOLER CONTROL PRESSURE WAS
 4 PSIG WHEN VALVE WAS FULLY
 OPENED. OPERATION NORMAL.
 FAN AIR VALVE HEALTH CHECK CARRIED
 OUT ON #2 ENG WITH REGULATED
 PRESSURE OF 75 PSI. CONTROL
 PRESSURE WAS 11 PSIG FOR PCCV &
 PRECOOLER CONTROL PRESSURE WAS
 0 PSIG WHEN VALVE WAS FULLY
 OPENED (LIMIT IS GREATER OR EQUAL
 TO 3 PSIG WHEN VALVE SHOULD BE
 OPEN OR 30 DEGREES FROM OPEN).
 THE VALVE FAILED.

FAN AIR CONTROL VALVE REMOVED.
 DUE NIL SPARES, FAN AIR CONTROL AIR
 VALVE ROBBED FROM ZS-OAO #1 ENG
 AND FITTED & SECURED. FAN AIR VALVE
 HEALTH CHECK CARRIED OUT ON #2
 ENG. WITH REGULATED PRESSURE OF
 75 PSI. CONTROL PRESSURE WAS 11
 PSIG FOR PCCV & PRECOOLER
 CONTROL PRESSURE WAS 0 PSIG WHEN
 VALVE WAS ONLY 45 DEGREES FROM
 OPEN (LIMIT IS GREATER OR EQUAL TO 3
 PSIG WHEN VALVE SHOULD BE OPEN
 OR 30 DEG FROM OPEN). THE VALVE
 FAILED.

VALVE REMOVED & RETURNED TO ZS-
 OAO.

22 12 2019

CARRY OUT GROUND RUN &
 CHECK BLEED OPERATION.

INSPECTED. NIL FAULT FOUND.

CONFIG: L/H PACK AUTO, R/H PACK OFF, ISOLATION VALVE CLOSED, APU BLEED CLOSED, BOTH ENGINE BLEED VLVs OPEN, N1 70%
 1545
 CONFIG: R/H PACK AUTO, L/H PACK AUTO, APU BLEED OFF, ISOLATION VALVE CLOSED, ENG BLEED VLV OPEN, N1 70%
 1515
 CONFIG L/H PACK AUTO, R/H PACK OFF, APU BLEED OFF, ISOLATION VALVE OPEN, L/H PLUS R/H ENGINE BLEED VALVES OPEN, N1 70%
 2525
 CONFIG: R/H PACK AUTO, L/H PACK OFF, ISOLATION VALVE OPEN, APU BLEED AIR CLOSED, L/H AND R/H ENGINE BLEED AIR VALVES ON
 N1 70%
 2525

CONTINUED

FAULT DESCRIPTION | ACTION STEPS

23 12 2019

#1 & #2 ENG_s DUCT PRESS STILL LOW WHEN PACKS ON & AT HIGH.
CHECK #1 ENG 450 F SENSOR TO PRSOV SENSE LINE FOR OBSTRUCTION & LEAKS.
CARRY OUT SINGLE PACK CONFIDENCE CHECK.
CARRY OUT ENG RUN ON COMPLETION OF THERMOSTAT INSTALLATION ON BOTH ENG_s & CHECK BLEED OPS.

GROUND RUN CARRIED OUT IAW AMM B737/25 GROUND RUN SHEET
DUCT PRESSURES RECORDED

N1%	IDLE	20%	30%	40%	50%	60%	70%	80%
LH ENG	26	26	26	27	27	36	45	44
RH ENG	24	24	26	27	27	36	45	44

#1 & #2 ENG_s PRECOOLER CONTROL VALVE REMOVED & INSTALLED.
#1 ENG 450 THERMOSTAT SENSOR REMOVED & INSTALLED.
#1 ENG PRECOOLER CONTROL VALVE CHANGED.
#1 ENG 450 THERMOSTAT SENSOR CHANGED.
GROUND RUN CARRIED OUT.
BLEED AND PACK OPERATION NOW NORMAL ON THE L/H SIDE.
SENSE LINE REMOVED FROM #2 ENG 450 DEG F SENSOR & AT PRSOV & AT BLEED AIR REGULATOR.
NIL OBSTRUCTION FOUND IN SENSE LINE.
SENSE LINE RESTORED TO NORMAL.
VALVE PRECOOLER CONTROL INSPECTED NIL DEFECTS EVIDENT.

CABIN LEAKAGE RATE FROM 4.0 TO 2.5 PSI FOUND TO BE WITHIN LIMITS 120-130 (SECONDS IS OPTIMUM: A/C WILL MAINTAIN PRESSURE IN FLIGHT EVEN WITH SLIGHTLY DEGRADED INFLOW.)

Parts Removed: VALVE-ZONE TEMP CONTROL, AIRCON ACCESSORY UNIT-ACAU.

GRND RUN PERFORMED BLEED OPS NORMAL.
ENG BLEED AIR CROSOVER APS TEST C/O. NIL LEAKS EVIDENT.
ALL OPS NORMAL. INSPECTED NIL DEFECTS EVIDENT.

END OF REPORT