FINAL REPORT

AAIU Synoptic Report No: 2004-018
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In accordance with the provisions of SI 205 of 1997, the Chief Inspector of Accidents, on 3 February 2003, appointed Mr Graham Liddy as the Investigator-in-Charge to carry out a Field Investigation into this occurrence and prepare a Synoptic Report.

Aircraft Type and Registration:	Boeing 737-2T5 EI-CKS	
No. and Type of Engines:	2 x Pratt & Whitney JT8D-15A	
Aircraft Serial Number:	52990	
Year of Manufacture:	1980	
Date and Time (UTC):	3 February 2003 @ 13.00 hrs	
Location:	Dublin Airport (EIDW)	
Type of Flight:	Public Transport - Scheduled	
Persons on Board:	Crew - 5	Passengers - 122[1]
Injuries:	Crew - 0	Passengers - 0
Nature of Damage:	Minor damage to pressurisation system	
Commander's Licence:	Air Transport Pilot's Licence	
Commander's Details:	Male, aged 35 years	
Commander's Flying Experience:	6,864 hours of which 6,284 were on type	
Information Source:	AAIU Field Investigation	

SYNOPSIS

Immediately after take-off from Dublin, on a scheduled flight to Bristol, a bang was heard in the cabin area, which was followed by a blast of hot air, and what appeared to be smoke, entering into the cabin in the area of Row 10. The Cabin Staff Supervisor (CSS) alerted the Flight Crew. The Captain declared an emergency and made an immediate return to Dublin Airport. After landing safely, he ordered an emergency evacuation of the aircraft. Inspection of the aircraft found that a duct joint in the pressurisation system had failed. This allowed heated engine air to enter the cabin. The Investigation has made a total of four Safety Recommendations.

[1] This figure includes 2 infants

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1 FACTUAL INFORMATION

1.1 History of the Flight

The aircraft was on a scheduled public transport flight from Dublin to Bristol with 120 passengers, 2 infants and 5 crewmembers on board. Take-off weight was 48.7 tonnes and reduced thrust was used at a calculated Engine Pressure Ratio (EPR) of 2.07. The First Officer was the Pilot Flying (PF). Immediately after a normal take-off, a loud bang was heard in the cabin area. This was followed by a blast of hot air, and what appeared to be smoke, entering into the cabin in the area of Row 10. The CSS alerted the Flight Crew, by intercom, that there was intense heat and smoke in the cabin. The Flight Crew had not noticed any anomaly apart from a slight change in the pitch of the sound coming from the air conditioning vents in the cockpit. They noted that there was no fire warning and all engine indications and parameters were normal. However, based on the report of the CSS, the Captain decided to declare an emergency and advised ATC of the nature of the problem. At this point the aircraft levelled off at 2,000 ft and prepared for a visual right hand circuit to Runway (RWY) 28.

The Captain called the CSS to the cockpit and unlocked the security door. The Flight Crew subsequently stated that when the CSS entered the cockpit, she was followed by a blast of hot air and what appeared to be smoke. The Captain advised the CSS of his intentions and she returned to the main cabin to prepare for an emergency landing.

The No.3 Cabin Crew Member (CCM), who was seated in the jump seat at the rear of the main cabin, noticed grey smoke in the mid-cabin area. She was making her way forward when she heard the Captain summoning the CSS to the cockpit on the Public Address (PA) system. She proceeded to the front of the cabin where she waited with the No. 2 CCM for the CSS to return from the cockpit. When the CSS returned, she briefed the CCMs and decided that insufficient time was available to give an emergency briefing to the passengers. A safety check of the main cabin was completed.

In the cockpit the Captain took control of the aircraft and called for the “Smoke Removal” checklist from the Quick Reference Handbook (QRH). The CSS confirmed that conditions in the cabin had not improved. The landing was performed, at Flap 30°, without further incident. The Captain brought the aircraft to a stop on the runway and called the CSS to the cockpit to assess the situation. She informed him that the cabin was still smoky and very hot, and recommended an evacuation. The Captain and First Officer completed the post-landing check list, including shutting down the engines and lowering the flaps fully. The Captain then announced an evacuation of the cabin on the PA.

In the evacuation, the two forward doors, the two aft doors and the two over-wing exits were used. However the wind caught the inflated slides from both forward doors and tossed them about. The CSS stopped passengers from using these slides until they were caught and stabilised by the airport fire service who had arrived on scene. She directed passengers to use the other exits until the forward slides were secured. Consequently most of the evacuation took place through the over-wing exits and rear doors.

When the airport fire service teams arrived on the scene, they noted that some of the passengers, who had exited through the over-wing exit on the right side of the aircraft, had walked along the wing, toward the wing-tip. The fire service personnel were concerned that some of these passengers might try to jump off the leading edge of the wing, and could be sucked into the engines which where still winding down at this time. To prevent this, the fire service personnel directed these passengers back toward the fuselage, from whence they could slide down the lowered flaps, at the rear of the wing, in accordance with the standard procedure. The return of these passengers to the exit area caused some confusion and blockage in the actual over-wing exit. Some other fire service personnel, who were positioned near the flaps and who were helping passengers to slide down the wing flaps, noted that the rear exit on this side of the aircraft was now devoid of exiting passengers and they advised passengers, who were still in the cabin at the congested over-wing exit, to move to the rear and to use the rear door. A number of passengers followed this advice.

After the event, six passengers were taken to hospital for observation, including one pregnant woman who was taken to hospital as a precaution. Some of these passengers has suffered trips and falls during the evacuation.

1.2 Inspection of the Aircraft

Subsequent inspection of the aircraft found that a duct, of approximately 100 mm diameter, which carries engine bleed air from the right engine to the right air conditioning mix chamber, had separated from the mix chamber (**Appendix A, Photo 1**). The mix chambers are located in the main cabin under-floor area, immediately aft of the forward cargo bay, in an area known as the "snake pit". This area is underneath Row 10. When the duct separated, large volumes of engine bleed air, at a pressure, above ambient, of approximately 1 to 3 PSI (0.07 to 0.21 bar) and a temperature of approximately 320ºF (160ºC) entered the snake pit. This hot air then entered the main cabin area through the grill vents at the bottom of the sidewalls on both sides of the cabin fuselage. There was no evidence of burning or charring, and no obvious source of smoke generation. However, it was noted that the ducts behind the grills were heavily covered with a fine grey dust and lint (**Appendix A, Photo 2**).

The mix chamber carried a date of 10-18-79. Mix chambers made at that time used an older material specification. A material with improved heat resistance was used on later models of the mix chamber. There was evidence of a repair on the body of the chamber. It appears that the flange was removed and re-riveted during this repair. An adhesive bonding agent should have been used in conjunction with the rivets to secure the flange to the mix chamber. The Investigation found evidence of the presence of such a bonding agent. However, it was impossible to determine if this bonding agent had been applied at the time of the repair, or if it was the remains of the original agent applied when the flange was originally fitted to the mix chamber. Examination of the bonding material indicated that it was not bonded to the flange at the time of the rivet failure.

1.3 Aircraft Information

This aircraft had been constructed in 1980 and its serial number was 52990. At the time of the incident it had accumulated 58,413 flight hours and 43,800 cycles.

The B737-200 has a total of six emergency exits. There are two doors at the forward end of the cabin, one at each side of the cabin, and two similar doors at the aft end. These four normal exits are equipped with pneumatically inflated escape slides, which exiting passengers use to slide down from the cabin to ground level. There are also two over-wing exits situated about half way along the cabin. The over-wing exits are not equipped with slides. The standard procedure is that the Flight Crew shall select full extension of the landing flaps, located at the rear of the wing, after landing. The passengers using the over-wing exits should turn to the rear immediately after passing through the cabin exit, proceed the short distance to the rear of the wing and then slide down the extended flaps, in the section between the fuselage and the engine, and onto the ground.

1.4 System Description

Bleed air taken from each engine is utilized to pressurize and heat the cabin. The hot air directly from the engine can be as high as 80 PSI (5.5 bar) pressure and 500°F (260°C). After it is pre-cooled to between 350° and 400°F (177° and 205°C), it enters the air conditioning pack. The pack flow control valve regulates the amount of flow by regulating the pressure to between 15 and 30 PSI (1 and 2 bar) depending upon cabin environment requirements. The regulated air can completely pass through an air cycle machine (ACM) or a small amount of hot air can bypass the ACM as controlled by the temperature control valve and join again in the mix chamber where the hot and cold air is mixed for supply into the cabin. The air pressure at the hot side of the mix chamber, where the flange separation occurred, normally varies from between 1 and 3 PSI (0.07 and 0.21 bar) with a temperature of between 320° and 350°F (160° and 177°C) but can be as high at 12 PSI (0.82 bar) under rare, full heat requirements as necessary for extremely cold ambient conditions. The B737-200 airplane does not have a cabin re-circulation system; only fresh air enters the cabin and is exhausted through the cabin pressure control valve located towards the back of the airplane.

1.5 Component Description

The mix chamber is moulded in a glass-fibre material. The duct carrying the bleed air from each engine to its respective mix chamber is made of metal and is approximately 100 mm (4 inches) in diameter. To secure the duct to the composite material of the mix chamber, a stainless steel flange is riveted onto the input stub of the mix chamber. The flange features a raised lip. There is a similar raised lip end of the duct pipe. A clamp holds these 2 lips together. At the maximum operating pressure of 12 PSI, the duct would exert a force of approximately 150 lbs (667 Newton's), which would have to be carried by the rivets (and the bonding agent if present), which secures the flange to the mix chamber. At the normal operating pressures of 1 to 3 PSI, the force would be 12 lbs to 36 lbs (53 to160 Newton's).

A total of 8 countersunk rivets are used to secure the flange to the mix chamber. The rivets are 1/8" (approximately 3 mm) diameter. The flange, which fits over the inlet of the mix chamber, is countersunk on the outer surface. The rivets pass through the ring and the composite material of the inlet. The rivets are clenched on the inner face of the inlet. In order to prevent crushing of the composite material by the axial loads of the riveting clenching process, a 5/16" (8 mm) diameter washer is inserted underneath the rivet clench (**Appendix B**).

1.6 The Failure

The Investigation found that all eight rivets failed in shear. The internal pressure in the pipe then forced the duct, with the ring and clamp attached, to depart from the mix chamber. This break allowed the bleed air to vent into the snake pit. A search of the snake pit recovered five of the countersunk heads and three of the clenched ends of the rivets in question. Inspection of the rivets fragments showed that they were of the correct material and had been correctly formed. All but one of the recovered segments exhibited a major reduction of material at a point along the rivet shank close to the countersunk head (**Appendix A, Photo 3 and Photo 4**). It was also noted that the countersink in the flange penetrated virtually the full thickness of the wall of the flange. This resulted in the absence of any parallel section bore in the flange rivet hole, with the effect of producing a sharp edge on this hole. This sharp edge bore directly on the rivet shank at the end of the countersink section of the rivet (**Appendix B)**. At a point on the rivets corresponding to the countersunk edge, a gross reduction of diameter of the rivet shank was found. On some of the recovered rivets this reduction was approximately 90% of the cross sectional area. It was noted that this loss of material was caused by wear, rather than cutting, and is believed to be due to fretting. It was also noted that some wear of the rivet shank had also occurred where the rivet shank passed through the glass fibre material of the mix chamber. Some of the faces of the washers that were in contact with the composite material exhibited a polished surface, indicating movement. None of the holes in the composite material had broken or cracked at the adjacent edge, but were axially elongated by up to 0.075". Some elongation in the holes of the flange was also noted as shown in **Appendix A, Photo 5**.

Examination of the same joint on the left system of this aircraft shows some slight indications of axial movement of the ring.

A follow-up fleet examination of the operator's fleet of B737-200 aircraft, conducted later the same day, found movement in the flange of one other duct in one other aircraft. This aircraft had accumulated 45,596 flight hours and 45,184 cycles. The mix chamber in question was replaced before this aircraft returned to service.

There are previous incidents on the B737 where the glass fibre material of the mixing chamber failed in the area of this flange. However, this event appears to be the first reported case of separation of the duct due to failure of the rivets.

1.7 Interim safety recommendations

Two days after this event the AAIU issued an interim report that made the following interim safety Recommendations:

The Irish Aviation Authority should devise a scheme of inspection and/or replacement of the B737-200 affected rivets on the mix chambers, on an initial priority basis and on a recurring basis, and the IAA should require operators of these aircraft to implement such inspections. **(S.R. 1 of 2003)**

The Boeing Aeroplane Company should review this failure, and consider the generation of a suitable inspection program to prevent this failure on B737-200 aircraft. **(S.R. 2 of 2003)**

1.8 Response to interim safety recommendations

The IAA made the following response to the interim Safety Recommendation **(S.R. 1 of 2003)** on 23 February 2003:

"*The only B737-200 aircraft currently on the Irish civil register are with Ryanair which has notified the manufacturer for advice on the subject incident.*

That operator has also carried out a fleet-wide inspection for looseness in the subject bleed air duct joint and all similar duct joints on these aircraft such as to detect any other instances of worn rivets.

It is, furthermore, proposed by that operator to systematically remove the air mixer assemblies during scheduled maintenance on these aircraft and arrange to have the rivets replaced in the subject joints.

The Authority considers that the airline's proposed action is a sufficient airworthiness response to this incident for the moment and will monitor its implementation."

Boeing informed the Investigation that they proposed to issue a service letter in regard to this matter, and expected to accomplish this by the first quarter of 2004. This service letter would recommend replacement of the mix chamber with a more heat resistant material and would also use stronger fasteners to secure the duct flange. Boeing issued Service Letter, AIR CONDITIONING PACK MIX DUCT SEPARATION, 737-SL-21-061, on 6 August 2004.

1.9 Survival Aspects

The Investigation examined the Operator's Passenger Safety Card, and determined that it was sufficiently clear in showing the direction that passengers should take after exiting the over-wing exits (**Appendix C**). The Investigation also noted that the actual exit paths were clearly marked on the aircraft wing. However the Safety Card did not provide any guidance as to how passengers should get down off the wing. The Investigation is aware that some operators of B737 include, on their safety card, a visual drawing of passengers sliding down the fully extended flap. An example of the relevant sections of such a Safety Card is shown in **Appendix D.**

1.10 Cockpit voice recorder (CVR)

This aircraft was equipped with a standard CVR with the ability to continuously record the last half hour of audio information in the cockpit. When the Investigation arrived at the aircraft about one hour after the event, it found that the aircraft power was still on, and that the circuit breakers (CB) for the CVR had not been pulled. Such action would have switched off the recorder and ensured that the recording relating to the event was not over-taped. In the absence of such action, this potentially valuable evidence was lost to the Investigation. A review of the operator's procedures showed that these did not call for the CVR CB to be pulled after an event in order to preserve such evidence.

The same operator had another event two months previous to this event, where the CVR CB was also not pulled and valuable information was lost (ref AAIU Report 2004-006 http://www.aaiu.ie/upload/general/4757-0.pdf). In September 2002, the IAA issued Irish Aviation Authority (Operations) Order 2002, SI No. 437 of 2002, Part V, Aircraft Instruments, Equipment and Safety Devices, Paragraph 52, subparagraph 5, (f) states that the flight recorders (iii) ….. "*shall be de-activated, if practicable, after an accident or serious incident involving the aircraft in which they are installed and shall not be re-activated prior to retrieval for examination of the recorded data*"

At the time of the event that is the subject of this Investigation, the provisions of SI No. 437, in relation to the de-activation of flight recorders, had not been incorporated into the Operator's Operations Manual.

The AAIU, in a Draft Report and in the Final Report of the first event, made a Safety Recommendation to the operator that their Operations Manual should include advice to aircrew regarding the de-activation of the CVR in post accident and incident situations. This Safety Recommendation has been published on 20 February 2004, as SR 16 of 2004, which was after the event that is the subject of this investigation. The operator has subsequently advised the AAIU that they have accepted this Safety Recommendation.

2 ANALYSIS

2.1 The Failure

2.1.1 It is noted that at the time of this event, this aircraft had accumulated relatively high flight hours and cycles, and that it was 22 years old. The other aircraft on which the other defective mix chamber was found had completed a similar number of cycles but less flight hours.

2.1.2 Examination of the bonding material indicated that it had either failed a long time ago, or was not replaced during previous repairs of the mixing chamber. It was not possible to determine where or when these repairs were accomplished. The condition of the bonding material indicated that it was in situ for a considerable period of years before this event.

2.1.3 The rivet shanks were worn away by the sharp edges of the countersunk hole of the flange. Eventually the loss of material in the rivets was sufficient to cause some to fail by simple overload. This, in turn, led to overload of the adjacent worn rivets and ended in cascade failure of all the rivets. The Investigation is of the opinion that dome head rivets would have been more suitable in this application. This would have done away with the need to countersink the rivet holes and the consequent creation of the sharp edges that bore on the rivets. A possible remedy of this problem would be to replace the flange with a new design using dome head rivets without a countersink in the flange.

2.1.4 The blast of pressurised bleed air from the failed joint, rushing through the sidewall ducts and grills in the opposite direction to the normal air flow, dislodged the dust that had accumulated in these ducts and then carried the dust into the cabin, where it was mistaken for smoke. Given the presence of very hot air in the cabin, it was reasonable to confuse this visual dust with smoke.

2.1.5 The Flight Crew had initialled the "Smoke Removal" checklist and then decided to land immediately. If they had continued the flight, and had then proceeded with the full "Air Conditioning Smoke" checklist they would have turned off a sequence of systems, waiting after each step to see if the action stopped the smoke/fumes. If each action is not successful, then the subsequent checklist actions are taken until the problem is halted. One of the steps on the checklist is closing the isolation valve and the switching the air conditioning pack to OFF for each engine in turn. If the checklist item of turning off the air conditioning pack of the right engine had been reached, the source of the hot air (and consequent "smoke") would have been eradicated. However, it is important to note that the crew had no warning or indications on their instruments of the nature of the abnormality, but they were presented with the very real evidence of the hot air and "smoke" emanating from the main cabin. Consequently they had no assurance that the "Air Conditioning Smoke" would be successful in curing the problem, as they did not have a positive indication as to the cause of the problem.

The "Air Conditioning Smoke" checklist procedure is a somewhat lengthy process. The obvious resource that was immediately available to the Flight Crew was the major international airport from where they had just departed and where they could land again immediately. This was the course of action they selected, as opposed to continued trouble-shooting of the problem in flight. This Investigation concurs with their decision.

2.1.6 The action of the senior CSS in this event was both positive and assertive, and was a significant factor in the successful resolution of this emergency.

2.2 The Evacuation

2.2.1 There was confusion at the right over-wing exit, which delayed the evacuation. There were several factors in this confusion:

- The number of passengers using the over-wing exits was larger than usual in this case, as the forward exits were not available in the earlier part of the evacuation, because the forward slides were being tossed by the wind.

- Some passengers, having made their way through the over-wing exit, were unsure as to where they should go next and in particular how they should get down off the wing. The absence of information in the Safety Card, as to how to get off the wing, may have been a factor in this confusion.

- The Operator's Safety Card only shows passengers descending from the aircraft by means of a slide. It is possible that some of the passengers may have been looking for a slide to get down off the wing.

- The instructions of the fire service personnel to passengers, who were further out on the wing, to "Go Back" may have been heard and interpreted by passengers in the over-wing exit as a direction to go back into the fuselage.

- The advice of the fire service personnel to passengers still in the fuselage to use the rear exit would have been heard by passengers in the exit and caused confusion in the exit area.

- A significant part of the cabin crew resource was involved in sorting out the problems with the two forward slides, and therefore they were not available to sort out the confusion at the over-wing exits.

Such confusion can understandably arise in any emergency evacuation. The most effective solution is to prevent such confusion by ensuring that passengers are fully aware of the exit procedures, and in the case of over-wing exits, of how to get down off the wing.

2.2.2 There is no doubt that in this evacuation, some passengers, who had exited onto the wing, were unsure as to how to get from the wing onto the ground. The Investigation considers that an average passenger would more easily and more completely understand the pictorial information, as presented in **Appendix D**. This in turn would reduce the potential for confusion, such as arose in this evacuation.

3 CONCLUSIONS

3.1 The failure of the duct was caused by excessive wear of the rivets. This wear was caused by the sharp edges in the countersunk of the flange.

3.2 The age, flight hours and cycles of the aircraft were factors in this failure, as was the design of the rivet installation. A possible failure to replace the bonding material during a previous repair may also have been a factor.

3.3 The failure of the duct did not threaten the safety of the aircraft. However the manifestations of the failure in the cabin were sufficient to cause concern to the passengers and crew. This concern was the basis for the crew's decision to declare an emergency, to initiate an immediate return to Dublin Airport and to evacuate the airplane after landing.

3.4 The actions of the aircraft crew were appropriate and effective.

4 SAFETY RECOMMENDATIONS

4.1 The aircraft manufacturer should issue the proposed service letter that would include a recommendation for stronger fasteners connecting the flange to the mix chamber. **(SR 35 of 2004)**

In response to this recommendation in the Draft Report, Boeing issued Service Letter, 737-SL-21-061, on 6 August 2004.

4.2 The Operator should review their Safety Card to ensure that the card clarifies how passengers should get down from the aircraft wing, when using the over-wing exits in an emergency evacuation. **(SR 36 of 2004)**

In response to the Draft Report of this event, Ryanair stated that they were examining how they could best respond to this Safety Recommendation.

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Appendix A

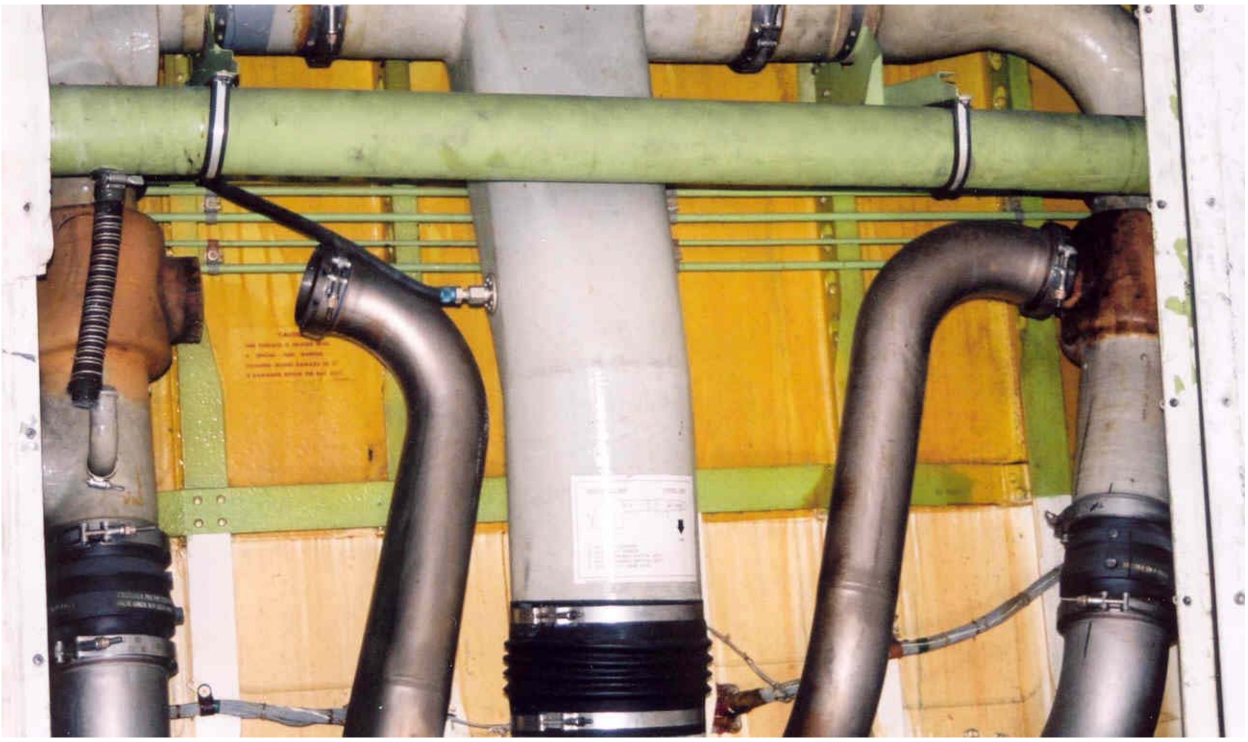


Photo 1

This photo shows the “snake pit”, as viewed from the forward cargo hold, looking aft with the rear screen removed. It shows the failed joint on the left. The mix chamber can be seen on the extreme left. The intact LH system can be seen on the right of the photo.

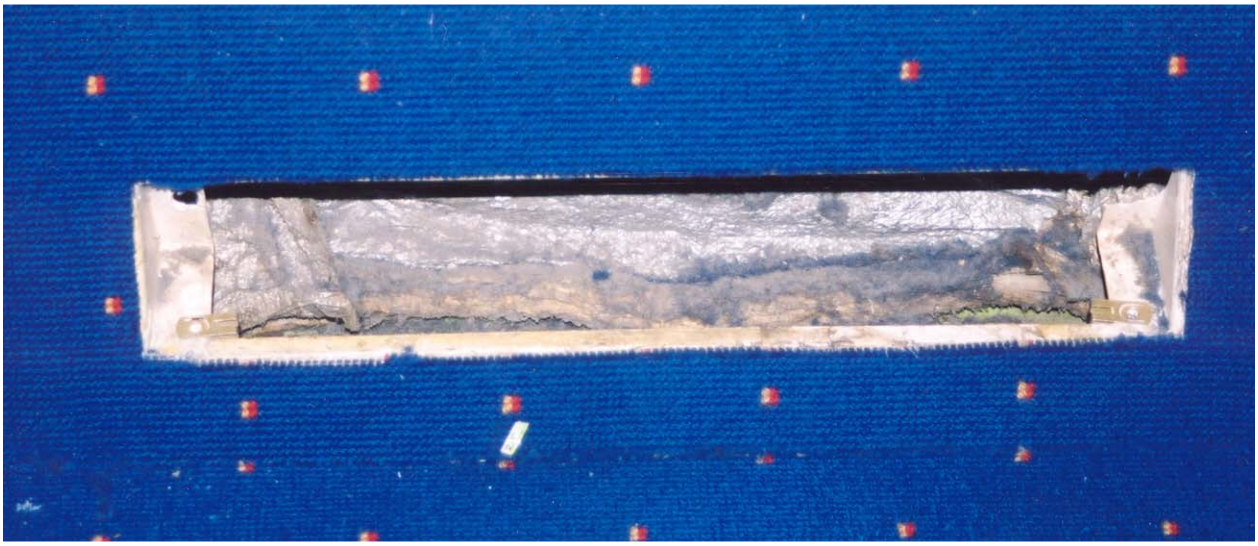


Photo 2

This shows one of the sidewall ducts with the grill removed. The dust and lint that caused the smoke effect can be seen in the duct.

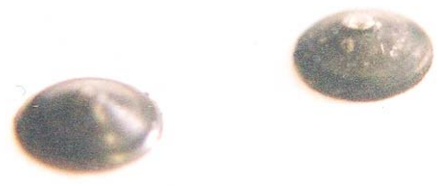


Photo 3

This shows the countersunk heads of two of the failed rivet segments recovered from the aircraft. It may be noted that the shank section has been worn almost fully through.

Photo 4

This shows the clenched end of the recovered rivets, with the washers still attached. The parallel shank section can be seen. The worn section is visible at the top of each rivet.

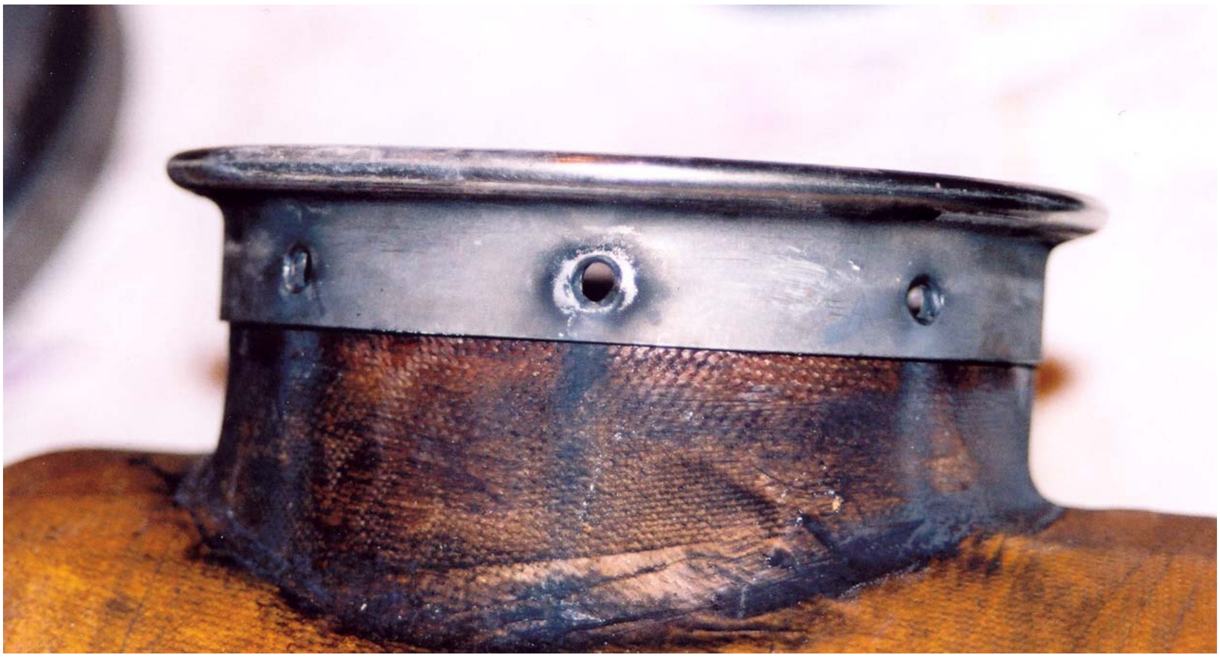
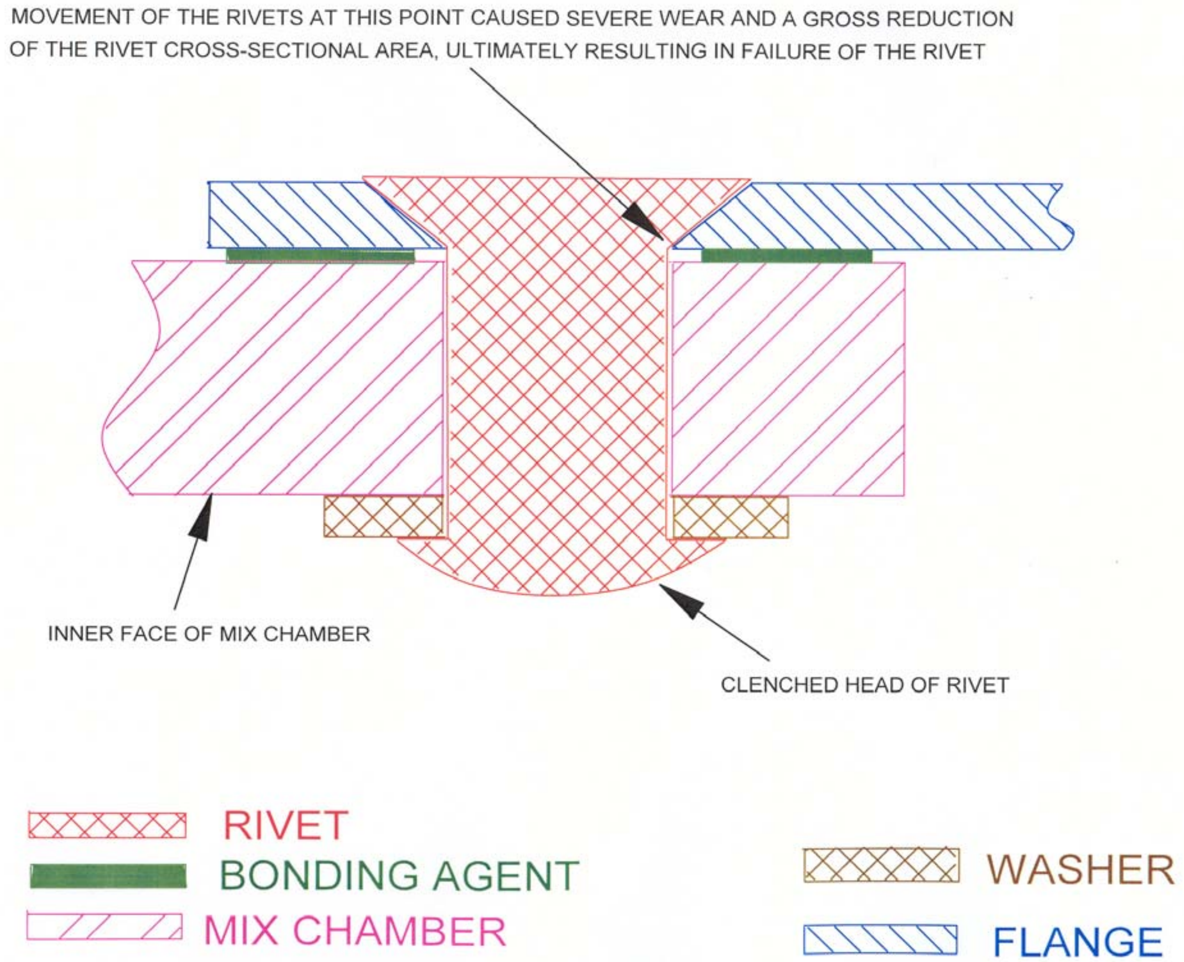


Photo 5

This shows the flange temporarily refitted to the mix chamber. The elongated holes in the flange can be seen.

Appendix B



This is a schematic drawing of the area where the failure occurred (not drawn to scale).

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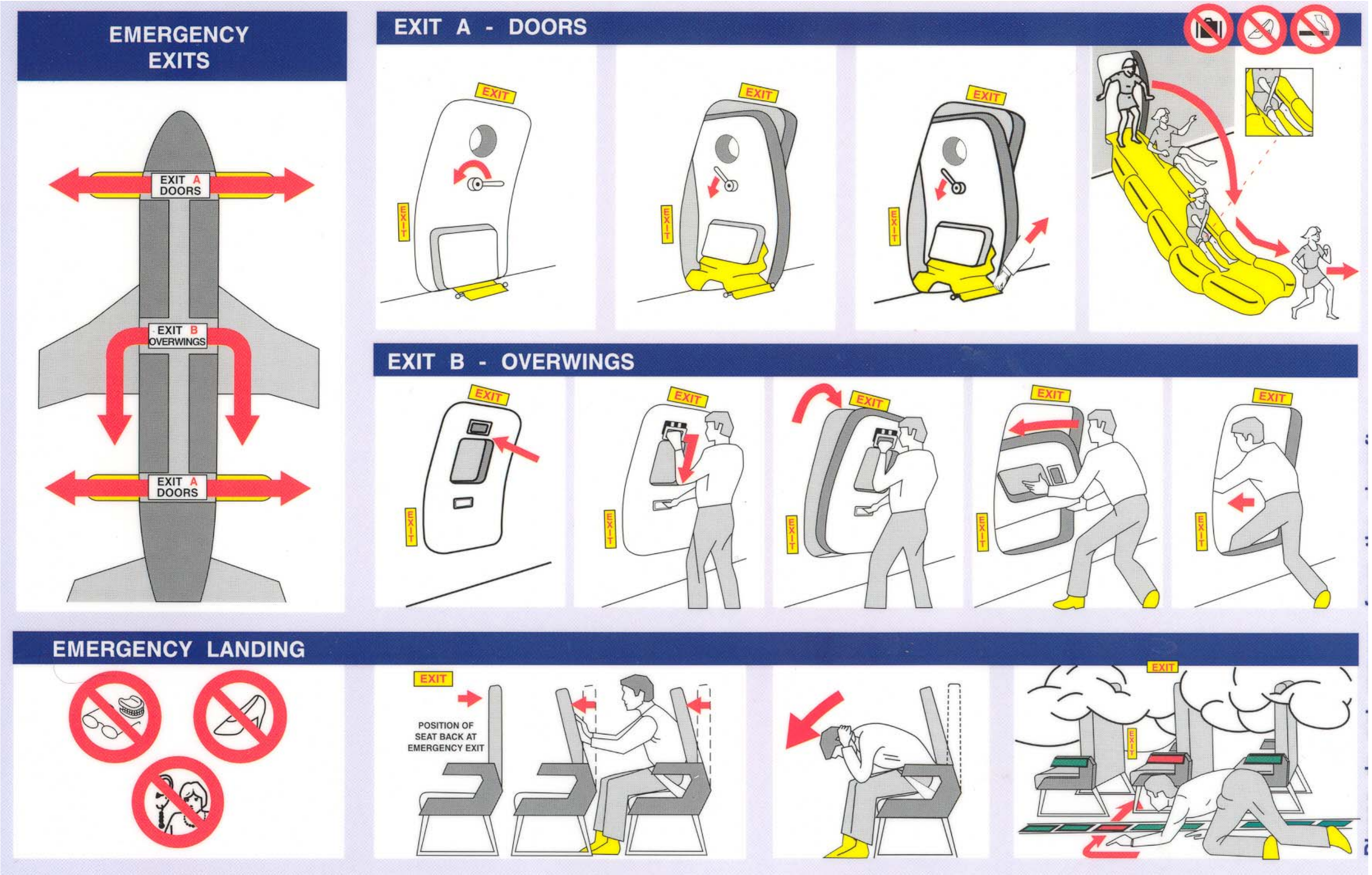
Appendix C



This is the Operator's Safety Card dealing with emergency evacuation procedures. It does not give obvious directions as to how passenger should get down off the wing.

Appendix D

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This is a Safety Card, used by another operator for a later version of the B737, for using the over-wing exits in an emergency evacuation. Note that it shows, pictorially, the path that passengers using the over-wing exit should take (upper left), and how they should get down off the wing (lower right).