AAIU Report No.2001-014
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Aircraft Type and Registration:	Boeing 737-548, EI-CDB
No. and Type of Engines:	2 x CFM 56 – 3B1
Aircraft Serial Number:	24919
Year of Manufacture:	1990
Date and Time (UTC):	7 December 2000, at 0715 UTC
Location:	During climb-out from Cork Airport (EICK)
Type of Flight:	Public Transport, (Scheduled)
Persons on Board:	Crew 2 Pilots, 4 CCM's Passengers 90
Injuries:	Crew Nil Passengers Nil
Nature of Damage:	Nil.
Commanders Licence:	ATPL
Commanders Age:	37 years
Commanders Flying Experience:	5802 hours
Information Source:	AAIU Pilot Incident Report Form Operators Incident Report AAIU Field Investigation

SYNOPSIS

Shortly after take-off from Cork Airport (EICK), the flight crew were alerted to a pressurisation problem. Continuing to climb in an un-pressurised condition, the aircraft reached FL 142 before a decision was made by the Captain to return back to the airport of departure. The aircraft landed without further incident at 0755 hours. There were no injuries. The investigation found that the pressurisation system had not been correctly configured for flight.

NOTIFICATION

On returning to EICK, the Captain reported to his operations controller, that the aircraft pressurisation system had failed in "Auto Mode" and that he was unable to control the cabin altitude in "Standby" or "Manual Mode". The Operator's Duty Operations Controller reported to the Air Accident Investigation Unit (AAIU) by INCID FAX at 0847 hours on the 7 December 2000, that EI-CDB had suffered a pressurisation control unit failure on initial climb-out from EICK. On the 11 December 2000, follow-up action indicated that the incident was considerably more serious than when first reported and as a result a decision was made by the AAIU to conduct an investigation.

1. FACTUAL INFORMATION

1.1 History of the Flight

1.1.1 Pre-departure

The aircraft (EI-CDB) with 6 crew members and 90 passengers on board was scheduled for a 0650 hours departure from EICK to Amsterdam (EHAM). The First Officer (F/O) was the designated Pilot-Flying (PF).

At 0620 hours, the cabin crew prepared the aircraft for the boarding of passengers, while the flight crew carried out the pre-flight and cockpit checks. During the "Before-start" checklist, the flight crew observed that their intended passengers were in fact boarding an unattended aircraft parked in front of them. Attempts to contact ground operations, in order to advise them of the situation, initially proved difficult. In the meantime, a ground engineer, who had noticed the error, intervened, and redirected the passengers back towards EI-CDB.

On foot of a slot delay EI-CDB was given a new departure time of 0720 hours. At 0654 hours the flight crew commenced a start on the No 2 engine using the auxiliary power unit (APU). Two attempts to start this engine failed, due to a slow rise in N2. The Captain discussed the problem with the duty engineer and it was subsequently decided to start No 1 engine and then carry out a cross-bleed start on the No 2 engine. The Captain made a public address (PA) announcement to advise the passengers of the situation.

Using the normal checklist, the non-normal checklist (for aborted starts) and the supplementary procedures checklist (for cross-bleed start), both engines were successfully started at 0711 hours. The Captain observed that the N2 on the No 2 engine was slightly slower to rise than the No 1 engine. This matter was discussed with the duty engineer and in the end it was decided to continue with the flight. The Captain did, however, request that the duty engineer arrange for an air-cart to be made available for their departure start at EHAM.

As the flight crew carried out their "After-start" checks, the Senior Cabin Crew Member (SCCM) entered the cockpit to inform the crew that an unfamiliar gurgling sound was coming from the front left cabin door seal. The Captain requested the F/O to go back and investigate the problem. On his return to the cockpit, the F/O briefed the Captain on what he had observed and it was agreed by both flight crew members that it was most likely water or dampness moving around the door seals on the initial pressurisation of the aircraft. The Captain advised the SCCM that he was happy to continue, but that if the noise persisted or worsened, she should inform him and he would then re-assess the situation. As the SCCM left the cockpit, the flight crew were alerted to the activation of the forward toilet smoke alarm. Due to the severity of the alarm the Captain made a PA to advise the passengers that there was no cause for concern. The Cabin Crew Members (CCMs) initially experienced some difficulty in silencing the alarm, so the Captain directed the SCCM to remove the battery from the manual smoke detector unit. The original source of the activation was considered to be smoke coming from the forward galley ovens, where breakfast was being prepared.

At 0717 hours, EI-CDB taxied for Runway (RWY) 17. During the investigation it was determined that neither flight crew could recall or confirm whether the “After-start” checklist had been fully completed.

1.1.2 Post-departure

The aircraft was airborne from RWY 17 at 0721 hours and continued to climb as cleared by ATC to FL 290. As the flight crew carried out their “After take-off” checklist the “Master Caution” light illuminated. The Captain immediately cancelled the caution and then informed the F/O (PF) that, the “Auto Fail” warning light on the overhead pressurisation panel was on. The F/O subsequently advised the investigation that at this particular stage of the incident he was not fully aware of the significance of the problem. Continuing with the “After take-off” checklist, the Captain briefed the F/O, that once the checks were complete he would carry out the non-normal checklist for “Auto-Fail”. In or around this time, the SCCM left her station and entered the cockpit to advise the Captain that both her fellow cabin crew member (seated beside her) and herself were experiencing problems with their ears. The Captain advised her that they did have a slight problem, but that they were sorting it out.

In a discussion with the investigation team, the SCCM recalled that very shortly after take-off her ears began to cause her some trouble and she felt a strange cold feeling on her face. She discussed this with her colleague seated beside her, who also confirmed experiencing similar symptoms. Because of this, she felt it necessary to advise the flight crew of what she was experiencing and to seek reassurance that everything was all right.

At approximately FL 060 the F/O (PF) engaged Autopilot (AP) B. Continuing in the climb the Captain started the non-normal checklist for “Auto-Fail”, which included reselecting the pressurisation system to “Standby Mode”. At approximately FL 100, the cabin altitude aural warning horn (indicating that the cabin altitude was 10,000 ft above sea level) sounded. Some confusion existed between the flight crew as to the location of the Cabin Altitude warning cut out button, but eventually it was located on the Cabin Altitude Panel and it was silenced. Having reached FL 110, the F/O requested descent from ATC back to FL 100. The descent was approved by ATC and the aircraft descended to and levelled at FL 100. The flight crew then continued with the “Auto Fail” checklist. Again, some confusion existed between the flight crew with regard to the location of the Cabin/Flight Altitude Placard. Once located the Cabin Altitude was set against the scale (believed to be 5,000 ft). Both the Captain and the F/O have confirmed to the investigation that, up to this point in the event, neither had checked the cabin altitude indicator and therefore incorrectly assumed that the “Standby Mode” was operating correctly. After remaining level at FL 100 for approximately 2 minutes the Captain announced to the F/O (PF) that the checklist was complete and then he requested further climb from ATC to FL 290. With clearance given by ATC, the F/O selected FL 290 in the altitude window of the Mode Control Panel (MCP) and the Captain selected vertical speed (V/S) mode for a rate of climb of between 500 and 700ft/min. When queried about the use of a non-standard climb (V/S 500-700 ft/min) the Captain recalled that this was done in order to give a lower rate of climb, thereby allowing for more time for further analysis and confirmation that the pressurisation system was functioning correctly.

As the aircraft recommenced its climb the F/O (PF) experienced a feeling of light-headedness. He checked the cabin altitude indicator on the cabin altitude panel above his head and observed that the cabin altitude was climbing with the aircraft. Passing through FL 125, the F/O informed the Captain that, the cabin was rising with the aircraft, it would soon reach FL 140 and that the cabin masks would drop. The F/O also advised the Captain that he was feeling light headed and that he was going on oxygen. While he did not fully don his oxygen mask the F/O did keep the mask up against his face and kept drawing on oxygen as and when he so desired. In or around this time, the Captain took over the roll of PF. At no stage during the incident flight did the Captain don his oxygen mask or indeed feel a personal need to go on oxygen.

The SCCM then entered the cockpit for the second time and informed the Captain (now the PF) that a number of passengers were complaining about pains in their ears, that the cabin was very cold and that the crew at the rear of the cabin had reported misting and cold temperatures. The SCCM returned to the forward galley.

Continuing in the climb, the Captain selected the pressurisation system to manual mode (MAN A/C Mode) in an effort to manually control the outflow valves. The Captain recalled that while there was a significant delay in their operation, the outflow valves did appear to be operating.

Located in the galley, the SCCM was informed by the No 2 CCM that the passenger oxygen masks had just deployed in the cabin. With all remaining CCM's returning to their stations to go on oxygen, the SCCM re-entered the cockpit for the third time and informed the Captain that the masks had deployed. The Captain told the SCCM that he was levelling the aircraft and returning to EICK. He also advised the SCCM that if the passengers wanted to go on oxygen they could, but that there was really no need to. The SCCM returned to her station and went on oxygen.

At approximately FL 141, the Captain selected "Alt Hold" on the MCP and then made a PA to inform the passengers of the situation. He advised them that the actual height of the aircraft did not necessarily require the use of oxygen, but that if anyone felt they needed it they should use it. The Captain then requested descent from ATC for EICK.

An initial descent clearance was given by ATC for FL 100. With the F/O still partially on oxygen, the Captain (PF) engaged the AP and the aircraft commenced its descent. In the cabin, the SCCM briefed the other CCM's on the situation. Some passengers were recognized as being slightly upset, so the SCCM went to the cockpit and suggested to the Captain that maybe passengers would be more comfortable if they were told to put on their oxygen masks. This was agreed upon and the SCCM returned to the cabin and made a PA to that effect. During subsequent interviews, the Captain advised the investigation that:

> He could not fully recall the events that occurred during the initial descent from FL 140. His first recollection was that of approaching FL 070, where he received an onward decent to 3,500 ft.

> He felt that this memory loss might have been as a result of the high workload at the time, the need to return to EICK, the fact that the F/O was mildly incapacitated, his attempts to effectively communicate with the SCCM/passengers and the fact that EICK had gone to Cat II operations. The Captain could not recall whether he had asked for descent checks.

The F/O advised that:

> The Captain had called for descent checks on two occasions and had briefed for the CAT II approach.

On downwind (approximately 3,500ft) to RWY 17 at EICK, it was observed by both flight crew members that the aircraft had started to pressurise, and the differential pressure between the aircraft altitude and the cabin altitude was increasing. Efforts were then made by the flight crew to try and control the outflow valve through the manual system. Neither flight crew member could recall making any pressurisation pack switch selection during the descent.

The aircraft was then vectored for an ILS approach to RWY 17, where it landed at 0755 hours with a maximum cabin pressure of 7 pounds per square inch (p.s.i.) There were no reported injuries to crew or passengers.

1.2 PERSONNEL INFORMATION

1.2.1	***Commander***:	Male, aged 37 years
	Licence:	ATPL
	Periodic Check (PC):	30 October 2000
	Instrument Rating:	30 October 2000
	Last line check:	27 June 2000
	Medical certificate:	5 December 2000
	Flying experience:	Total Flying: 5802 hours
		Total on Type: 267 hours (P1)
		Last 90 days: 121 hours
		Last 28 days: 23 hours
		Last 24 hours: 1 hours 34 mins
	Duty Time:	Up to incident: 2 hours
	Rest Period:	Prior to incident: 16 hours 40 mins
1.2.2	***Co-pilot (F/O):***	Male, aged 34 years
	Licence:	ATPL
	Periodic Check (PC):	13 November 2000
	Instrument Rating:	13 November 2000

Last line check:	29 July 2000
Medical certificate:	25 February 2000
Flying experience:	Total Flying: 2216 hours Total on Type: 216 hours (P2) Last 90 days: 98 hours Last 28 days: 19 hours Last 24 hours: 1 hours 34 mins
Duty Time:	Up to incident: 2 hours
Rest Period:	Prior to incident: 16 hours 40 mins

1.2.3 ***SCCM:*** Female, aged 34 years

Service with company: 12 years

1.2.4 Training Records

The Captain joined the company in April 1988. Initially qualifying on Shorts 360, he flew a number of different types as co-pilot including B737/200, B747/100 and the Fokker 50. In August 1999 he was upgraded to Commander on Fokker 50 and in June 2000 he converted onto B737/300/500 series aircraft. During both his conversions onto B737, he received the full syllabus of training for that type, which included simulator training for pressurisation failures such as "Auto-Fail" and "Rapid Depressurisation" emergency procedures.

The F/O joined the company in June 2000. Previous to that, he had worked with another company as a third pilot and co-pilot on Airbus 300. He qualified as a co-pilot on B737/300/500 series aircraft in late July 2000. Records show that he had received the full syllabus of training for that type, which included, simulator training for pressurisation failures such as, "Auto-Fail" and "Rapid Depressurisation" emergency procedures.

Both the Captain and the F/O had received training in the principles of Crew Resource Management (CRM), having completed the Operators Multi-Crew Course (MCC). The SCCM completed a CRM Course approximately six years ago.

1.3 AIRCRAFT INFORMATION

1.3.1 Leading Particulars

Registration:	EI-CDB
Manufacturer:	Boeing
Model:	737-548
Serial No:	24919
Year of Manufacture:	December 1990
Engines:	Two CFM 56 – 3B1
Certificate of Registration:	Valid
Certificate of Airworthiness:	Valid

1.3.2 Technical

A technical inspection, which was carried out on EI-CDB after the incident, determined that the pressurisation system, when correctly configured, was fully serviceable.

1.3.3 Aircraft Systems

1.3.3.1 Pressurisation System Description

Cabin pressurisation is controlled during all phases of airplane operation by the cabin pressure control system. The cabin pressure control system includes two control modes, which are available by selecting automatic/standby (AUTO/STANDBY) and a manual (MAN) pilot-controlled mode. The system uses bleed air supplied by the engines and distributed to the air conditioning system. Pressurisation and ventilation is controlled by modulating the outflow valve and the overboard exhaust valve. Cabin altitude is normally rate-controlled by the cabin pressure controller up to a cabin altitude of 8,000 ft at the airplane maximum certified ceiling of 37,000 ft.

The AUTO system consists of two identical controllers, with one controller alternately sequenced as the primary operational controller for each new flight. The other automatic controller is immediately available as a backup. In the AUTO or STANDBY mode, the pressurisation control panel is used to preset two altitudes into the auto controllers:

- FLT ALT (flight or cruise altitude).
- LAND ALT (landing or destination airport altitude).

Take-off airport altitude (actual cabin altitude) is fed into the auto controllers at all times when on the ground. The air/ground safety sensor signals whether the airplane is on the ground or in the air.

On the ground, the controller modulates the outflow valve toward close and the cabin begins to pre-pressurised. This ground pressurisation of the cabin makes the transition to pressurised flight more gradual for the passengers and crew, and also gives the system better response to ground effect pressure changes during takeoff. In the air, the auto controller maintains a proportional pressure differential between airplane and cabin altitude. By increasing the cabin altitude at a rate proportional to the airplane climb rate, cabin altitude change is held to the minimum rate required. The cruise mode is activated when the airplane climbs to within 0.25 p.s.i. of the selected FLT ALT, while the descent mode is activated when the airplane descends 0.25 p.s.i. below the selected FLT ALT. The cabin begins a proportional descent to slightly below the selected LAND ALT.

The controller programs the cabin to land slightly pressurised, so that rapid changes in altitude during approach result in minimum cabin pressure changes. While taxying in, the controller drives the outflow valve slowly to the full open position depressurising the cabin.

A green manual (MAN) light illuminates with the pressurisation mode selector, in the MAN position. Manual control of the cabin altitude is used if both the AUTO and STANDBY modes are inoperative. In the MAN mode, the outflow valve position switch is used to modulate the outflow valve by monitoring the cabin altitude panel and valve position on the outflow valve position indicator. A separate DC motor, powered by the DC standby bus, drives the outflow valve at a slower rate than the automatic modes. Outflow valve full range of motion takes up to 20 seconds.

1.4 FLIGHT RECORDERS

1.4.1 Cockpit Voice Recorder (CVR)

A Fairchild 93A100-80 CVR (30 minute loop) was fitted to EI-CDB. After a brief technical inspection of the pressurisation system at EICK, the aircraft was re-positioned to its home base for further examination. As the operator did not remove the CVR after the aircraft had landed at EICK, the entire incident recording was taped over during the transit to Dublin Airport (EIDW).

1.4.2 Flight Data Recorder (FDR)

A Sundstrand 980-4100-DXUN FDR was fitted to EI-CDB. The FDR was down loaded and considered to be in good working order, as all the declared parameters were recorded. Analysis of the FDR determined that the both pressurisation packs were in the "Off" position for take-off and remained in that position until the aircraft descended back down through FL 095. An extract of the FDR covering the pertinent events from the time the aircraft becomes airborne until weight-on-wheels (W.O.W) is recorded, is presented as **Appendix A** to the report.

1.5 MEDICAL INFORMATION

1.5.1 General

The F/O (PF) felt himself becoming incapacitated and decided to use his oxygen at a cabin altitude of approximately 12,500 ft. At no stage in the incident flight did the Captain don his oxygen mask or indeed feel a personal need to go on oxygen.

1.5.2 Incapacitation

In the context of aviation, it is recognized that there are varying degrees of incapacitation. These can range from being partially or mildly incapacitated, where there is a reduction in capacity of an individual to perform, to total incapacitation, where an individual is totally removed from the system as an effective component. Some examples include, a change in personality, impaired thinking or judgement, slow mental reactions, muscular in-coordination, diminished vision and hearing, impairment of memory and unconsciousness.

1.5.3 Barometric Pressure/Barotrauma

With increasing altitude, there is a decrease in the density of the atmosphere and an exponential decrease in the barometric pressure. Associated with this pressure event are other phenomena such as temperature drop. From a biological viewpoint, the barometric pressure drop is the most specific feature of the altitude climate. The relationship between barometric pressure and operating ceiling of aircraft is shown in Figure 1.

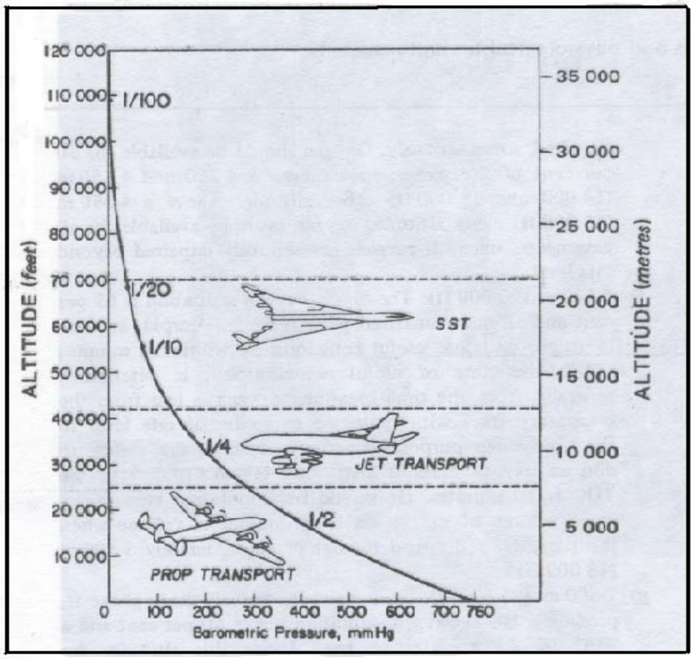

Figure 1

A matter of practical importance is that barotraumas (bodily effects of changes in barometric pressure) may occur at low altitudes because of the steep slope of the altitude pressure curve at lower levels. Even normal shifts in pressurised cabins can result in barotrauma since descent from only 6,500 ft to sea level entails a pressure differential of 150 mm Hg. The highest rate of barometric change occurs below 10,000 ft.

1.5.3 Hypoxia

A most important characteristic of biological significance of the flight environment is the decrease in partial pressure of oxygen with increasing altitude. Hypoxia can, for practical purposes be defined as, decreased amounts of oxygen in organs and tissues, i.e. less than the physiologically normal amount. With the increase in altitude, the air pressure decreases and without a supplemental oxygen supply or a pressurised cabin, the amount of oxygen being absorbed through the membranes of the lungs becomes insufficient to support the functions of the various body tissues, including the brain.

The symptoms produced in the body by hypoxia are both subjective and objective. Rarely are all the signs and symptoms found in any one person. Table 1 below, shows common signs and symptoms, which might occur.

It is difficult to state precisely at what altitude a given individual will show symptoms. The threshold of hypoxia is generally considered to be 3,300 ft since no demonstrable physiological reaction to decrease atmospheric pressure has been reported below that height. In practice, however, a significant decrement in performance does not occur as low as that, but as altitude increases above that level, the first symptoms of hypoxia begin to appear and a more realistic threshold would be around 5,000 ft. What is of main concern is that the very nature of hypoxia itself is such that the pilot can become the poorest judge of when he or she is suffering from its insidious effects.

Subjective Symptoms	INCREASING HYPOXIA	Objective Symptoms
Breathlessness		Hyperventilation
Headache		Yawning
Dizziness		Tremor
Nausea		Sweating
Feeling of warmth about face		Pallor
Dimness of vision		Cyanosis
Blurring of vision		Drawn, anxious faces
Double vision		Tachycardia (Rapid beat)
Confusion; exhilaration		Bradycardia (Slow beat)
Sleepiness		Poor judgement
Faintness		Slurred speech
Weakness		In co-ordination
Stupor		Unconsciousness; Convulsions
↓		

Table 1

A description of the threshold altitudes and physiological limitations encountered during flight due to hypoxia is presented as **Appendix B** to the report.

1.6 ORGANISATIONAL AND MANAGEMENT

The Operator's **Operations Manual (Part A)** – Section 8.8 covers operating procedures for oxygen requirements. Under Para 1.2, Pressurisation Failure, the following is stated:

"In the event of a pressurisation failure, all flight crew members must use oxygen continuously after 30 minutes when the cabin altitude exceeds 10,000 ft and at all times when the cabin altitude exceeds 13,000 ft".

The Operator's **Operations Manual (Part B)** requires that, *"on passing 10,000 ft, the flight crew will, "Check Pressurisation".*

1.7 ADDITIONAL INFORMATION

1.7.1 Checklists (normal)

The Operator's **Normal Checklist** covers the normal checklist for all phases of flight. With specific regard to pressurisation, the following checklist actions are required to be completed by the flight crew:

Before Start…………AIR COND & PRESS………PACK(S), BLEEDS ON, SET
Cleared for Start……AIR CONDITIONING PACKS…..……………………OFF
After Start…………..AIR COND & PRESS…...…………..………....PACKS ON
After Take-off………AIR COND & PRESS…..……….….………PACKS SET

1.7.2 Checklist (Non-normal)

The Operator's **Quick Reference Handbook (QRH)** covers, among other things a checklist for use by flight crew to cope with non-normal situations, for example, failures/warnings of particular systems. The non-normal checklist begins with steps to correct the situation or condition. It also assumes that system controls are in the normal configuration for the phase of the flight, prior to the initiation of the non-normal procedures. While the non-normal checklist covers a number of Air Conditioning and Pressurisation failures, the main events would be considered:

Emergency Descent - with the condition that the flight crew are unable to control cabin pressure with the airplane above 14,000 ft Mean sea-level (MSL);
Rapid Depressurisation - with the condition that a rapid loss of cabin pressure occurs when the airplane altitude is above 14,000 ft MSL; and
Auto Fail – the Auto Fail light illuminated indicates a controller fault or loss of power in the operational controller.

With regard to the use of crew oxygen regulators, the non-normal checklist for emergency descent requires that: "*Flight crew must use oxygen when the cabin altitude is above 10,000 ft. To conserve oxygen, position the normal 100% selector to NORMAL*".

2. ANALYSIS

2.1 Pre Auto-Fail

Analysis of the FDR has determined that the air conditioning packs were not initially switched "On" during the "After-start" checks and remained in the "Off" position until the aircraft descended back down through FL 095 on its return to EICK. With pack switches in the "Off" position engine bleed air is unable to pass through the air conditioning packs and thus the aircraft is unable to pressurise. The non-pressurisation of the aircraft caused the cabin altitude to rise with the aircraft altitude.

The flight crew were subjected to a number of awkward technical and operational issues during their preparation for flight. While not uncommon for flight operations, these problems were cumulative in nature, occurred during different critical times and would be considered an obvious source of distraction to the flight crew.

The problem of non-selection of switches is not uncommon in aviation. Whilst the potential consequences of incorrect setting of switches can vary, they are nevertheless symptomatic of the same problem. The problem being that the pre-departure procedures and drills may be incomplete, wrongly completed, or in some cases omitted. Factors such as tiredness, rushing or being rushed, distractions, crews not working as a team, not cross checking each other's actions, not communicating effectively, can all contribute in one way or another to the problem. As work pressure increases, the more likely an individual is to make a mistake, due the effects of stress.

Standard Operating Procedures **(SOP's)** are procedures, which afford maximum safety and protection to the aircraft, passengers, and crew. The application of SOP's, provide flight crews with the best means of ensuring that the possibility of error is minimized, thereby reducing the likelihood of an error chain developing.

The Operator's **Operating Procedures** emphasise that normal checklists are considered reference checklist and therefore require that the checklist will be used on every flight and phase of operation for which a checklist exists. Normal operations dictate that the PF will initially pre-position the switches to their required selection. The checklist is then called for by the PF and the Pilot-Not-Flying (PNF) reads out the checklist using the challenge and response method. Both the PF and the PNF are required to verify switch position or status. In addition, the checklist will only be called complete when all items have been accomplished and the required responses given. At that time, the pilot reading the checklist will announce, "(Checklist name) complete". If any item has not been completed when challenged, the checklist must be held until that item has been accomplished.

The Operator's **Normal Checklist** requires flight crew action for air conditioning/pressurisation on four separate occasions, namely "Before-Start/Cleared for Start/After-Start/and After Take-off". A subsequent discussion with both flight crew members determined that neither flight crew member could recall or confirm whether the "After-Start" checklist had been fully completed. The continued distractions that occurred during preparation for flight should have acted as a reminder to both flight crew members that there was a strong likelihood that a check may have been missed. In the event, it is clear that both flight crew members did not adhere to the Operator's SOP's with regard to completion and verification of the normal checklist, as the packs were not selected on and the flight crew took-off under the assumption that the pressurisation system was properly configured.

The illumination of the amber "Auto Fail" light on the forward overhead panel provides an indication to the flight crew that a failure has occurred in the automatic pressurisation control. "Auto Fail" will come on if any of the following conditions occur:

Loss of DC Power
Controller fault in the operational Controller
Excessive rate of cabin pressure change (1,800 ft/min)
High cabin altitude (above 13,875 ft)

Under normal pressurised conditions, if the illumination of the "Auto Fail" light occurs, the pressurisation control automatically transfers to the other automatic control (Standby Mode).

Selection of the pressurisation selector from "Auto Mode" to "Standby Mode" extinguishes the amber "Auto Fail" light and illuminates the green "Standby Mode" light on the panel. The green light signifies that the pressurisation system is now operating in the "Standby Mode". However, it is not an indication that the pressurisation system is functioning correctly. This can only be confirmed through the monitoring of the cabin rate of climb and the differential pressure on the forward overhead cabin altitude panel.

2.2 Post Auto-Fail

The "Auto Fail" light illuminated on EI-CDB shortly after take-off. It is considered most likely that this occurred as a result of an excessive rate of cabin pressure change being sensed by the automatic controller. In the belief that the automatic pressurisation control had failed, the flight crew continued with the "After take-off" checks and sourced the non-normal checklist for "Auto Fail".

The Operator's **Quick Reference Handbook (QRH)** non-normal checklist assumes that system controls are in the normal configuration for the phase of the flight, prior to the initiation of the non-normal procedures. During the fault analysis of a particular failure, CRM principles and airmanship should provide for the determination of what is actually set on the system and what is the true condition of the system.

It is clear that any fault analysis that may have been carried out by the flight crew after the initial illumination of the "Auto Fail" light proved inadequate, as the true selection/condition of the cabin pressurisation panel and the cabin altitude panel had not been determined. In solely relying on the non-normal checklist for "Auto Fail", the pressurisation mode selector was selected to "Standby Mode", the "Auto Fail" light extinguished and the green "Standby Mode" light came on. The flight crew then made the assumption that the problem had been solved and that the pressurisation system was operating correctly.

As the aircraft climbed through FL 100, the cabin altitude aural warning horn sounded, indicating that the cabin altitude had reached 10,000 ft MSL. The aircraft was then descended from FL 110 to FL 100, where it levelled for approximately 2 minutes. The flight crew reported some confusion with regard to the location of the cabin altitude warning cut out button and the cabin/flight altitude placard. Having converted onto type six months previous to this incident, both flight crew members had received recent training in the operation of the pressurisation system. In any event, it is possible that this confusion caused an additional source of stress and distraction for the flight crew, as it would appear that no fault analysis was carried out at that time on the cabin altitude warning itself. The flight crew re-confirmed the non-normal checklist for "Auto Fail" and in the continued assumption that the pressurisation was operating correctly, albeit in "Standby Mode", the climb was recommenced for FL 290.

The on-set of light-headedness would appear to have provided the instigator for the F/O (PF) to determine the true condition of the pressurisation system. The F/O then advises the Captain of the condition of the cabin altitude panel, in particular, that the masks would drop if they continued to climb. In addition to this, the SCCM enters the cockpit for the second time and provides vital clues regarding the condition of the cabin. However, with the F/O partially on oxygen, the Captain (now PF) allows the aircraft to continue its climb. Further attempts to stabilize the cabin continued with the selection of "MAN Mode" and the manipulation of the outflow valves. While movement of the out flow valve indicator on the forward overhead panel would have occurred, the action would of had no effect on the pressurisation system, as the aircraft was not pressurised.

The automatic deployment of the cabin oxygen masks should normally occur when the cabin altitude comes within the design range of 13,650 ft MSL and 14,350 ft MSL. The FDR does not have the facility to record the time of actual deployment. The ambient pressure corrected to sea level at EICK on the day of the incident was 994 hPa. The FDR records altimeter settings of 1013 hPa. With the aircraft reaching a maximum level of FL 142 and levelling at FL 141, a conversion to MSL indicates that the aircraft cabin altitude would have most likely reached a maximum of 13,638 ft MSL and levelled at 13,574 ft MSL.

The third entry of the SCCM onto the flight occurred almost immediately after the cabin masks automatically deployed and at that time the Captain advised her that he was levelling the aircraft. This would indicate that mask deployment occurred somewhere within the lower segment of the design range. Remaining at FL 141 for approximately 1 minute, the Captain (PF) then initiated an autopilot descent for EICK. The total time that the crew members and passengers experienced cabin pressure at or above 10,000 ft MSL was approximately 12 minutes.

The absence of the CVR denied the investigation of vital information regarding the overall cockpit environment, the fault analysis of the flight crew and the actions carried out. It is therefore not possible to determine whether the aircraft would have kept climbing in its un-pressurised condition without the intervention of the SCCM. What can be said is that the continued persistence of the SCCM in keeping the flight crew advised of the deteriorating cabin condition did, without doubt, contribute to the safe conclusion of this serious incident.

2.3 Incapacitation

Medical research has shown that the first symptoms of hypoxia begin to appear around 5,000 ft. However, the majority of commercial jet aircraft operate with cabin altitudes of between 7,000-8,000 ft and flight crews are both familiar and comfortable under these conditions. In reaching these cabin altitudes, aircraft cabins are designed with pressure differentials (difference between cabin pressure altitude and aircraft pressure altitude), which represent the compromise between the physiological ideal and the optimal technological design. In general, while the aircraft rate of climb is in the order of 2,000–3,000 ft/min, cabin pressure altitude changes at a rate of approximately 500 ft/min, which represents an acceptable physiological compromise to equilibrate pressures within the body and the surrounding environment, with a minimum of discomfort.

As EI-CDB continued its un-pressurised climb, the rate of cabin pressure change would have been similar to the aircraft's rate of climb, which was recorded to average 2,900 ft/min, up to FL 100 (where barometric pressure reduces at the fastest rate) and from FL 100 to FL 142, an average of 841 ft/min. Under normal pressurised conditions, the Boeing 737 - 500 cabin pressure will rise at approximately 500 ft/min. The rate of cabin pressure change experienced by the crew of EI-CDB was therefore far in excess of what they would normally be subjected to.

Bearing in mind the following:

- The rate of un-pressurised climb,
- The fact that the F/O (PF) became incapacitated at approximately FL 125,
- The aircraft was at or above FL 100 for over 12 minutes,
- Both flight crew members reported to have experienced some confusion regarding the location of the cabin altitude warning cut-out button and the cabin/flight altitude placard, and
- The fact that the Captain was unable to recall the events during the initial descent,

there is strong evidence to suggest that both the flight crew were suffering to some degree from the effects of altitude/hypoxia. With the F/O partially on oxygen and the Captain not choosing to go on oxygen, the possibility existed, whereby the Captain could have become incapacitated, as the aircraft continued its un-pressurised climb.

2.4 Operating Procedures – Training

The **Non-normal Checklist** for emergency descent and rapid depressurisation provides for a condition whereby the failure occurs above 14,000 ft MSL. While no specific non-normal checklist provides for the failure of the cabin to pressurise, the emergency descent does require that flight crew must use oxygen when the cabin altitude is above 10,000 ft MSL.

The Operator's **Operating Procedures** for oxygen requirements (Pressurisation Failures), are at variance with the non-normal checklist, as they specify that flight crew members must use oxygen continuously after 30 minutes, when the cabin altitude exceeds 10,000 ft and at all times when the cabin altitude exceeds 13,000 ft. The investigation is of the opinion that operating procedures should reflect the requirements of the QRH checklist. In addition, due to the varying nature and effects of altitude/hypoxia on different individuals, it would be considered prudent for flight crews to be required to don oxygen masks:-

i. Immediately after a cabin altitude warning system activates; and/or
ii. When the cabin altitude exceeds 10,000 ft; and/or
iii. When the integrity of the pressurisation system is considered suspect.

With regard to the operator's periodic checks and simulator training, it has been determined that a wide number of failures relating to the pressurisation system (both controllable and uncontrollable) are practiced during the climb/cruise phase of simulated flight. The aspect of an aircraft failing to pressurise in the climb is difficult to simulate. None the less, this type of failure can in itself be confusing to flight crew and insidious in nature. The investigation therefore considers it appropriate that more emphasis of this type of failure should be incorporated into the operator's ground school/CRM training.

3. CONCLUSIONS

(a) Findings

3.1 The aircraft pressurisation system was fully serviceable at the time of the incident.

3.2 Both flight crew members were medically fit, fully rested and licensed in accordance with IAA Regulations to undertake the flight.

3.3 Both flight crew members had converted on type, six (6) months previous to the incident and had completed and passed all technical and procedural syllabus training for the particular aircraft type.

3.4 Both flight crew members failed to adhere to the Operator's SOP's in relation to completion and verification of the normal checklist. However, it is recognized that the flight crew were subjected to a number of distractions during their preparation for flight.

3.5 When presented with the "Auto Fail" and the "Cabin Altitude" warning, neither flight crew member carried out a thorough analysis of the situation, in order to determine the true selection and condition of the pressurisation system.

3.6 The F/O recognized the possible on-set of incapacitation and as a result used his oxygen mask. The Captain did not go on his oxygen at any stage during the flight, nor did he feel a personal need to do so.

3.7 The Captain, who had overall responsibility for the conduct and safety of the flight, did not fully appreciate the significance of all the information provided to him during the unfolding of events and thus allowed the un-pressurised aircraft to continue its climb.

3.8 With the F/O partially on oxygen and the Captain not choosing to go on oxygen, the possibility existed, whereby the Captain could have become incapacitated, as the aircraft continued its un-pressurised climb.

3.9 The continued persistence of the SCCM in keeping the flight crew informed of the cabin situation was a major factor in ensuring the safe outcome of this serious incident.

3.10 Failure to preserve the contents of the CVR hindered certain aspects of this investigation.

3.11 The Operator's Operating Procedures for crew oxygen requirements were at variance with the Operator's QRH non-normal checklist.

(b) Causes

Failure of both flight crew members to complete and confirm their "After-start" and "After take-off" normal checklist for air conditioning and pressurisation and the lack of a thorough analysis of the initial "Auto Fail" and "Cabin Altitude" warning, caused the aircraft to be operated without pressurisation.

4. SAFETY RECOMMENDATIONS

It is recommended that:

4.1 In order to prevent the possible on-set of insidious hypoxia the Operator should reiterate, to their flight crews, the need to fully don oxygen masks, when the cabin altitude exceeds 10,000 ft and/or where the integrity of the pressurisation system is in doubt. **(SR 33 of 2001)**

4.2 The Operator should include in pilot recurrent training scenario's providing for insidious pressurisation failures, such as, failure of the aircraft to pressurise and insidious incapacitation. **(SR 34 of 2001)**

4.3 The Operator should amend operating procedures to reflect the requirements for the use of flight crew oxygen in the non-normal QRH checklist. **(SR 35 of 2001**)

4.4 The Operator should review the CRM principles specifically related to workload management and stress control. **(SR 36 of 2001)**

APPENDIX A

Event	Time	Alt 1013 (Note 1)	L/R Pack H/L	L/R Pack On/Off	Isol Valve	Elapsed Time	Remarks
Airborne	0721	00.	High	Off	Open		
Auto Fail on			High	Off	Open		After T/O
Cabin Alt Warning	072441	10,000 Approx	High	Off	Open	0 min 0	Avg ROC 2900 ft/min
1st Max Level	0725	11,104	High	Off	Open	0 min 19	
Back to FL 100	0726	10,000	High	Off	Open	1 min 19	Level 2 min
Re-commenced climb	0728	10,000	High	Off	Open	3 min 19	R.O.C 841 ft/min
2nd Max Level	0733	14,208	High	Off	Open	8 min 19	
Levelled	073310	14,144	High	Off	Open	8 min 29	1 min 20
Start Descent	073430	14,144	High	Off	Open	9 min 49	
Through FL 100	0737	10,000	High	Off	Open	12min 19	
Through FL 095	073730	9,504	Low	On	Closed		Packs on
Land on	0755	Ground W.O.W	Low	On	Closed		Flight time 34 min

Note 1. FDR readout on 1013 hPa, QNH 994 hPa

APPENDIX B

Threshold Altitudes and Physiological Limitations

The following are considered the threshold altitudes and physiological limitations encountered during flight due to hypoxia:

It is recognized that an infinite series of cabin altitude versus time profiles are physically possible between 8 000ft (where de-pressurisation is considered to begin) and the maximum cruising altitudes. Therefore, selected critical cabin altitudes for civil aviation planning are utilized. These are selected on the basis of physiological end-points and chosen at 8 000ft, 12 000ft, 14 000ft, 15 000ft, 20 000ft, 25 000ft, 34 000ft, 37 000ft and 45 000ft.

The physiological significance of these end-points is as follows:

(a) 8 000ft. The cabin altitude provides a blood oxygen saturation of approximately 93% in the resting individual who does not suffer from advanced cardiovascular or pulmonary disease. After suffering a hypoxic experience, this is the ceiling of the altitudes to which an individual should be returned for physiological compensatory mechanisms to effectively re-oxygenate the body. Operationally this is why this altitude has been prescribed as the altitude above which passenger oxygen must be available in specified amounts.

(b) 10 000ft. The cabin altitude provides a blood oxygen saturation of approximately 89%. After a period of time at this level, the more complex cerebral functions such as making mathematical computations begin to suffer and night vision is markedly impaired. This is why flight crew members must use oxygen when the cabin pressure altitude exceeds this level.

(c) 12 000ft. The blood oxygen saturation falls to approximately 87% and in addition to some arithmetical computations difficulties, short-term memory begins to be impaired and errors of omission increase with extended exposure. Oxygen must be used by each crew member on flight duty and provided for each other crew member during the flight when the cabin altitude is above this level in consideration of the physiological findings.

(d) 14 000ft. The blood oxygen saturation is approximately 83% and all persons are impaired to a greater or lesser extent with respect to mental function including intellectual and emotional alterations. At this cabin altitude, oxygen should be provided for at least 10% of the passengers, in recognition of the marginal physiological aspects and the problems experienced by a variable proportion of the general population.

(e) 15 000ft. This altitude gives a blood oxygen saturation of 80 % and all persons are impaired, some seriously. Oxygen should be available for 30 % of the passengers between 14 000 – 15 000ft cabin altitude. Above 15 000ft cabin altitude, oxygen must be available for all passengers, since all persons are seriously impaired beyond this level.

(f) 20 000ft. The blood oxygen saturation is 65% and all un-acclimatized persons become torpid, increase in stupor, and lose useful consciousness within 10 minutes (TUC, the time of useful consciousness).

(g) 25 000ft. This altitude and all those above it produce a blood oxygen saturation below 60 % and a TUC of 2.5 minutes. Above this altitude, the occurrence of bends begins to be a threat.

(h) 30 000ft. The TUC is approximately 30 seconds.
(i) 34 000ft. The TUC is approximately 22 seconds.
(j) 37 000ft. The TUC is approximately 18 seconds.
(k) 45 000ft. The TUC is approximately 15 seconds