Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT
Aviation Occurrence Investigation AO-2007-062
Final

Depressurisation event 246 km south-west of Coolangatta, Queensland
17 November 2007
VH-VBC
Boeing Company 737-7Q8

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Abstract

On 17 November 2007 a Boeing Company 737-7Q8 aircraft, registered VH-VBC, with two flight crew, four cabin crew and 145 passengers was being operated on a scheduled passenger service from Coolangatta, Queensland to Melbourne, Victoria. During the takeoff, the Master Caution system activated and the right BLEED TRIP OFF light illuminated. The pilot in command, who was the pilot flying, elected to continue the takeoff. Once airborne the Bleed Trip Off non-normal checklist was actioned. The right engine bleed could not be reset with the effect that, when above flight level (FL) 170 (17,000 ft above mean sea level), only the left engine bleed air was available for airconditioning and cabin pressurisation.

At FL318 during the climb, the flight crew observed the left PACK TRIP OFF light illuminate, followed by a rapid loss in cabin pressure and the cabin rate of climb indicator showing a rate of climb of about 2,000 ft/min. The crew fitted their emergency oxygen masks, commenced the Emergency Descent checklist and began a rapid descent to 10,000 ft. During the descent, the cabin altitude exceeded 14,000 ft, at which time the passenger oxygen masks deployed automatically. The aircraft was diverted to Brisbane for landing. There were no reported injuries to passengers or crew and no damage to the aircraft.

The investigation found that a combination of technical faults contributed to the loss of pressurisation and identified a number of other safety factors relating to operational procedures and cabin crew knowledge of the passenger oxygen system.

The operator conducted an internal investigation of the incident and carried out a number of safety actions as a result. Those actions included the enhancement of a number of the operator's manuals and the amendment of the operator's cabin safety recurrent training. In addition, the operator's passenger oxygen use in-cabin brief was enhanced to include advice that oxygen would flow to passengers' masks even if the associated bag was not inflated.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, risk controls and organisational influences.

Contributing safety factor: a safety factor that, if it had not occurred or existed at the relevant time, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

Other safety factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report.

Other key finding: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Risk level: The ATSB's assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level as it existed at the time of the occurrence. That risk level may subsequently have been reduced as a result of safety actions taken by individuals or organisations during the course of an investigation.

Safety issues are broadly classified in terms of their level of risk as follows:

- **Critical** safety issue: associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.
- **Significant** safety issue: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.
- **Minor** safety issue: associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

Safety action: the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

FACTUAL INFORMATION

Sequence of events

On 17 November 2007 a Boeing Company 737-7Q8 aircraft, registered VH-VBC, with two flight crew, four cabin crew and 145 passengers was being operated on a scheduled passenger service from Coolangatta, Queensland to Melbourne, Victoria. Take-off performance considerations required the aircraft's pneumatic system to be configured for a 'No Engine Bleed Takeoff'.[1] That configuration was set just prior to runway line up (see Appendix A).

At 1952 Eastern Standard Time[2], shortly after take-off thrust was set and at a recorded ground speed of 27 kts, the Master Caution system activated and the right 'BLEED TRIP OFF' amber light illuminated. The copilot called out the fault and the pilot in command, who was the pilot flying (PF), elected to continue the takeoff.

Once the aircraft was airborne, the pilot in command's attention was momentarily drawn to resolving the bleed trip off. At 900 ft above ground level (AGL), the autopilot was engaged, the trip reset switch was pushed and the Bleed Trip Off non-normal checklist was then actioned (Appendix B). However, the right engine bleed could not be reset. The flight crew then reconfigured the airconditioning and pressurisation system, selecting the left engine bleed air ON, leaving the right engine bleed air OFF and the isolation valve in the CLOSE position. The use of the auxiliary power unit (APU) air was limited to flight level (FL) 170 and below,[3] so the APU air was selected to OFF, the APU was shut down and the After Takeoff checklist was then carried out. As the right engine bleed could not be reset, only the left engine bleed air system was available for airconditioning and pressurisation once above FL170.

During the climb, one of the cabin crew informed the flight crew that the temperature in the cabin was uncomfortably high. In response, the copilot adjusted the cabin temperature controller to a cooler setting while setting a higher temperature for the flight deck. The flight crew chose to continue to Melbourne at FL250, which was lower than the flight-planned cruise level. At 2009, the flight crew observed that they had entered icing conditions and decided to climb to FL350 to exit and then avoid those conditions. Recorded information indicated that neither the engine nor wing anti-icing was activated by the flight crew during the climb, or during the subsequent rapid descent.

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1 During a normal 'bleeds on' takeoff, bleed air is drawn from both engines in order to supply the airconditioning and pressurisation system. That would reduce the available thrust which, in turn, would have a bearing on the maximum weight that could be lifted. If aircraft weight, the ambient conditions and/or a limiting runway were such that the maximum available thrust was insufficient to achieve the required take-off performance, the flight crew could configure the aircraft for an engine 'bleeds off' takeoff.

2 The 24-hour clock is used in this report to describe the local time of day, Eastern Standard Time (EST), as particular events occurred. Eastern Standard Time was Coordinated Universal Time (UTC) + 10 hours.

3 Level of constant atmospheric pressure related to the datum of 1013.25 hPa, expressed in hundreds of feet. FL170 equated to 17,000 ft above mean sea level (AMSL).

At 2013, while passing FL318, the flight crew observed the left PACK TRIP OFF light illuminate and a rapid loss in cabin pressure. They reported that the cabin rate of climb indicator showed an initial rate of climb of about 2,000 ft/min and then stabilised at about 1,500 ft/min. The crew fitted their oxygen masks and commenced a rapid descent to 10,000 ft.

As the cabin crew were preparing for the cabin service, the cabin supervisor, who was standing in the forward galley, noticed that the aircraft had commenced a descent and became aware of unusual noises from the flight deck.[4] She immediately directed the other cabin crew members to stow the cabin service carts, the stowage for which was at the rear galley.

Shortly after reaching the rear galley with their service carts, the cabin crew observed the seat belt sign illuminate. In response, they immediately stowed the carts and other loose items. At 2014, the pilot in command informed one of the cabin staff via intercom that the cabin crew should stow the service carts and proceed to their stations, stating that there was a problem but not explaining further. The pilot in command reported that, at that time, the cabin altitude[5] was around 11,000 ft and so he elected to postpone the emergency descent announcement to the cabin in anticipation of descending below 14,000 ft before the cabin altitude reached that level. (Passenger oxygen masks are set to deploy automatically if the cabin altitude reaches 14,000 ft.)

At 2018, when the aircraft was descending through FL143, the cabin altitude exceeded 14,000 ft, at which time the passenger oxygen masks automatically deployed as specified. The flight crew then reviewed the Rapid Depressurisation checklist.

All four cabin crew were at the rear of the aircraft cabin and, in accordance with company procedures, immediately fitted the nearest oxygen mask and secured themselves in the nearest seat. The closest available seats were the four cabin crew jump seats at the rear of the cabin. One cabin crew member then instructed the passengers via the public address system to fit their oxygen masks. Two of the cabin staff, one either side of the aircraft, were unable to confirm oxygen flow to their individual masks and, believing them to be unserviceable, moved to and used the oxygen masks in the aircraft lavatories that were adjacent to the crew jump seats. While activating the oxygen masks in the lavatory, one of the cabin crew pulled one of the two available masks and its tubing away from the oxygen generator, rendering the mask unserviceable. The second mask was activated successfully.

By 2020, the aircraft was established at 10,000 ft but the flight crew noticed that the cabin altitude was at 11,000 ft. Air Traffic Control clearance was requested and given for an additional descent to 8,000 ft. Once established at that altitude, the pilot in command used the public address system to inform the cabin crew and passengers that the aircraft was at a safe altitude and that the cabin crew should resume their duties. Published cabin crew follow-up actions were then carried out, including checking on fellow crew members and passengers.

[4] Those noises were believed to be the sounds of the flight crew donning their oxygen masks.

[5] Cabin altitude describes the air pressure within the aircraft cabin by reference to the altitude at which the external air pressure would be the same as the pressure inside the cabin.

The flight crew conducted the Pack Trip Off non-normal checklist and was able to reset the left airconditioning pack and right bleed air system, rendering both airconditioning packs operational and the aircraft pressurised. The flight crew decided to divert to Brisbane, which was accomplished without further incident. It was reported that some of the passengers suffered discomfort but there were no reported injuries to passengers or crew and no damage to the aircraft.

After the flight, the cabin crew were stood down from further duties. The flight crew stated that their initial intention was to stand down but, due to the unavailability of a substitute crew, they chose to operate a replacement aircraft to Melbourne later that evening. That decision was made after consultation with their Senior Line Operations Manager; the crew stating that they were fit to operate the flight.

Personnel information

Flight crew

Records from the operator indicated that the crew were properly licensed and qualified for the flight. The pilot in command and copilot completed proficiency checks in the aircraft simulator 5 and 7 weeks prior to the incident respectively. During those checks, both pilots practised an emergency descent as a result of an airconditioning malfunction.

Table 1: Flight crew experience

	Pilot in command	Copilot
Type of licence	Air Transport Pilot (Aeroplane) Licence	Air Transport Pilot (Aeroplane) Licence
Medical certificate	Class 1	Class 1
Total flying experience	13,000 flying hours	3,400 flying hours
Experience on type	3,500 flying hours	500 flying hours
Hours in the preceding 30 days	50	67
Hours free of duty prior to commencing work period	18	18
Last proficiency check	13 October 2007	30 September 2007
Crew Resource management training	16 August 2007	4 April 2007

The pilots were flying the last sector of a 4-day roster away from their home base of Melbourne. Both pilots reported that they were adequately rested and medically fit for the flight. The operator provided the Australian Transport Safety Bureau (ATSB) with the flight and duty time records for both pilots and the results of a fatigue analysis program that was used by the operator to assess any roster-related fatigue levels of the flight crew. The operator's analysis determined that roster-related fatigue was not an issue.

Cabin crew

There were four cabin crew members on the aircraft, including the cabin supervisor. Their experience levels with the operator ranged from about 18 months to 4 years. All of the cabin crew were current in respect of their emergency procedures training requirements.

Aircraft information

Aircraft systems information

The aircraft was equipped with two independent, pneumatically-powered airconditioning packs to provide conditioned air to the flight deck and passenger cabin for comfort and pressurisation. The pressurisation system was designed to maintain the cabin altitude at a safe level for the passengers and crew. A single pack was capable of maintaining pressurisation and acceptable temperatures throughout the aircraft up to the maximum certified ceiling of 41,000 ft (FL410). The cabin altitude was normally rate controlled by the cabin pressure controller up to a cabin altitude of 8,000 ft at the aircraft's maximum certified ceiling.[6] If a situation occurred, as in this event, where suddenly neither pack was operating, the residual cabin pressure would leak at a rate that was reliant on a number of aspects; such as the serviceability of the cabin door seals.

The left airconditioning pack processed bleed air from the left engine and the right pack bleed air from the right engine. Two-pack operation from a single bleed air source was not recommended by the manufacturer due to excessive bleed air requirements. In flight, the Auxiliary Power Unit (APU)[7] could also be used to supply air to one airconditioning pack at altitudes up to 17,000 ft.

Bleed air, which was obtained from the respective engine's compressor section, was directed through the engine bleed air valve into the main pneumatic duct (Figure 1). The engine bleed air valve, which acted as a pressure regulator and shutoff valve (PRSOV), maintained proper system operating pressure and reduced bleed air outflow in response to high bleed air temperatures. The valve would close automatically and independent of the bleed air switch position, when the engine bleed air temperature or pressure exceeded a predetermined limit. If that occurred, the BLEED TRIP OFF light on the pilots' overhead panel would illuminate.

Left and right bleed air duct pressures were displayed by left and right pointers on the bleed air duct pressure indicator that was located on the pilots' overhead panel. Under normal conditions, the left and right pressures would indicate a similar value. Pilots were requested to report any significant variation between the two duct pressures, as a difference of greater than 15 psi between systems was an indication that maintenance action may have been required.

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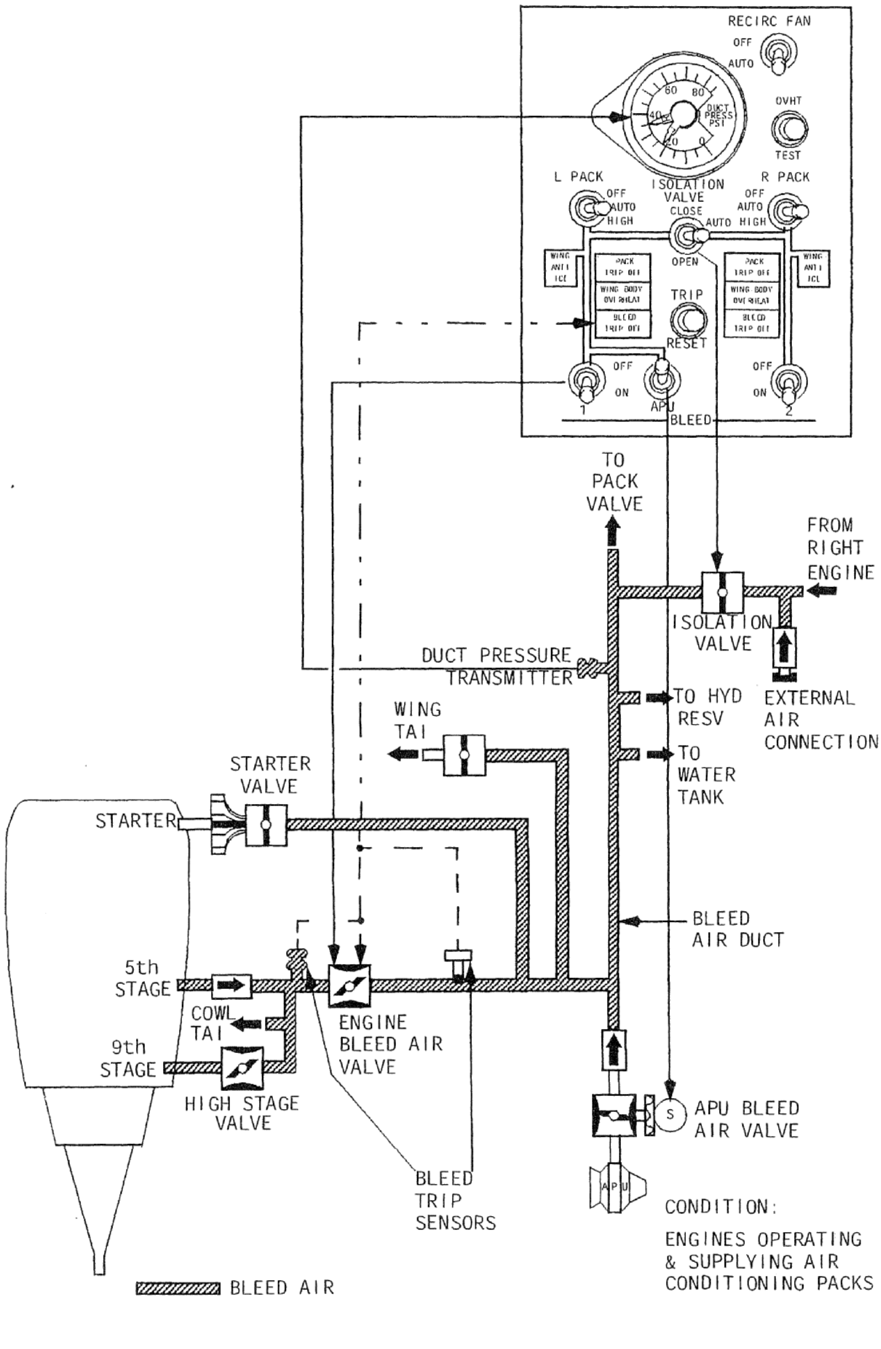
6 That was, if operating at 41,000 ft, in normal circumstances, the aircraft's cabin altitude would not exceed 8,000 ft.

7 The APU was a small turbine engine mounted in the tail of the Boeing 737 that provided auxiliary alternating current (AC) power and bleed air for engine starting or airconditioning. In-flight starts of the APU were able to be attempted at any altitude. APU bleed air was available for airconditioning up to 17,000 ft.

Figure 1: Bleed air system schematic



Anti-ice system

The wing anti-ice system used bleed air from the main pneumatic manifold to ensure an air supply when one bleed air source was not available; such as during one engine inoperative flight. If icing conditions were anticipated, the Isolation Valve switch was required to be selected to AUTO to prevent the asymmetric application of wing anti-ice. There was no engine performance degradation for that configuration, until wing anti-ice was actually used.

Unlike the wing anti-ice system, the engine anti-ice system heated the engine's cowl via a separate bleed air from the associated engine in order to prevent ice buildup, which could break off and enter the affected engine. Engine anti-ice, and therefore bleed air was used continuously in icing conditions.

Passenger oxygen system

The passenger oxygen system was supplied by individual chemical oxygen generators that were located at each overhead Passenger Service Unit (PSU). Four continuous flow masks were connected to each generator.

A generator supplying two masks was located in the ceiling above each attendant station and in each lavatory.

The oxygen masks automatically dropped from the PSUs if the cabin altitude exceeded approximately 14,000 feet. They could also be deployed from the flight deck.

A PSU's oxygen generators were activated (oxygen flowed) when any mask in the affected unit was pulled down. Pulling one mask in a PSU 'set' down caused all masks in that unit to deploy, and 100% oxygen to flow to all masks. A green, in-line flow indicator was visible in the transparent oxygen hose whenever oxygen was flowing to the mask. Oxygen would flow for approximately 12 minutes, and could not be shut off.

The operator's *Operations Manual (Part B) Volume B3: Crew- Safety Equipment and Procedures*, stated:

> There may be a burning smell when the masks drop. Passengers and crew may not feel the flow of oxygen through the mask and should check the green flow indicator in the tubing as the primary check of whether oxygen is flowing or not.

While documented procedures directed the crew to sight the flow indicator to verify oxygen flow, those procedures did not highlight the fact that the oxygen mask reservoir bag did not inflate. Additionally, the documented procedures did not highlight to the crew that pulling on the tubing would not activate the oxygen flow to the mask, but would cause the mask to be disconnected from the PSU and become inoperable.

The operator experienced a depressurisation incident on 9 November 2005 that indicated a number of possible deficiencies in cabin crew training. The operator's investigation into that occurrence found that some cabin crew were not aware of; the likelihood of a burning smell when the oxygen units were activated, the amount of force needed to activate the system, the differences in the aircraft's masks and those used during demonstration, and the inability of some passengers to determine whether the oxygen was flowing.

Maintenance history

Right bleed air system

Two days prior to the incident, a flight crew operating the aircraft recorded a split (difference) in bleed air duct pressures of up to 17 psi during the climb, and little or no split during the cruise and descent. The lesser bleed air duct pressure was the right duct, with indications as low as 28 psi during the climb. There were no other pneumatic system anomalies reported. Maintenance staff noted the duct pressure split and requested subsequent flight crews to complete a Duct Split Record Sheet. The anomaly was recorded as 'not a defect' and noted for attention at the overnight stop.

The next day (the day before the incident) a flight crew operating the aircraft recorded a maximum split of 18 psi but no record was taken of the pressures in the climb or cruise. The split was noted by maintenance staff and the Duct Split Record Sheet was forwarded to Maintenance Watch.

On the day of the incident, the flight crew operating the preceding flight recorded a maximum split of 14 psi and that the right bleed duct pressure was as low as 30 psi in the climb. Maintenance staff noted the duct split information and recorded it as serviceable.

Flight crew were required to record any duct pressure splits greater than 15 psi because differences of that magnitude could be an indication of the 'drifting performance'[8] of a bleed air system. Although splits greater than 15 psi were not defined as an unserviceability, the aircraft manufacturer recommended that action should be taken to investigate and restore bleed system performance to normal operation at a convenient opportunity when manpower and equipment was available. The minimum serviceable duct pressure was defined by the aircraft manufacturer as 18 psi.

Following the depressurisation incident, the operator's maintenance organisation conducted a right bleed air system health check, including a functional check of the bleed air system components. That check revealed that the high-stage valve was leaking and it was replaced. The high-stage regulator and the PRSOV also failed the health check, were deemed unserviceable, and were replaced.

Left airconditioning system

On the day of the incident, the preceding flight crew reported that the left airconditioning system's ram door was open during cruise. The ram air system provided cooling for the heat exchangers in the airconditioning system and operated automatically. When on the ground, or during slow flight with the flaps not fully retracted, the ram door would move to the full open position for maximum cooling. The RAM DOOR FULL OPEN light on the pilots' overhead panel would illuminate whenever the ram door was fully open. In normal cruise, the ram door modulated between open and closed. The initial assessment by engineers during the time available between flights concluded that the cause was a faulty ram air door actuator, and the aircraft was dispatched with the door locked in the open position in accordance with the aircraft's Minimum Equipment List (MEL) (see *Minimum equipment list* discussion on page 20).

Following the depressurisation incident, the operator's maintenance organisation discovered a split in the flexible hose between the heat exchanger inlet duct and the heat exchanger body. Information from the aircraft manufacturer indicated that the split in the flexible hose resulted in a reduced airflow over the heat exchangers,

8 That was, the performance of the bleed air system was less than optimal and on a downward trend, but was still a functioning system.

causing the left airconditioning pack to overwork, and eventually for the left pack to trip due to the turbine inlet temperature exceeding limits. That occurred at an altitude that was less than the aircraft was certified capable of operating at on a single airconditioning pack.

Flight recorders

The aircraft was fitted with a flight data recorder (FDR) and a cockpit voice recorder (CVR). The ATSB analysed the data from both recorders as part of the investigation.

Operational procedures

Operations manual structure

In accordance with Civil Aviation Regulation (CAR) 215, the operator provided an Operations Manual for the use and guidance of operational personnel. The Operations Manual consisted of a number of parts, including:

- *The Boeing 737 Operations Manual Volumes 1 and 2*
- *The Boeing Flight Crew Training Manual (FCTM)*
- *The Boeing 737 Quick Reference Handbook (QRH)*
- the *Operations Manual (Part A) Volume A1, Operating Policy and Procedures – General*
- the *Operations Manual (Part B) Volume B3, Crew – Safety Equipment and Procedures.*

Rejected takeoff

The operator's QRH, which was designed primarily as a cockpit aid, contained the following advice regarding rejected takeoffs:

> The captain has the sole responsibility for the decision to reject the takeoff.
>
> The decision must be made in time to start the rejected takeoff maneuver by V1.
>
> Prior to 80 knots, the takeoff should[9] be rejected for a system failure or activation of the master caution system.

and that:

> The captain must assess the situation and use good judgement to determine the safest course of action.

9 The word *should* was defined by the operator as a company recommended procedure.

Non-normal procedures

The QRH Checklist Introduction advised crews on the use of Non-Normal Checklists (NNC), stating (in part):

> Checklists can have both recall and reference items. Recall items are critical steps that must be done from memory and are placed within a box. Reference items are actions to be done while reading the checklist.

and that:

> Non-normal checklists assume system controls are in the normal configuration for the phase of flight before the start of the NNC.
>
> Non-normal checklist use starts when the airplane flight path and configuration are correctly established. Only a few situations need an immediate response. Usually, time is available to assess the situation before corrective action is started. All actions must then be coordinated under the captain's supervision and done in a deliberate, systematic manner. Flight path control must never be compromised.
>
> Following completion of the applicable non-normal checklist items, normal checklists are used to verify that the configuration is correct for each phase of flight.
>
> The pilot flying may also direct reference procedures to be done by recall if no hazard is created by such action, or if the situation does not allow reference to a checklist.

The NNC for Bleed Trip Off (see Appendix B) consisted of reference items only.

Warning systems

The *Operations Manual Volume 2* contained information on the Boeing 737 aircraft systems. The chapter on Warning Systems described the aural, tactile and visual warning signals that alerted a flight crew to the conditions requiring action, or described the cautions in the operation of the aircraft. The introduction to that volume stated:

> Conditions which require the immediate attention of the flight crew are indicated by red warning lights.
>
> Conditions which require the timely attention of the flight crew are indicated by amber caution lights.

If a caution condition existed, the appropriate system annunciator(s) and Master Caution lights would illuminate in amber.

Anti-ice operation in flight

The *Operations Manual Volume 1* contained information on flight crew procedures, including guidance on the in-flight operation of engine anti-ice. It stated that engine anti-ice must be ON during all flight operations when icing conditions existed or were anticipated; except during the climb and cruise when the temperature was below -40°C SAT (static air temperature). Engine anti-ice was required to be ON before and during descent in all icing conditions, including at temperatures below -40° C SAT.

Supplementary procedures

Supplementary Procedures included procedures that were accomplished as required rather than routinely performed on each flight. The *Operations Manual Volume 1*, which was normally stored in the aircraft's library, outlined the supplementary procedure for a No Engine Bleeds Takeoff and Landing (reproduced in Appendix A). The introduction to that chapter stated:

> At the discretion of the Captain, procedures may be performed by recall, by reviewing the procedure prior to accomplishment, or by reference to the procedure during its accomplishment.

Further advice in respect of the procedure for a No Engine Bleed takeoff was available in the Flight Crew Training Manual (FCTM.) The section in the FCTM on Non Normal Operations – Air Systems, stated, in part that:

> Additionally, when doing a no engine bleed takeoff, reference to the No Engine Bleed takeoff supplementary procedure, in conjunction with good crew coordination, reduces the possibility of crew errors.

Rapid depressurisation/emergency descent

The NNC to be followed by crews in the event of a Cabin Altitude Warning or Rapid Depressurisation was provided in the operator's QRH. That checklist (see Appendix C) described the condition as 'a rapid loss of cabin pressure with the airplane altitude above 14,000 feet'.

Also provided in the QRH was the Emergency Descent checklist (see Appendix D). That checklist described the condition as being 'unable to control cabin pressure with [the] airplane above 14,000 ft MSL or [in] conditions [that] require a rapid descent'.

Further advice on the basic techniques and procedures for application in the case of a rapid descent was available in the 'Maneuvres' chapter of the FCTM, which essentially described the emergency descent checklist.

Flight crew comments

The pilot in command advised that his understanding of the operator's procedures was that NNCs took priority over all normal and supplementary normal checklists. That was, once a NNC was carried out, the affected system switches should remain as configured on completion of that NNC. For that reason, the crew left the isolation valve switch in the CLOSE position, instead of placing it to AUTO. He believed that was the safe option. The right bleed switch was left in the OFF position, as the bleed valve had automatically closed due to the earlier bleed trip off.

The pilot in command also stated that when the left pack tripped off, being aware of the immediate consequences for the cabin pressurisation system, his immediate focus was on descending the aircraft to a safe altitude; rather than attempting to reset the tripped pack, or undertaking other troubleshooting measures. To achieve that, he decided to carry out a rapid descent commensurate with the moderate rate of depressurisation that was being experienced, rather than an emergency descent. The pilot in command also indicated that omitting to use the engine anti-ice system as per Standard Operating Procedures (SOP's) was an oversight.

Flight crew training

As a CAR 217-approved training organisation, the operator provided training and checking to ensure that operating crews maintained competency and operated in accordance with the required standards. Simulator sessions exposed crews to normal, abnormal, and emergency procedures that might be expected during line operations. In addition to evaluating crews' procedural knowledge and technical and manipulative abilities, simulator sessions also evaluated crews' situation management and crew coordination.

The operator's B737 Fleet Standards Manager commented that simulator sessions reflected the philosophy stated in the QRH; that NNC use should start once the aircraft's flight path and configuration were correctly established. A Master Caution would have advised the crew of an abnormal condition, or a fault that required crew attention but not immediate action.

If a Master Caution was generated after 80 kts during the takeoff, the manager indicated that the preferred practice was for crews to recall the Master Caution at a more appropriate time. A crew would be expected to concentrate on the takeoff and, once the aircraft was positively airborne; to retract the landing gear, climb to the acceleration altitude, retract the flaps and establish the aircraft at a safe height (preferably above the minimum safe altitude (MSA)). The PF would then request a recall of the Master Caution and for any relevant checklists to be actioned by the pilot monitoring.

History of Bleed Trip Off light illumination during a No Engine Bleed takeoff

In 1995 the aircraft manufacturer issued an FCOM Bulletin for the 737-300/400/500 series aircraft after several operators reported that during a No Engine Bleed Takeoff the BLEED TRIP OFF light illuminated. The bulletin highlighted that the illumination of the trip off light occurred because a relief valve, which was specifically built into the aircraft's pneumatic system to limit the duct pressure upstream of the bleed valve during a No Engine Bleed Takeoff, did not have enough flow capacity to limit the pressure in the duct to below the overpressure switch activation point. Activation of the overpressure switch caused the BLEED TRIP OFF light to illuminate.

The aircraft manufacturer advised that the bleed system could be reset if the duct pressure fell below the overpressure switch point. Furthermore, the duct pressure could be reduced by selecting the engine anti-ice ON. The bulletin suggested that the procedure should be carried out at a minimum height of 1,500 feet AGL, or when obstacle clearance height had been attained. That was to maintain consistency with the existing Operations Manual Supplementary Normal No Engine Bleed Takeoff and Landing procedure, and to minimise crew work load during the initial take-off phase of flight.

The manufacturer issued the bulletin as an interim procedure while awaiting the replacement of the relief valve with a new, higher capacity valve. Operators were given the choice of incorporating the new valve, or retaining the old valve and incorporating the bulletin in the operations manual.

The manufacturer did not re-issue the bulletin for the 737 NG[10], because there was no record to indicate to the manufacturer that it was a wide spread problem. The 737 NG incorporated a new relief valve to significantly reduce the probability of an occurrence. The high-stage relief valve capacity was increased to help keep the pressure build up below the bleed trip limit during a no-bleeds takeoff. However, if the high-stage valve sustained a significant leak, the problem could still occur.

The duct pressure reduction procedure could be used on 737 NGs to relieve the pressure and allow the bleed valves to open and the manufacturer advised of the provision to another operator of a 'No Technical Objection' approval for the use of the procedure in that operator's 737 NGs.

Minimum equipment list

Because of the various levels of redundancy in modern aircraft, under certain conditions, an acceptable level of safety could be maintained with specific items of equipment inoperative for a limited period of time until repairs could be carried out. In such cases, Civil Aviation Safety Authority (CASA) approved a schedule of permissible unserviceabilities for an aircraft, in the form of a Minimum Equipment List (MEL). An aircraft's MEL specified equipment that was considered able to be inoperative or unavailable without affecting the safety of the aircraft.

An approved MEL allowed for the operation of a specific aircraft under specific conditions with a particular item(s) of equipment inoperative at the time of dispatch for the intended flight. The affected aircraft, however, still complied with its type design standards. Included in the MEL were details of any mandatory maintenance procedures or operating restrictions. In respect of the incident aircraft, the operator's MEL stated that, in regard to airconditioning, one airconditioning pack may be inoperative, provided that the flight altitude remained at or below FL250.

An MEL was used during the preparation for a flight to assist in dispatch decisions where the affected aircraft had an unserviceability. Use of the MEL was not applicable to an unserviceability or a malfunction that occurred or was discovered during flight. Once an aircraft was either pushed back, towed from the blocks, or started to move under its own power for the purpose of flight, the flight crew would handle any equipment failure in accordance with the aircraft's QRH.

Equipment unserviceability occasionally occurred between the time an aircraft taxied and the time it took off. If the approved flight manual contained procedures for handling such an unserviceability, or if the pilot in command considered that the unserviceability did not affect the safety of flight, the flight could continue. In those circumstances, when workload permitted, the crew could consult the MEL to determine whether any operational limitations or maintenance procedures indicated that a return for maintenance action or replanning may have been prudent. In any case, the unserviceability had to be addressed prior to the next flight.

Reporting of occurrences

The operator's *Operations Manual (Part A) Volume A1: Operating Policy and Procedures – General*, contained information in respect of the management of accidents and incidents. That included flight crews passing the details of any

[10] VH-VBC was an NG or 'Next Generation' variant of the Boeing 737.

occurrences to the operator’s Operations Control Centre (OCC) staff who, depending on the nature of the occurrence, took further action.

In this occurrence, and based on the information available at that time, the OCC decided that no further safety assessment was required. The incident was, however, an Immediately Reportable Matter (IRM) as defined in the *Transport Safety Investigation Act 2003* and *Regulations*, [11] and should have been notified to the operator’s safety department on-call representative by the OCC for further evaluation, before being on forwarded to the ATSB.

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11 Relevant content and requirements reproduced in the Aeronautical Information Publication (AIP) for information and ease of access to flight crew.

ANALYSIS

Introduction

The aircraft depressurised during climb through Flight Level (FL) 318 because the sole source of pressurisation air at the time, the left airconditioning pack, became inoperative. This analysis examines the series of events leading up to the depressurisation and discusses a number of other safety factors that were identified during the investigation.

Depressurisation event

The leak from the closed high-stage valve in the right bleed air system resulted in a duct pressure increase that triggered the overpressure switch in the high-stage regulator, leading to the bleed trip off. The enduring nature of the overpressure condition meant that the crew's attempts to reset the right bleed air system were unsuccessful. The effect was that only the left airconditioning pack was available for the subsequent climb.

The left airconditioning pack tripped off as a result of the reduced cooling airflow over the heat exchanger. The reduction in airflow was the result of a damaged flexible inlet hose, and occurred despite the ram air door having been locked open by the maintenance engineers.

The aircraft was certified capable of operating up to a maximum ceiling of FL410 on a single airconditioning pack. The bleed trip occurred post dispatch, meaning that the operator's Minimum Equipment List maximum operating altitude of FL250 was of no effect. However, the decision by the flight crew to climb to FL350 placed additional load on the left, degraded airconditioning pack that was not capable of operating at the maximum ceiling. That increased the risk that a trip off might occur.

Other safety factors

Air system maintenance

The maintenance action to initially monitor the identified bleed air drift was in accordance with the applicable maintenance procedures. The potential for the evolving bleed air problem to have a significant influence on the operation of the aircraft could not have been foreseen at that time.

As it turned out, the report of the open left airconditioning ram air door by the preceding flight crew was a symptom of the split in the flexible hose that contributed to the depressurisation. Equally, the open door might have been a result of a fault with the door actuator, as diagnosed by the maintenance engineers. In which case, the decision to lock the ram air inlet door in the open position offered a practical means to troubleshoot the fault, while allowing for the continued operation of the aircraft.

Operations

The decision to continue the takeoff after the Master Caution activated at less than 80 kts was contrary to the operator's rejected takeoff criteria, and increased the risk of the underlying aircraft problem having effect during the remainder of the flight. Similarly, the decision to address the bleed trip off soon after takeoff, rather than waiting until the aircraft was above the minimum safe altitude, increased the risk of the flight crew being distracted from their primary flying tasks at a critical phase of the flight.

A bleed trip off was less likely in the 737 NG than in previous 737 models due to inherent design changes, and the possibility of using engine anti-ice to facilitate system reset after a bleed trip off was not documented for the 737 NG aircraft. However, as indicated in this occurrence, trip offs can still occur in the 737 NG, and the incorporation in the 737 NG documentation of the manufacturer's advice on using anti-ice to facilitate bleed trip reset would increase the likelihood of a successful reset in that aircraft type.

In order to prevent engine ice buildup, Standard Operating Procedures (SOP's) specified the use of the aircraft's engine anti-ice system under defined conditions. There were no clear reasons for the flight crew having not activated the aircraft's engine anti-ice protection on encountering icing conditions during the cruise at FL250, and the likely icing conditions on the subsequent climb and descent.

The right bleed trip off complicated the reconfiguration of the air bleed system after the no engine bleed takeoff. By choosing not to follow the after takeoff section of the 'No Engine Bleed Takeoff' checklist, the flight crew isolated the right wing anti-ice system from the left and only operating bleed air source. In a high workload environment, such as during a rapid descent, multiple demands on the flight crew can necessitate the prioritising of work functions and critical items may be missed, as evidenced in this occurrence by the overlooking of engine anti-icing requirements. In the event that wing anti-icing had been required, and was selected, a closed isolation valve would have put the aircraft at risk of asymmetric icing and the associated flight control difficulties.

The discretion applied by the pilot in command to not conduct a full emergency descent was allowed for in the operator's emergency descent procedure. However, by not activating the passenger oxygen system, or informing the cabin crew of the nature of the problem, the cabin crew's situational awareness during the rapid descent was limited somewhat. The proactive action by the cabin supervisor to commence securing the cabin meant that the lack of advice from the flight crew did not adversely affect the cabin preparations.

Success in managing operational threats is highly dependent on the correct use of the checklist system and adherence to standard operating procedures. While flight crew have discretion in the execution of some checklist procedures, reference to checklists provides a higher level of assurance that procedures will be properly conducted.

Cabin crew

The difficulty reported by some cabin crew with the operation of the cabin's oxygen system was an indication of a lack of system knowledge by some crew members. A depressurisation event is a stressful time for crews, and their reaction to such events is highly dependent not only on the quality of the training received but, also on each individual's familiarity with the documented procedures and aircraft systems. The action by the cabin supervisor to secure the cabin without specific advice of the emergency from the flight crew, maximised the response time available to the cabin crew.

FINDINGS

From the evidence available, the following findings are made with respect to the depressurisation event that occurred on 17 November 2007 and involved Boeing Company 737-7Q8 aircraft registered VH-VBC, and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- During a No Engine Bleed Takeoff, a defective high-stage valve allowed a pressure increase in the aircraft's right bleed air system that triggered the system's overpressure switch to activate the right bleed trip off. Attempts by the flight crew to reset the system were unsuccessful.
- The flight crew continued the flight and climbed above flight level 250, which was the aircraft's minimum equipment list-specified ceiling with a single airconditioning pack operating.
- The left and only operating airconditioning pack tripped off due to a reduced air flow over the system's heat exchanger due to a damaged flexible hose. As a result, the aircraft depressurised.

Other safety factors

- The action to continue the takeoff was contrary to the operator's procedures and increased the risk of the (at that time) unknown underlying aircraft problem having effect during the remainder of the flight.
- The action to address the right bleed system fault soon after takeoff increased the risk of the flight crew being distracted from their primary flying tasks at a critical phase of the flight.
- Following the no engine bleed takeoff, the flight crew did not reconfigure the air system controls in accordance with the supplementary procedure, inadvertently isolating the right wing anti-ice system from the operating bleed air source, and putting the aircraft at risk of asymmetric wing icing.
- The flight crew did not activate the aircraft's engine anti-ice systems when operating in icing conditions, increasing the risk of an engine icing event.
- The cabin crew displayed an inconsistent knowledge of the operation of the cabin oxygen system, increasing the risk of reduced cabin staff performance or passenger injury.

Other key findings

- A published procedure to reset bleed trips in earlier model B737 aircraft, and that may have been of use in this case, was not published for the B737 NG.
- The cabin supervisor exhibited very good situational awareness, acting to secure the cabin without specific advice from the flight crew as to the nature of the emergency.

SAFETY ACTION

Any safety issues identified during the conduct of an investigation are listed in the Findings and Safety Actions sections of the report. However, whereas an investigation may not identify any particular safety issues, relevant organisation(s) may proactively initiate safety action in order to further reduce their safety risk.

All of the relevant organisations identified during this investigation were given a draft report and invited to provide submissions. Although no safety issues were identified during this investigation, the following proactive safety action was submitted by those organisations.

Aircraft operator

As a result of this incident, the flight crew undertook additional training before being re-certified by the operator for return to line duties. In addition, the operator conducted an internal investigation of this occurrence and, as a result of that investigation:

- introduced a system of automatic flight crew stand down for those involved in an Immediately Reportable Matter
- focussed the 2008-2009 cabin crew safety equipment and procedures recurrent training on a decompression scenario and cabin and flight crew actions, encompassing the areas of concern that were identified during the operator's investigation
- amended the appropriate manuals to provide further guidance to crews on oxygen mask operation
- modified the pre-take-off passenger safety demonstration to include advice that oxygen would flow through passengers' masks even though individual bags may not have inflated.

APPENDIX A: NO ENGINE BLEED TAKEOFF AND LANDING SUPPLEMENTARY PROCEDURE

No Engine Bleed Takeoff and Landing

When making a no engine bleed takeoff or landing with the APU operating.

Takeoff

Note: If anti–ice is required for taxi, configure for a "No Engine Bleed Takeoff" just prior to take–off.

Note: If anti–ice is not required for taxi, configure for a "No Engine Bleed Takeoff" just after engine start.

Right PACK switch .... AUTO

ISOLATION VALVE switch .... CLOSE

Left PACK switch .... AUTO

Engine No. 1 BLEED air switch .... OFF

APU BLEED air switch .... ON

Engine No. 2 BLEED air switch .... OFF

After Takeoff

Note: If engine failure occurs, do not position engine BLEED air switches ON until reaching 1500 feet or until obstacle clearance height has been attained.

Engine No. 2 BLEED air switch .... ON

APU BLEED air switch .... OFF

When CABIN rate of CLIMB indicator stabilizes:

- Engine No. 1 BLEED air switch .... ON
- ISOLATION VALVE switch .... AUTO

APPENDIX B: BLEED TRIP OFF NON-NORMAL CHECKLIST

BLEED TRIP OFF

Condition: **A BLEED TRIP OFF light illuminated indicates the related engine bleed air temperature or pressure is excessive.**

WING ANTI-ICE switch . . . . OFF

TRIP RESET switch . . . . Push

[The BLEED TRIP OFF light extinguishes if bleed air temperature has cooled below limits.]

If the BLEED TRIP OFF light remains illuminated:

PACK switch (affected side) . . . . OFF

[Causes operating pack to regulate to high flow in flight with flaps up.]

Avoid icing conditions.

■ ■ ■ ■

If the BLEED TRIP OFF light extinguishes:

WING ANTI-ICE . . . . As needed

CAUTION: Use of wing anti-ice above approximately FL350 may cause bleed trip off and possible loss of cabin pressure.

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APPENDIX C: CABIN ALTITUDE WARNING OR RAPID DEPRESSURISATION NON-NORMAL CHECKLIST

CABIN ALTITUDE WARNING OR RAPID DEPRESSURIZATION

Condition: **One or more of the following conditions:**

- **The intermittent cabin altitude/configuration warning horn sounds and the CABIN ALTITUDE lights (if installed and operative) illuminate in flight**
- **There is a rapid loss of cabin pressure with airplane altitude above 14,000 feet.**

Oxygen masks and regulators . . . . On, 100%

Crew communications . . . . Establish

Pressurization mode selector . . . . MAN

Outflow valve switch . . . . CLOSE

If pressurization is restored, continue manual operation to maintain proper cabin altitude.

Passenger signs . . . . .ON

If cabin altitude is uncontrollable:

Passenger oxygen switch . . . . .ON

Activate passenger oxygen if cabin altitude exceeds or is expected to exceed 14,000 feet.

Emergency descent . . . . Initiate

Accomplish the EMERGENCY DESCENT checklist if the airplane is above 14,000 feet MSL and control of cabin pressure is not possible, or cabin pressure is lost.

APPENDIX D: EMERGENCY DESCENT NON-NORMAL CHECKLIST

< EMERGENCY DESCENT >

Condition: **Unable to control cabin pressure with airplane above 14,000 feet MSL or conditions require a rapid descent.**

EMERGENCY DESCENT . . . . .Announce

The captain will advise the cabin crew, on the PA system, of impending rapid descent. The first officer will advise ATC and obtain the area altimeter setting.

ENGINE START switches . . . . CONT

THRUST levers . . . . CLOSE

Reduce thrust to minimum or as needed for anti-ice.

SPEED BRAKE . . . . FLIGHT DETENT

DESCENT . . . . .Initiate

Target speed . . . . .Mmo/Vmo

If structural integrity is in doubt, limit speed as much as possible and avoid high maneuvering loads.

Level-off altitude . . . . Lowest safe altitude or 10,000 feet, whichever is higher

CAUTION: (737-700 with winglets). When gross weight is greater than 64,864 kgs., speed brake will autostow to the 50% flight detent if airspeed exceeds 320 knots. Do not override autostow function unless airspeed is less than 320 knots.

SPEED BRAKE . . . . DOWN DETENT

Smoothly lower the SPEED BRAKE lever and level off. Add thrust and stabilize on altitude at desired airspeed.

CREW OXYGEN REGULATORS . . . . .NORMAL

Flight crew must use oxygen when cabin altitude is above 10,000 feet. To conserve oxygen, position the regulator to NORMAL.

ENGINE START switches . . . . As needed

APPENDIX E: SOURCES AND SUBMISSIONS

Sources of Information

The sources of information during the investigation included:

- the flight and cabin crew of VH-VBC
- the aircraft operator
- the aircraft manufacturer.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003*, the Australian Transport Safety Bureau (ATSB) may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the Civil Aviation Safety Authority (CASA), the operator, the flight crew, the aircraft manufacturer and the US National Transportation Safety Board.

Submissions were received from CASA, the operator, the flight crew and the aircraft manufacturer. The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.

Depressurisation event, 246 km south-west of Coolangatta, Queensland
17 November 2007
VH-VBC, Boeing Company 737-7Q8