FINAL REPORT

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In accordance with the provisions of SI 205 of 1997, the Chief Inspector of Accidents, on 16 January 2001, appointed Mr. John Hughes, Inspector of Accidents, as Investigator-in-Charge to conduct a Field Investigation into this occurrence and prepare a Synoptic Report.

Aircraft Type and Registration:	B737-500 EI-CDF
No. and Type of Engines:	Two CFM56-3B1 engines
Aircraft Serial Number:	25737
Year of Manufacture:	1992
Date and Time (UTC):	16 January 2001 @ 07.42 hrs
Location:	Near Wallesey, North Wales
Type of Flight:	Public Transport, (Scheduled)
Persons on Board:	25
Injuries:	None Reported
Nature of Damage:	Nil
Commanders Licence:	ATPL
Commanders Age:	40 years
Commanders Flying Experience:	8,000 hours
Information Source:	Aircraft Operator

SYNOPSIS

The aircraft had taken off from Dublin Airport and was climbing to FL 370 enroute for Dusseldorf, when over Wallasey, the aircraft suffered a complete loss of pressurisation. The Captain initially requested ATC permission to descend, but when this was refused due to traffic, a PAN was declared and the aircraft was immediately given clearance to descend. Meanwhile, the crew attempted to regain control of the cabin pressure using "Standby Mode" and "Manual Mode" but with no effect. As the aircraft passed FL 280, control of pressurisation was suddenly re-established. The crew decided to return to Dublin and the aircraft landed there without further incident.

NOTIFICATION

The Operator notified the AAIU of this occurrence on the day of the incident.

INTRODUCTION

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1. FACTUAL INFORMATION

1.1 History of the Flight

Flight EI-692 took-off from Dublin Airport at 0700 hours enroute for Dusseldorf. The aircraft was light with a crew of 6 and only 25 passengers on board. It climbed rapidly to FL370. At that flight level the crew noticed that the pressure differential reached 8.1 p.s.i. The cabin altitude rate then started to climb, initially to 800 ft/min, and reached a maximum of at least 4,000 ft./min. The Captain was expecting the aural altitude warning to sound at a cabin altititude of 10,000 ft. About 30 seconds later this warning sounded. The system went from "Auto" to "Standby" and the "Auto Fail" light came on. The system could not control the rate of cabin climb in "Standby Mode" nor in "Manual Mode".

The Captain reported that the outflow valve indicator indicated that the outflow valve was fully closed and that the duct bleed pressure was 20 p.s.i with engine "cruise power" set.

The crew warned the cabin staff that the oxygen masks might deploy. The crew requested clearance for descent, but this was initially denied by ATC due to traffic. The crew then declared a PAN and requested a lower altitude. This was immediately approved. As the aircraft descended through FL 280, control of the pressurisation was suddenly established. The crew then decided to return to Dublin at low altitude. The aircraft landed at Dublin without further incident. There were no reported injuries.

1.2 Captains Comments

The Captain said that both air conditioning packs were switched ON at the time. He said that following the failure of the automatic mode, both the "Auto Fail" light and the "Standby" light came on. When he put the mode selector switch to "Standby", the "Auto Fail" light went out. He could not be sure if he switched to Manual AC or Manual DC following the failure of the standby system to control the rate of cabin climb. The crew had donned their oxygen masks and the Captain informed the SCCM that as the cabin altitude was passing 13,000 ft the cabin oxygen would soon automatically deploy. Shortly afterwards the cabin masks dropped. There was a burning smell in the cockpit and cabin area.

The cabin altitude was climbing at a rate greater than 4000 ft/min and the cabin could have reached a maximum altitude of 16,000 ft. When control was re-established the system was in Manual mode. They then switched to Standby mode for the remainder of the flight.

1.3 Pressurisation System Description

1.3.1 General

Cabin pressurisation is controlled during all phases of airplane operation by the cabin pressure control system. The cabin pressure control system includes four control modes, which are available by selecting automatic (AUTO), standby (STANDBY), manual-AC (MAN-AC) or manual-DC (MAN-DC) pilot-controlled modes. 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. In the MAN mode, this valve can be operated independently either by an AC servo motor or by a DC servo motor. Under these circumstances the MANUAL annunciator light over the control panel comes on. Two safety over pressure relief valves are also incorporated into the system. Cabin altitude is normally rate-controlled by the cabin pressure controller up to a cabin altitude of 8,000 ft at the aircraft maximum certified ceiling of 37,000 ft.

In AUTO mode the pressure rate of change is automatically controlled. The outflow valve is controlled through the AC servo motor and the pressurisation control panel is used to preset two altitudes into the auto controller:

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

The STANDBY mode is a semi-automatic backup to the AUTO system but can also be independently selected by the crew. The outflow valve is now controlled through the DC servo motor. The pressure rate of change is manually controlled and the pressurisation control panel is used to preset two parameters into the auto controller:

- CABIN ALT
- CABIN RATE

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 thus depressurising the cabin. If certain limits are exceeded in AUTO mode during flight, then the system automatically reverts to STANDBY mode.

In the MAN-AC mode, the outflow valve position switch is used to operate the AC servo motor on the outflow valve by monitoring the cabin altitude panel and valve position on the outflow valve position indicator.

In the MAN-DC mode, the DC servo 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.

Pressurisation control is automatically transferred from AUTO mode to STANDBY mode, if the cabin pressure rate of change exceeds 1.0 p.s.i. per minute or cabin altitude exceeds 13,895 feet. The AUTO FAIL and STANDBY lights will then come on. However, if the standby mode is for any reason inoperative, only the AUTO FAIL light will come on.

There is a delta P module installed adjacent to the pressure controller, which provides a maximum of 7.45 psi with the pressurization mode selector in AUTO and 28,000 ft or below selected with the FLT ALT selector. A 7.80 P is provided when FLT ALT above 28,000 ft is selected with the pressurization mode selector in AUTO mode. STANDBY maximum pressure differential is 7.8 psi.

Under certain circumstances where either the AC power or the DC power is temporarily withdrawn from the system, the outflow valve shaft may be locked in position either by the AC actuator clutch or DC actuator clutch engagement. Under these circumstances the valve position indicator may indicate the outflow valve in the closed position.

1.3.2 Cabin Pressurisation Outflow Valve

(a) The outflow valve is a thrust recovery rotating gate valve which is driven by either a rotary dc electrical actuator or a rotary ac electrical actuator. Each actuator connectes to the gate shaft with an electrically operated spring-loaded clutch. AUTO and AC MANUAL modes operate the actuator. STANDBY and DC MANUAL modes operate the dc actuator. When either actuator is in operation the clutch to the other actuator is disengaged.

(b) With no electrical power to the clutches, the dc actuator clutch is spring loaded disengaged and the ac actuator clutch is spring loaded engaged. The clutches are energized when operating from the standby system or the manual dc system. With electrical power to the clutches, the dc actuator clutch is engaged and the ac actuator clutch is disengaged.

1.4 Aircraft Maintenance

1.4.1 Previous “C” Check.

The aircraft completed a “C” Check on 12 January 2001. During this check a cabin pressure controller (CPC) and an outflow valve had been replaced. The outflow valve on the aircraft had been removed for a bench check and its replacement was a repaired item which was tested and inspected by the Operator’s Maintenance Organisation and installed on the aircraft. The outflow valve and cabin pressure controller had previously been on EI-BXI (737-448) and EI-CDH (737-548) respectively.

Following its “C” check on the 12 January 2001, the single pack dispatchability confidences check was carried out. This checks the ability of the air conditioning pack(s) to provide sufficient inflow of air and the ability of the aircraft structure to maintain cabin pressure.

1.4.2 Checks carried out on arrival at Dublin

On arrival at Dublin following the incident, the Maintenance Organisation replaced the following items:

- Pressure Select Panel.

- Cabin Pressure Controller. (CPC)
- Two Pressure relief valves.
- One Outflow Valve and Heater.
- Supply Duct (found ruptured).

A test flight was then carried out and showed a cabin leakage rate, only a little outside the standard parameters (2250 ft/min). Leaks through doors were improved and the aircraft again test flown. The aircraft was returned to service on 18 January 2001.

1.4.3 Base Workshop Testing

Shop testing of the above units was carried out on all but the CPC which was returned to the U.S. manufacturer for testing. In-house tests of the remaining units showed no significant faults on any of the units tested. Results of these tests, carried out at the Maintenance Organisation's workshops, on the above components found:

(a) Pressure Select Panel: High resistance on FLT ALT reset knob and intermittent high resistance on LAND ALT button (Not considered to have given rise to the incident.)

(b) Outflow Valve: Minor resistance anomaly in position feedback circuit (not considered to be a problem.)

(c) Outflow heater gasket: No fault found.

Based on examination of photographs supplied by the event Operator, the aircraft manufacturers considered that the ruptured duct was not likely to result in the extremely high rate of cabin climb experienced during this incident. Following discussions between the Maintenance Organisation and the manufacturer, the outflow valve was dispatched to the manufacturer in the USA.

1.4.4 Component Manufacturers Testing

The report on the Outflow Valve showed that it had defects in addition to, and more significant than, those reported by the Organisation's workshop. However, no single defect could account for the incident.

The faults found by the manufacturer on both the CPC and Outflow Valve were as follows:

(a) Outflow Valve: DC motor shorted (Consequences for Manual and Standby Mode Operation).

(b) CPC: Temperature sensitivity anomaly in the autofault board.

The component manufacturers intended to carry out "closed loop testing" with the equipment but later advised that this was not possible. The report was forwarded to the aircraft manufacturers for analysis but no additional suggestions for a definite cause of this event was proposed.

1.5 Discussions Held

The Operator, Maintenance Organisation and Aircraft Manufacturer discussed at length the implications of the faults found. However no single fault could account for the rapid loss of pressurisation. It was concluded that a *"Combination of factors including failure of the CPC in AUTO mode and Defective Outflow Valves, coupled with the sensitivity of the system design with respect to activation of the pressure relief valves, could result in the incident observed".* The aircraft manufacturer did later respond as follows:

"When the 737 is operated at low gross weights, the airplane is capable of sustaining a high rate of climb up to the cruising altitude. If this is done, the airplane is capable of climbing faster than the cabin pressure controller logic can reduce the cabin pressure. This results in reaching the pressure differential where the overpressure relief valves open, venting cabin pressure"

Note: The relief valve is designed to open at 8.5 p.s.i. maximum.

1.6 CPC Testing

It emerged during discussions with the manufacturer, that testing of the CPC on Automated Test Equipment (ATE) can be problematic because of the various modification states possible on these units. At the time of this incident the Maintenance Organisation were sending CPC's to the U.K. for repair and shop report. However, this capability has now been restored to the home base. The Organisation stressed that this capability *"will improve the response time for troubleshooting problem units. As part of the work in this regard a set of required modifications will be establishwd and carried out on all units received in the shop. Shop test procedures will also be improved in relation to the outflow valves."*

1.7 Flight Data Recorder (FDR) Information

The FDR indicated that the aircraft climbed rapidly from take-off to 37,000 ft, reaching that altitude in 13 minutes. The maximum rate of climb recorded was 4320 ft/min.

It remained at that altitude for 2 min 21 secs. During that time the roll, pitch, airspeed and heading were constant. The aircraft then descended at a rate of 4736 ft/min reaching an altitude of 28,000 ft in a further 1 min 54 secs, when the system recovered. The descent then continued for 10 minutes to 10,000 ft at a rate of 1800 ft /min.

1.8 Threshold Altitudes and Physiological Limitations

The varying nature and effects of altitude/hypoxia on the individual and consequential increasing incapacitation of flight crew were covered in AAIU Report No.2001-014 which reported on the absence of pressurisation in flight on a similar B737-500 one month previously.

2. ANALYSIS

The Standby mode uses the D.C. servo motor to modulate the outflow valve. However, if this were shorted the motor would be inoperative. The Captain did not indicate if he switched to MAN-AC or MAN-DC. If he had switched to MAN-AC the system should have been able to close the outflow valve provided AC voltage was present.

The Captain indicated that the valve position indicator was indicating a closed valve. In fact the valve could have been locked in an unclosed position during that time.

If the differential pressure exceeded 8.5 p.s.i. then the two safety relief valves should have activated. This would cause an increase in cabin altitude. The Captain said that this exceeded 4,000 ft/min and that the cabin could have gone to 16,000 ft altitude. (This would have taken 2 minutes from the time at which the cabin was at 8,000 ft altitude. The aircraft was then about to descend). Control should have been automatically transferred when the cabin altitude rate exceeded 2000'/min, or the cabin altitude of 13,895 ft. As the aural altitude sounded within 30 seconds, the former figure would have initiated this warning. The Standby system light came on which would have indicated that the system was serviceable and available. However, when switched to that system the Captain said control was not possible.

He then switched to the MAN Mode. If the DC actuator motor of the outflow valve was shorted at that stage neither the STANDBY Mode or the MAN DC mode would have functioned. The Manual AC Mode should have operated provided that the DC actuator clutch was disengaged and that there was no DC supply to the AC actuator clutch to disengage same.

Considering the time taken to transmit a request to descend, making a PAN call and then initiating a descent, the loss of pressurisation control must have taken place just on arrival at 37,000 ft, for the aircraft only remained at that height for 2.3 minutes.

On descent from 37,000 ft to 28,000 ft the aircraft descended at a rate of 4857'/min and took a further 1.85 minutes to reach that altitude. Loss of pressurisation therefore lasted for about 4 minutes. If STANDBY-mode was then used effectively to control pressurisation then the DC actuator motor must have functioned properly from then to the end of the flight. This is at variance with the report from the manufacturers of the outflow valve which later indicated a DC actuator short circuit.

The Inspector agrees with the conclusions reached at a meeting between Representatives of the Operator, Aircraft Manufacturer and the Maintenance Organisation and quoted at 1.5 above. It also agrees with the final conclusions reached in the report as follows:

"*The fact that there were supply side difficulties could explain the length of time required for the system to stabilise during descent*".

3 CONCLUSIONS

3.1 Findings

(a) Control over the pressurisation was lost on reaching 37,000 ft and was regained during descent at 28,000 ft after approximately 4 minutes.

(b) Faults were subsequently found on the CPC by the manufacturer of the CPC and the outflow valve actuator.

(c) The supply duct was ruptured and was replaced.

(d) Two test flights were later required in order to confirm the Operator's dispatchability confidence check on this aircraft.

(e) At the time, CPC's with differing modification states existed throughout the Operator's fleet.

3.2 Causes

3.2.1 Faults were subsequently found by the manufacturer of the Cabin Pressure Controller (CPC) and the Outflow Valve which could have been inherent in the pressurisation control system at the time of the event leading to a late recovery in crew control.

3.2.2 An air supply duct was found ruptured. This also could have contributed to a late recovery in crew control combined with borderline aircraft sealing.

4. SAFETY RECOMMENDATIONS

4.1 A standard set of modifications for the CPC should be established over similar aircraft of the Operators' fleet. **(SR 27 of 2003)**

4.2 Shop test procedures at the Maintenance Organisations' base for the Outflow Valves should be improved. **(SR 28 of 2003)**

Note: The above Recommendations have also been made in the Organisation's Report.

4.3 As a result of the observation made at Para.1.5, the aircraft manufacturer should inform crews in the Flight Crew Training Manual (FCTM) that "light load, rapid ascent" condition has the potential for relief valve operation during such ascent. **(SR 29 of 2003)**