Serious Incident

Aircraft Type and Registration:	Boeing 737-8K5, G-TAWD
No & Type of Engines:	2 CFM56-7B27E turbofan engines
Year of Manufacture:	2011 (Serial no: 37265)
Date & Time (UTC):	17 October 2023 at 0615 hrs
Location:	East coast of UK, North Lincolnshire
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 6 Passengers - 187
Injuries:	Crew - None Passengers - None
Nature of Damage:	None reported
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	53 years
Commander's Flying Experience:	18,000 hours (of which 1,600 were on type) Last 90 days - 291 hours Last 28 days - 86 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

A CABIN ALTITUDE warning was activated as the aircraft passed FL130. Both engine bleed air systems had been inadvertently left off for the departure, so the aircraft failed to pressurise. The crew selected both systems on and continued the climb. The aircraft then generated a PACK caution, so the crew stopped the climb at FL200. After discussion with the operator's maintenance control the commander decided to return to the departure airfield. Recorded data indicated that the CABIN ALTITUDE warning remained on for 43 minutes. The crew did not don oxygen masks.

History of the flight

The aircraft was operating a sector from Manchester Airport (MAN) to Kos Airport, Greece. Neither of the pilots were originally scheduled to operate the service and both were rostered for a standby duty commencing at 0300 hrs. The commander was awoken by a notification on his smartphone roster app at 0100 hrs indicating he had been assigned the Manchester to Kos duty. The co-pilot was notified by a phone call from crewing at 0230 hrs. Both pilots were given a report time of 0430 hrs.

On a previous flight the aircraft's air conditioning packs had not been operating correctly and a maintenance work order had been generated to investigate the issue. Immediately prior to the incident flight, maintenance work had been carried out on the air conditioning packs and noted in the aircraft technical log.

The co-pilot downloaded the Operational Flight Plan while at home and reviewed the weather and the aircraft status. They noted that there were no open defects in the technical log. The commander reported to the crew room on time and was then contacted by the co-pilot whose journey had been affected by the closure of a motorway. As the co-pilot was going to be late reaching the airport it was agreed that the commander would assume the PF role and that the co-pilot would meet the crew at the aircraft.

At the aircraft the commander conducted the walk round checks, then boarded and began the commander and PF pre-flight duties. During these he noted that there were no open defects in the technical log but that work had been carried out on the right air conditioning pack after the aircraft's last flight. The co-pilot arrived as the passengers were boarding at approximately 0500 hrs. The pilots knew each other from previous flights and the commander said that although an on-time departure was desirable, preparing the aircraft correctly would be paramount. The co-pilot recalled that they did not feel under pressure but did try to conduct their pre-flight duties in an expedited manner.

The taxi out and the departure from Manchester were uneventful. The commander was PF and recalled he manually flew the aircraft until the after-takeoff checks were completed. The after-takeoff checklist, carried out by the PM on a challenge and response basis, includes a check that the bleed air switches are selected ON. Both pilots recall completing this checklist and were sure that the bleed switch positions were visually verified as being ON. The commander recalled that, with the aircraft passing approximately 15,000 ft amsl, the CABIN ALTITUDE warning light illuminated accompanied by the associated warning horn. In his report the commander stated that '*It was quickly noticed that both engine bleeds were off, these were placed straight back on and the problem was resolved.'* The commander then stated '*The aircraft was levelled off and the QRH[1] was actioned. Once this was completed, shortly afterwards the right pack failed.'* Neither pilot actioned the QRH Cabin Altitude Checklist which contains memory items, including the immediate use of oxygen masks. The commander recalled noticing that both engine bleed switches were selected to OFF and that he directed the co-pilot to switch them ON. Both pilots recalled that the bleed switches were selected ON before they requested a level off at FL150 from ATC. Once the aircraft was level the commander recalled that memory items from the checklist for cabin altitude warning should have been completed. However, as the bleed systems were now on and believing the situation to be under control, he decided that the memory items, including the use of oxygen masks, were disproportionate to the situation.

Once level the commander checked the cabin altitude indication on the overhead panel and recalled it was approximately 2,000 ft and believed this was achieved "within a couple of minutes" of the engine bleed switches being selected ON. He then decided that the crew should read through the checklist to ensure there were no actions he felt should be done or any other information they should be aware of. Satisfied that the situation was under control and that the cabin altitude was below 3,000 ft, the crew felt safe to continue the flight and a further climb was requested from ATC.

Footnote

[1] Quick Reaction Handbook (QRH). Contains normal and non-normal checklists for the aircraft.

During the climb the MASTER CAUTION illuminated and drew the attention of the crew to a PACK caution on the overhead panel indicating a fault in the right air conditioning pack. The crew requested a level off at FL200 from ATC and actioned the QRH checklist for a right PACK caution. They were not able to recover the right air conditioning pack and, aware this would impose some limitations on the return flight, the commander decided to discuss the situation with the operator's maintenance control (Maintrol). After consulting Maintrol it was agreed that the aircraft should return to Manchester. As the aircraft was above maximum landing weight the crew planned to enter a hold with the landing gear extended to burn fuel and reduce weight. The senior cabin crew member was brought to the flight deck for a briefing and the situation was explained to the passengers over the public address system. Once the aircraft weight had been satisfactorily reduced the aircraft made a normal approach to Runway 05 at Manchester.

Recorded information

The FDR information was downloaded by the AAIB and a copy sent to the aircraft manufacturer for analysis. CVR data was not recovered. A digest of the information analysed by the operator from the Quick Access Recorder Data is as follows:

06:06:35 Airborne from Runway 05 Flap 5 departure.

06:07:09 Thrust reduction to climb thrust.

06:07:12 Autopilot(AP) A engaged.

06:07:51 Acceleration and flap retraction phase commenced.

06:08:29 All flaps indicate 'up'.

06:08:32 Selected altitude increased to FL190.

06:10:08 Selected altitude increased to FL280.

06:11:50 CABIN ALTITUDE recorded above 10,000 ft. Passing FL130. At this point the CABIN ALTITUDE warning activated.

06:12:11 Selected altitude reduced to FL150, aircraft passing FL139.

06:12:26 AP Pitch mode changes to altitude acquire with aircraft passing FL145.

06:12:47 AP altitude hold captured at FL150.

06:13:03 ENG BLEED 1 switched ON, then ENG BLEED 2 switched ON.

06:16:46 Selected altitude raised to FL280.

06:18:37 Selected altitude reduced to FL200.

06:19:26 AP altitude hold captured at FL200.

06:23:10 R pack switched OFF – L pack transitions to HIGH flow.

06:34:53 180° turn to return to MAN.

06:35:09 CABIN ALTITUDE recorded descending below 10,000 ft.

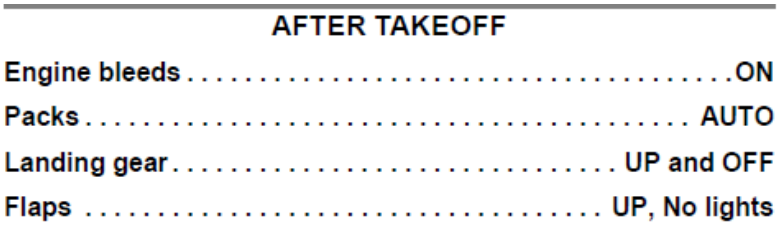
06:49:41 Descent commenced from FL200.

06:58:54 FL090 acquired.

07:11:19 Aircraft enters hold at FL90, north-east of MAN 07:51:28 Hold exit.

08:10:16 Touchdown at a weight of 64,360 kg.

The recorded data shows the autopilot was engaged at 1,980 ft and that the flaps indicated fully retracted at 4,000 ft, though the commander's recollection was that he flew the aircraft manually until the after-takeoff checklist was complete. Checking that the flaps are fully retracted and that the bleed switches are ON are part of the after-takeoff checklist which is shown at Figure 1.



AFTER TAKEOFF

Engine bleeds . . . . . ON

Packs . . . . . AUTO

Landing gear . . . . . UP and OFF

Flaps . . . . . UP, No lights

Figure 1

After-takeoff checklist

Both pilots recalled that the bleed switches were selected ON within a few seconds of the cabin altitude warning. The QAR data shows a delay of approximately 73 seconds between the cabin altitude warning and the bleed switches being selected ON. During that time the aircraft levelled at FL150.

An analysis of the FDR data by the AAIB indicated that the CABIN ALTITUDE warning remained active for 43 minutes, until 06:53:47.

It was not possible to recover data from non-volatile memory within the cabin pressurisation controllers aboard the aircraft and therefore the actual cabin altitude during the period that the cabin altitude warning was triggered was not ascertained. However, the FDR data showed that the passenger oxygen masks in the cabin were not deployed. As they deploy automatically if the cabin altitude exceeds 14,000 ft, the maximum was below that limit.

Engineering Information

The operator carried out an internal investigation into the maintenance work carried out during the night before the incident flight on a fault related to the right air conditioning pack (there had been two entries in the aircraft technical log in the days before, but no fault had been found). The Fault Isolation Manual task required the Bleed 1, Bleed 2 and Bleed APU

switches to be selected OFF, and the left and right Pack switches to be selected to AUTO ahead of a test of the system. After the test, the Pack switches were to be left in the OFF position and all other switches returned to their original position.

The packs were operated for two hours without fault after which they were shut down. The engineer followed the post-test procedure and placed the Pack switches in the OFF position, and believed all other switches had been returned to their original configuration. A separate engineer, allocated to the departure, did not detect that the bleed switches were, in fact, in a 'non-normal' configuration ie OFF.

Aircraft information

Cabin altitude warning

The aircraft cabin altitude warning consists of an aural warning horn and a red CABIN ALTITUDE warning light on each pilot's forward panel. The light illuminates simultaneously with the aural warning when the cabin altitude is greater than 10,000 ft and remains illuminated until the cabin altitude pressure switch deactivates. The cabin altitude pressure switch can deactivate between 500 and 1,500 ft below the activation altitude. Neither pilot could recall if the CABIN ALTITUDE warning light remained illuminated after the engine bleed switches were selected ON.

Bleed air system

Air for the bleed air system can be supplied by the engines, APU, or 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. 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 engine bleed air controls and indicators on a B737-800 are on the right side of the overhead panel (OHP). The air conditioning panel is shown in Figure 2.

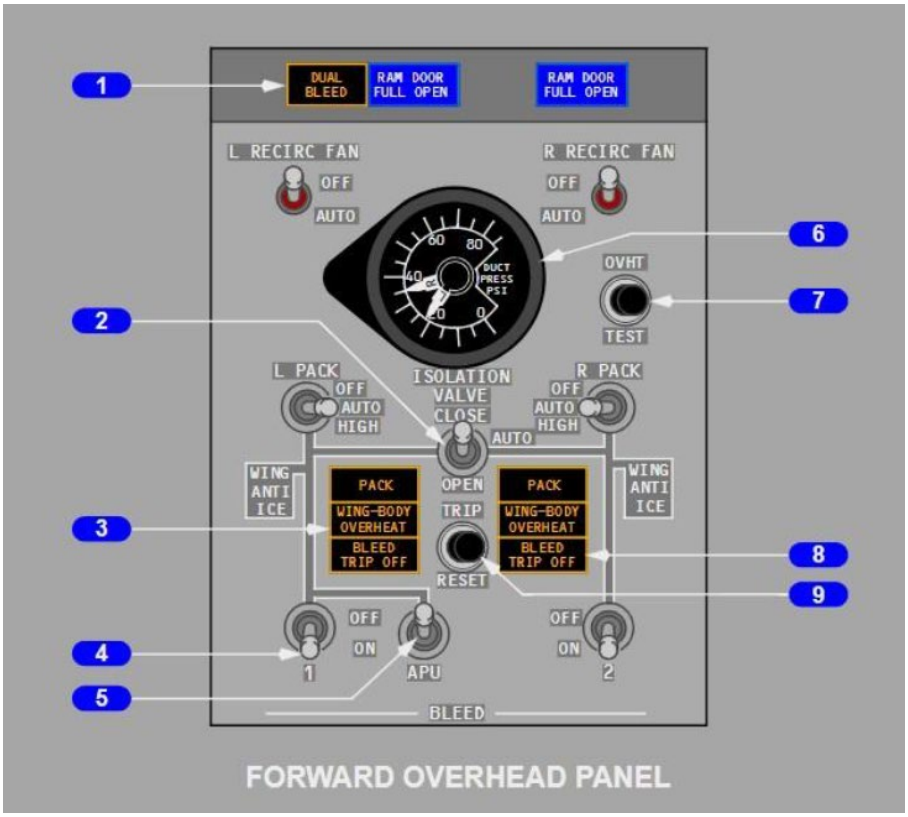


Figure 2

Air conditioning panel
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The engine bleed switches are indicated by the number 4. The commander pointed out the difficulty of seeing these switches from his seat position.

The engine bleed switches should be positioned ON as a part of the co-pilot's pre-flight procedure. If this does not happen, the next procedural opportunity to notice the omission is as part of the after-takeoff checklist. In adverse weather where de-icing is required or if performance limitations require a no engine bleed takeoff, then the engine bleed switches may require manipulation before and after takeoff. In these circumstances there are published procedures for crews to follow. Neither was applicable for this flight.

Cabin altitude indications

The cabin altitude indicators (Figure 3) are also in the OHP adjacent to the bleed air system controls. The cabin altitude gauge at number 1 has two needles. The longer needle indicates the cabin pressure differential to the outside air and the smaller needle indicates the cabin altitude. The gauge at number 2 shows the cabin rate of climb or descent. As these gauges are located close to the bleed switches the commander would have similar difficulty in reading them. The commander recalled the needle being between the one and 2 o'clock position on the dial but was uncertain if it was the large or small needle.

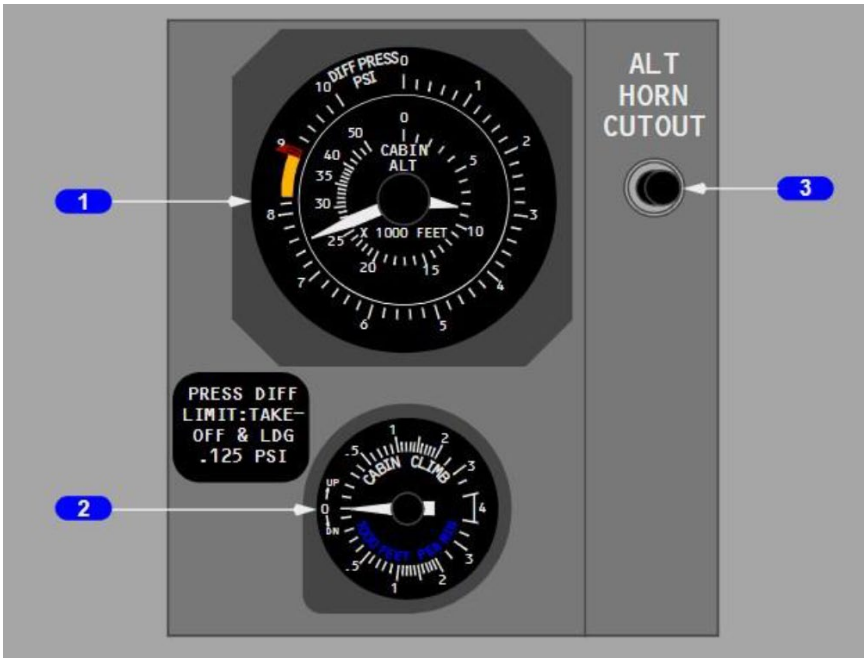

Figure 3

Cabin altitude indicators
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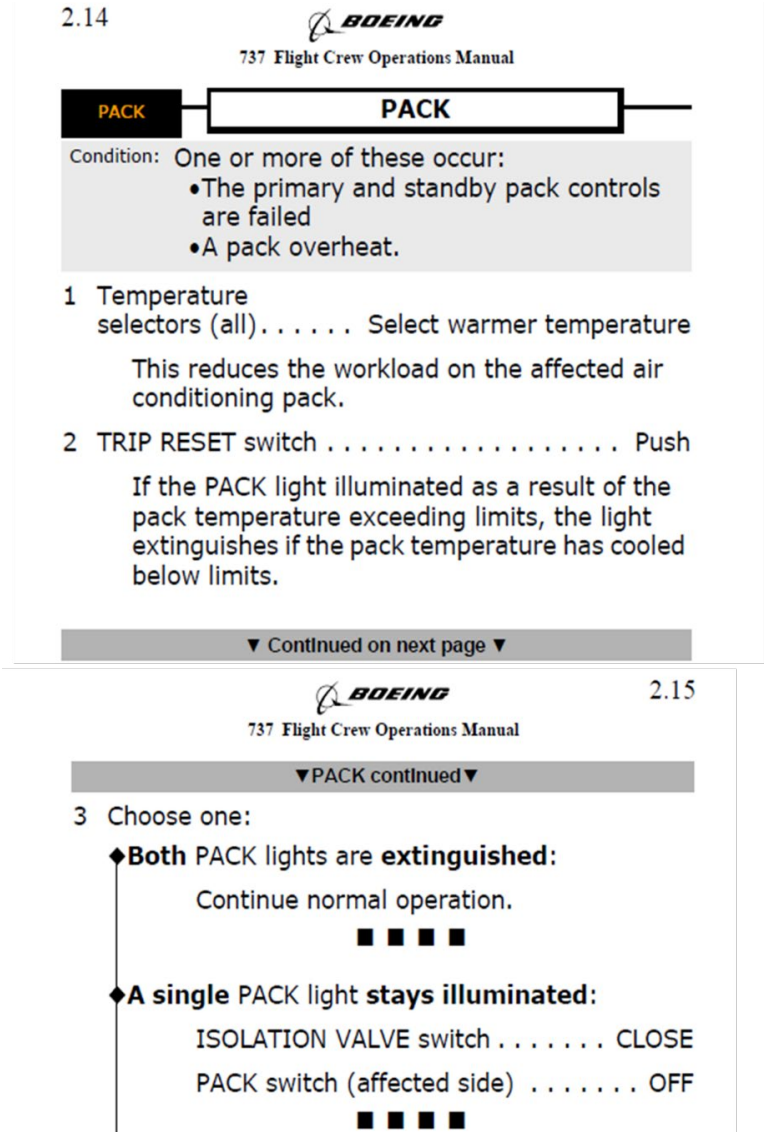
The aircraft manufacturer stated that the pressurisation system would control the cabin rate of descent at a maximum of 750 fpm. Once the bleed switches were selected ON it would have taken over nine minutes for the cabin altitude to reach 3,000 ft.

Air conditioning system

The air conditioning system provides temperature-controlled air by processing bleed air from the engines, APU, or a ground air source in air conditioning packs. Conditioned air from the left pack, upstream of the mix manifold, flows directly to the flight deck. Excess air from the left pack, air from the right pack, and air from the recirculation system is combined in the mix manifold. The mixed air is then distributed through the left and right sidewall risers to the passenger cabin. Electronic controllers command the pack temperature control valve toward open or closed to satisfy pack discharge requirements. If a primary pack control fails, the affected pack is controlled by the standby pack control in the opposite controller. Should both primary and standby controllers fail, the PACK light illuminates immediately. Should either a primary or standby pack controller fail, the PACK, Master Caution and AIR COND system annunciator lights will illuminate when the Master Caution recall button is pressed. The QRH contains a checklist for crew to use in response to a PACK caution illuminating and this is shown at Figure 4. The checklist directs crews to select a warmer temperature on the cabin and flight deck temperature controllers to reduce the load on the affected pack. The crew could not recall what cabin temperatures had been selected on the incident flight. On return to Manchester the right pack was checked by the operator's engineers and no fault was found.



2.14

BOEING

737 Flight Crew Operations Manual

PACK

PACK

Condition: One or more of these occur:

- The primary and standby pack controls are failed
- A pack overheat.

1 Temperature selectors (all) . . . . . Select warmer temperature

This reduces the workload on the affected air conditioning pack.

2 TRIP RESET switch . . . . . Push

If the PACK light illuminated as a result of the pack temperature exceeding limits, the light extinguishes if the pack temperature has cooled below limits.

▼ Continued on next page ▼

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▼PACK continued▼

3 Choose one:

◆**Both** PACK lights are **extinguished**:

Continue normal operation.

■ ■ ■ ■

◆**A single** PACK light **stays illuminated**:

ISOLATION VALVE switch . . . . . CLOSE

PACK switch (affected side) . . . . . OFF

■ ■ ■ ■

Figure 4

Pack QRH Checklist
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Hypoxia risk

As the aircraft did not pressurise, the crew and passengers were exposed to the risk of hypoxia. At cabin altitudes above 10,000 ft but below 14,000 ft, without the pre-existence of significant medical issues, the likelihood of loss of consciousness is very small. However, in this altitude window the hypoxic exposure can be sufficient to affect cognitive performance and decision making to the point where the decline would be observable in cognitive tests. In this range of altitudes there are many variables that affect the severity and impact of hypoxia, including duration of exposure, rate of hypoxia onset (eg rate of climb if no pressurisation), physical workload, fatigue, individual responses and type of task being performed. In this range of altitudes it is also difficult to separate the relative contribution of hypoxia versus other performance degraders such as fatigue, distraction or other human performance issues.

The aircraft climb was interrupted by the crew attending to the PACK caution. If the aircraft had continued to climb, the aircraft's passenger oxygen system would have deployed automatically when the cabin altitude reached 14,000 ft, and the pressurisation AUTO FAIL master caution would have been triggered at 15,800 ft cabin altitude, according to the Flight Crew Operating Manual. As progressive exposure to hypoxia increased, the likelihood of the crew taking correct recovery actions would have decreased.

Fatigue

The operator's fatigue team had discussions with both pilots and conducted a fatigue analysis. Individual work history showed that both pilots had been working harder than usual. A key metric used to gauge fatigue is the Samn-Perelli Score (SPS)[2] obtained through statistical analysis of rosters and sleep achieved. SAFE[3] analysis of the commander's roster for the previous eight weeks placed him in the top 10% of the operator's B737 commanders, scoring high for fatigue when comparing work/duties completed. For the incident duty the commander scored 4.48 on the SPS scale and so fatigue was not a sufficient explanation on its own for the omissions made in response to the CABIN ALTITUDE warning. For the co-pilot, the percentage of time with a high SPS and the total time with an SPS above five were both low. Sectors flown in the previous eight weeks were low both in comparison to the overall community and to the operator's MAN co-pilots.

Analysis found that in terms of acute fatigue[4], the duty was not in itself particularly fatiguing, but the commander's pre-duty rest was disturbed with just three hours sleep achieved. There were several indicators from the analysis of the previous eight weeks that suggested chronic fatigue was a possible factor for the commander. He had carried out a significant number of overtime duties and, although they were not necessarily individually fatiguing, the cumulative disruption may have been a factor. The SAFE analysis also showed that the commander's exposure to fatiguing duties was amongst highest across the operator's B737 fleet and joint highest amongst its commanders at Manchester.

Though the commander did not believe fatigue was a factor in this event, the analysis of his roster over the eight weeks preceding the event and the rest period immediately before it suggest that fatigue could still have been a contributory factor. It should be noted that fatigue, particularly chronic fatigue, can be insidious such that an individual may not recognise the symptoms in themselves.

Crew training

Experience of cabin altitude/decompression during recurrent training is required every three years as detailed in the operator's training manual. The co-pilot completed a decompression training module in the B737 simulator on 5 January 2023 and the commander carried out a classroom session on 10 March 2022. Neither pilot experienced a realistic, surprising, cabin altitude or decompression event in the simulator during their annual training/checking, although such surprise is difficult to generate in the simulated environment.

Footnote

[2] Samn-Perelli 7-Level fatigue scale. | Download Scientific Diagram (researchgate.net) [Accessed August 2024].

[3] A biomathematical fatigue model that predicts fatigue hazards experienced by commercial aircraft pilots.

[4] Acute fatigue is associated with sleep restriction or extended hours awake within the last 1 or 2 days.

The cabin altitude warning experienced in the aircraft during the event flight occurred at a relatively low level, outside of the more extreme area of the flight envelope where such an event is normally experienced in the simulator.

QRH Information

The aircraft QRH contains Quick Action Index (Figure 5) for situations that require a quick response. Titles shown in upper case are annunciated by a light, alert or other indication.

These checklists can have both memory and reference items. Memory items are immediate actions which must be done before reading the rest of the checklist. It is the operator's policy that memory items shall be carried out without reference to the checklist. Once complete the crew use the QRH to ensure that no memory items have been omitted prior to commencement of the reference items. The end of the memory items is signified by a dashed horizontal line. The QRH checklist for CABIN ALTITUDE is at Figure 6

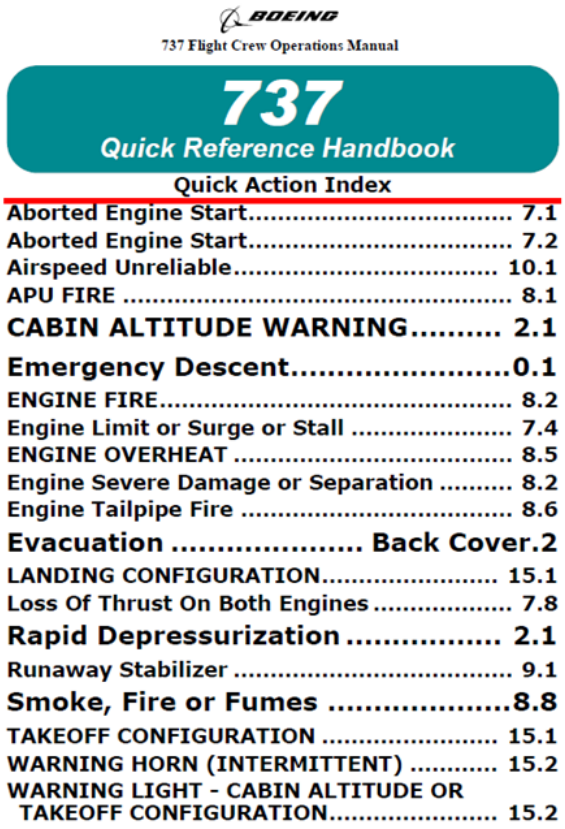

Figure 5

QRH Quick Action Index
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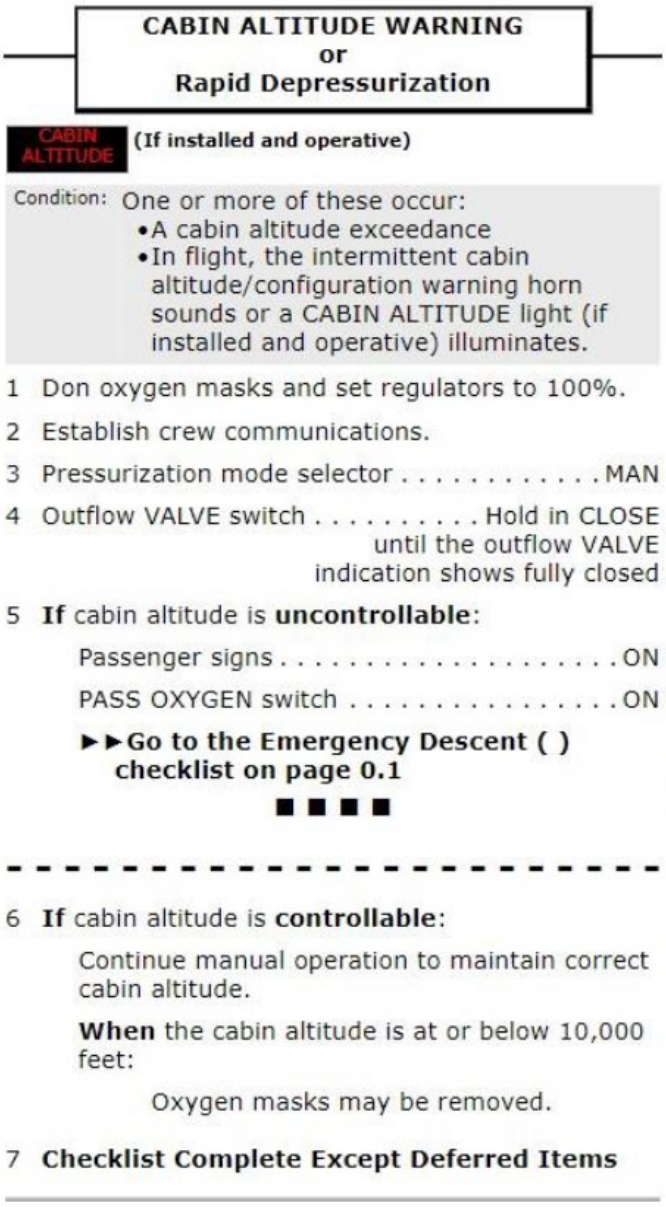

CABIN ALTITUDE WARNING
or
Rapid Depressurization

CABIN ALTITUDE **(If installed and operative)**

Condition: One or more of these occur:
- 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 Pressurization mode selector . . . . . MAN

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

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

Passenger signs . . . . . ON

PASS OXYGEN switch . . . . . ON

►►**Go to the Emergency Descent ( ) checklist on page 0.1**

■ ■ ■ ■

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

Continue manual operation to maintain correct cabin altitude.

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

Oxygen masks may be removed.

7 **Checklist Complete Except Deferred Items**

Figure 6

Cabin Altitude Warning Checklist
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Analysis

Maintenance work was carried out during the night before this flight during which the engine bleed air switches were selected OFF. The engineer carrying out the maintenance believed that the switches had been returned to the ON position after the work had been completed, but it appears that they were left OFF. The engineer assigned to the aircraft's departure did not detect the incorrect switch position.

During the pre-start procedures by the flight crew, it was not identified that the engine bleed switches were set OFF nor was this oversight detected in the after-takeoff checks. The crew did not use the prescribed memory items in response to a cabin altitude warning and may have misinterpreted the cabin altitude gauge readings after the engine bleed switches were selected to ON.

The departure was early in the morning and the commander's rest had been disturbed by his mobile phone and as a result he had slept for only three hours in the night preceding the duty. Additionally, his workload over recent weeks had been higher than average for the operator and he had been exposed to a number of potentially disruptive overtime duties. It is possible, therefore, that fatigue was a factor in the commander's decision making. The co-pilot had a lower fatigue risk than the commander but their journey to work had been disrupted and they had arrived late at the aircraft. Although the co-pilot recalled that they did not feel under pressure, they were trying to expedite the departure. It is possible, therefore, that in completing their procedures in an expeditious manner they were more vulnerable to seeing what they expected to see. As both bleed switches were in the same position, OFF, it is possible the co-pilot perceived them to be ON, since that was their expectation.

The engine bleed switches are not mentioned again until the after-takeoff checklist so there was no further procedural opportunity to identify the incorrect switch positions until the aircraft was airborne. After takeoff the PF calls for the after-takeoff checks, which are completed by the PM using challenge and response techniques. It appeared likely that during these checks the co-pilot again saw what they expected to see and so did not notice that the engine bleed switches were still selected OFF. The switches are on the opposite side of the cockpit to the commander, reducing the likelihood that he would notice that they were in the wrong position.

The aircraft continued to climb with the bleed air systems off and so the cabin failed to pressurise. The CABIN ALTITUDE warning was triggered with the aircraft at approximately FL130. The aircraft QRH specifies memory items in response to this warning, the first of which is to don oxygen masks and establish crew communications. The crew did not conduct the memory items but in response to the warning the commander noticed the engine bleed switches were OFF and directed them to be selected ON. The crew recalled that this was done very quickly, though in fact 73 seconds elapsed between the warning and the bleeds being selected ON, during which the aircraft was levelled at FL150. Although the memory items were not carried out, the pilots were perhaps pre-disposed to check the bleed switches due to the entry in the aircraft tech log, related to air systems, which they had noted earlier. The pilots may have suffered a startle effect at the initial warning, but simple memory items are included in checklists to support crew decision making in crisis and support pilots by creating a structure for them to follow.

Crew training is generally focussed on rapid decompression at high altitudes. This event occurred at a much lower level with much less grave symptoms and so may have subconsciously conditioned the degree of urgency attributed to the response by the crew.

With the bleed switches selected ON, the crew assumed that the aircraft systems would correct the cabin altitude and that the rest of the memory items beyond donning oxygen masks would have been disproportionate. However, donning the oxygen masks as an immediate action would have given both pilots immediate protection from any hypoxia risk and allowed them to clarify the situation with the highest risk removed.

The crew's expectation was that selecting bleeds ON would have resolved the problem. The commander's recollection was that the cabin altitude was 2,000 ft within "a couple of minutes". The aircraft was level at FL150 for three minutes and 30 seconds before recommencing the climb to FL280. The commander recalled seeing the needle on the cabin pressure gauge as being between the one and two o'clock positions. If the longer needle on the gauge was in that position it would indicate a cabin pressure differential of between one and two psi, suggesting a cabin altitude that was still high. Confirmation bias may have been a factor for the commander as his expectation was that turning on the bleed air system would have rapidly resolved the problem. However, the aircraft pressurisation system would have required over 10 minutes to achieve a cabin altitude of 2,000 ft.

Certain that the problem had been resolved the crew continued the climb and neither pilot recalled the red CABIN ALTITUDE warning light as being on. During the climb the right PACK caution illuminated. The crew stopped the climb at FL200 and actioned the QRH for the PACK caution, but this did not recover the pack and so the crew sought advice from the operator's Maintrol. Dispatching for the return leg to Manchester with a pack inoperative would have imposed limitations on the altitude to which the aircraft could climb and would have incurred significant performance penalties, so the decision was taken to return to Manchester. No technical cause for the pack fault was subsequently found but a likely cause is that the system was placed under a high load by the crew selecting low temperatures for the air conditioning, although neither pilot could recall what temperatures were set on the aircraft.

The recorded data indicated that the CABIN ALTITUDE warning remained on for 43 minutes. During that time the associated red warning light should have been illuminated, though neither pilot recalls seeing it. As the passenger oxygen masks did not deploy, the cabin altitude did not exceed 14,000 ft but, nevertheless, it was likely that the crew and passengers were exposed to a progressive hypoxia risk. While any loss of consciousness was highly unlikely, a negative impact on the ability of the crew to process information and make decisions was probable.

The climb to cruising altitude was interrupted by the PACK caution. Had the aircraft continued to climb, the passenger oxygen system would have deployed at 14,000 ft cabin attitude, and at 15,800 ft the AUTO FAIL caution on the pressurisation would have triggered a further master caution, and each of these events would have been a further opportunity to re-assess the situation. With one pack operational, the aircraft would have pressurised at a rate of climb below that of the aircraft, leaving a risk of progressive hypoxia that, coupled with fatigue, could have reduced the crew's ability to respond appropriately to these indications.

Conclusion

The aircraft departed with the engine bleed air system off because the switches had been incorrectly left OFF following maintenance activity and had not been turned ON during pre-flight procedures. The after-takeoff checklist is designed to trap the latter omission, but the incorrect switch selection went undetected by the crew. The aircraft failed to pressurise, but the crew did not complete the prescribed QRH drills in response to a CABIN ALTITUDE warning, which remained illuminated for 43 minutes.