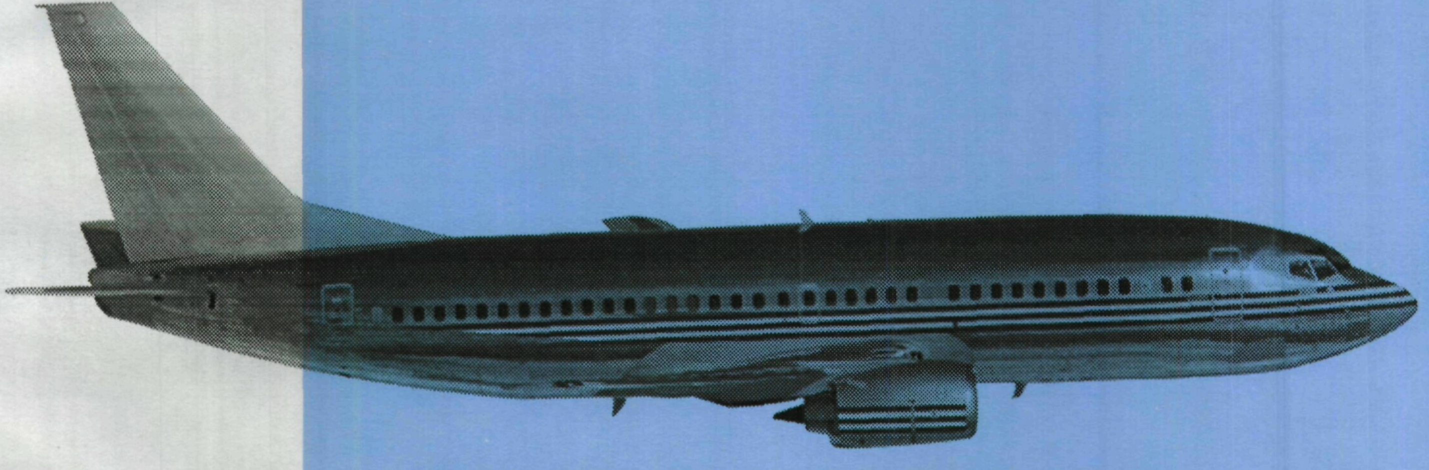
BUREAU OF AIR SAFETY INVESTIGATION REPORT

BASI Report
B/910/1309



Boeing 737-376
Sydney, NSW
21 December 1991

BASI
Bureau of Air Safety Investigation

DEPARTMENT OF Transport
AUSTRALIA

Department of Transport

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CONTENTS

GLOSSARY OF TERMS AND ABBREVIATIONS

ARB	Air Registration Board (UK), now CAA (UK)
BASI	Bureau of Air Safety Investigation
BCAR	British Civil Aircraft Requirement
CAA	Civil Aviation Authority
CAO	Civil Aviation Order
CFM	Commercial Fan Moteur
	(Designation of engines manufactured by GE/SNECMA)
DFDR	Digital Flight Data Recorder
EGT	Exhaust Gas Temperature
FA	Flight Attendant
FAA	Federal Aviation Administration (USA)
FAR	Federal Aviation Regulation (USA)
g	Gravity acceleration
ID	Plastic identification tag
LATg	Lateral forces as a percentage of g
N1	Engine fan speed
NTSB	National Transportation Safety Board (USA)
RPM	Revolutions per minute
UTC	Universal Co-ordinated Time

All times are Australian Eastern Summer Time (Co-ordinated Universal Time + 11 hours) unless otherwise indicated.

SYNOPSIS

On 21 December 1991, at 1646 hours Eastern Summer Time, a Boeing 737-376, VH-TAJ, operating a scheduled passenger service, landed at Sydney (Kingsford Smith) Airport.

Shortly after reverse thrust was selected, a failure occurred in the right engine. The aircraft veered abruptly from the runway centreline and oscillated laterally before being stabilised.

Two flight attendants who were in forward facing seats in the rear of the aircraft received minor injuries during the aircraft deceleration, when their restraint system permitted excessive lateral movement.

The investigation determined that the right engine failed following the ingestion of a thrust reverser cascade, which had detached as a result of a fatigue failure of the mounting flange. The flight attendants' seat and restraint system did not comply with applicable Australian design requirements.

1. FACTUAL INFORMATION

1.1 History of the flight

Boeing 737-376 registered VH-TAJ was conducting a scheduled passenger service from Brisbane, Queensland to Sydney, New South Wales with 116 passengers and seven crew. During the landing at Sydney, as maximum reverse thrust was attained at approximately 110 kts, one thrust reverser cascade segment fitted to the right engine separated from its mounting flanges and was ejected. It was carried forward by the reverse thrust airstream and ingested by the engine, which suffered extensive damage. The sudden engine failure and the resultant asymmetric reverse thrust caused the aircraft to be shaken laterally and to diverge from the runway centreline. Two FAs seated in the rear of the aircraft suffered minor injuries.

The aircraft was controlled within the confines of the runway. Rescue and fire services attended the aircraft after it had moved onto the taxiway and stopped. An evacuation was not required and the aircraft was subsequently towed to the terminal.

1.2 Injuries to persons

	Crew	Passengers	Others
Fatal	–	–	–
Serious	–	–	–
Minor	2	–	–
None	5	116	–

1.3 Damage to aircraft

Damage was confined to the right engine.

1.4 Other damage

No other damage was reported.

1.5 Personnel information

The aircraft crew were appropriately licensed and qualified to undertake the flight.

The two injured FAs were seated at the aft FA station adjacent to the left rear door (L2).

The FA seated closest to the door had been flying for 11 years, was 165 cm tall and weighed 55 kg. The other FA was on the inboard side of the seat, had been flying for four years, was 162 cm tall and weighed 48 kg.

1.6 Aircraft information

1.6.1 Leading particulars

Type	Boeing B737-376
Serial Number	23487
Year of manufacture	1986
Certificate of Registration	VH-TAJ—current at the time of the incident
Certificate of Airworthiness	Current at the time of the incident
Total airframe hours/cycles	13,730 hours/9,765 cycles
Engines	2 x CFM56-3B2

1.6.2 Thrust reverser cascade installation

Manufacturer	The Boeing Company
Failed cascade Part Number	315A1212-10
Position	Right engine thrust reverser, number 5 position
Date fitted	New with the aircraft in September 1986
Hours/cycles at failure	13,730 hours/9,765 cycles

Maintenance history:

• overhaul period	Every 20,000 hours
• in-service inspection	Every 3,000 hours concurrent with A16/A17 check
• last inspection	May 1991 at 11,732 hours/8,585 cycles
• inspection type	Visual
• hours/cycles since inspection	1,998 hours/1,180 cycles

1.7 Meteorological information

Although rain and runway standing water had been reported, there is no indication that weather conditions contributed to the incident.

1.8 Aids to navigation

Not relevant.

1.9 Communications

Not relevant.

1.10 Aerodrome information

Not relevant.

1.11 Flight recorders

The DFDR readout showed the touchdown at 16:43:00. The engine failure commenced 7.5 seconds later and was indicated by a rapid decrease in the right engine fan RPM (N1), a corresponding EGT increase and LATg excursions. Very rapid oscillations of LATg occurred for 1.5 seconds through to 16:43:09. There was a peak of 0.12g to the left at 16:43:09 then the lateral g moved to a peak of 0.14 to the right at 16:43:13. These movements corresponded with the aircraft's peak heading change and diversion from the runway centreline.

1.12 Wreckage and impact information

The right engine thrust reverser number 5 cascade was ingested through the inlet cowl and impacted the fan as the engine attained maximum reverse thrust RPM. Severe damage occurred to the fan assembly and to the cowl acoustic and abradable surfaces. Debris was ingested by the core, damaging the rotor and stator assemblies. Vibration-induced damage occurred to components mounted on the fan frame. One gearbox mounting link was fractured.

1.13 Medical and pathological information

One of the two injured FAs reported that on touchdown, they felt several large shudders and were 'thrown around like rag dolls'.

Both FAs later reported disabling discomfort from internal strains and bruising, and one was subsequently diagnosed as having a crack fracture of the fourth and sixth ribs on the left side. Each had sustained injuries consistent with the effects of movement within a loosely fitting restraint harness and pressure from the restraint harness straps.

1.14 Fire

Although smoke, flame and multiple detonations were reported at the time of the engine failure, there was no fire.

1.15 Survival aspects

Not relevant.

1.16 Tests and research

1.16.1 Cascade failure investigation

Post-flight inspection of the thrust reverser disclosed that the number 5 cascade on the outboard side of the right engine had been liberated. Only the cascade forward and rear flanges were recovered, these having remained attached to the torque box and to the rear support ring respectively by the four mounting bolts on each flange.

The failed flanges were forwarded to The Boeing Company for detailed analysis, concurrent with an extensive investigation of the cascade design and operating characteristics. The Boeing report concluded that the cascade segments can be preloaded during installation to a greater extent than anticipated, and this preloading, coupled with the dynamic loading applied during reverse thrust, provides sufficient combined loading on the forward flange to introduce fatigue cracking. If the cracking progresses far enough, the forward flange is weakened to the point where the remaining material will experience a ductile failure.

An evaluation carried out by the CAA Materials Evaluation Facility concluded that the only stress concentrator present was the radius in the change of section of the forward flange to the vanes. The fatigue evident in the forward flange may be related to the application of forces, including those applied by the thrust reverser actuating mechanism, causing flexing of one corner of the flange.

1.16.2 Fleet inspections

An immediate visual inspection of the fleet by the operator found another two cracked cascades. Subsequent visual, dye penetrant and eddy current inspection techniques located further examples of cracked cascades.

On 13 January 1992, Boeing issued a service letter requiring all operators to perform once only eddy current inspections of the cascades. By 2 February 1993 Boeing had received reports from eleven operators who had inspected a total of 146 aircraft. From those inspections a total of 73 cracked cascades were found on 38 aircraft.

The cracking is unique to the CFM 56-3 equipped aircraft, and has been found on cascades fitted to both left and right engines. All cracks examined by Boeing initiated at the inner surface near an edge of the forward mounting flange. All cracks have been located in the root radius where the flange transitions to the vane area. The cracked cascades have mostly been located adjacent to the thrust reverser actuators which are attached to the cascade support flange.

1.16.3 g-load estimation

It was reported that the aircraft experienced very rapid lateral shaking as a result of the failure of the cascade. The accelerometer supplying the DFDR information is located near the centre of mass of the aircraft, at fuselage station 663. The FA seat at the rear of the aircraft is at station 990. Consequently, the loads experienced at the rear of the aircraft would be greater than the loads experienced by the accelerometer.

Accurate assessment of the loads experienced by the FAs proved impossible. To derive deceleration forces using graphical information requires a clear indication of aircraft displacement at the relevant location. Deceleration is derived from a velocity curve, which in turn is derived from the displacement curve. Due to limitations of the accuracy of the localiser deviation signal (one reading per two seconds) and the LATg signal (four readings per second) it was not possible to determine if the recorded peaks were the actual peaks. It may be that the recorded value is representative of a load still increasing, or conversely, decreasing.

What could be determined was that although the lateral loads at the FA station were in excess of the 0.14g recorded at the accelerometer, they were still of low value; however, very rapid reversals were experienced.

1.16.4 Harness and seating considerations

The predominant inadequacy of the harness installation was that the FAs found extreme difficulty in properly tightening the harness to prevent movement within the harness. This was related to:

- the overall size of the seat;
- the installed angle of the lap strap;
- the bifurcation of the upper torso strap; and
- the direction and angle of pull required to tighten the upper torso straps.

The seat as installed was 30 inches wide. This was found to be barely adequate for two normal-sized adults to share and on many occasions would result in one or both FAs being partially unsupported by the seat, with a consequent inability to achieve adequate tightening of the harness.

The lap strap was anchored via a hook and swivel to the bulkhead in a manner that caused it to remain approximately horizontal when fastened. The lap strap was able to ride well up above the area of the pelvis with the probability of causing significant soft tissue damage to the abdomen during high g excursions. The belt attach points did not allow the belt to achieve the required downward and aft pull which would position the belt over the iliac crests of the pelvis. When properly installed with a 45° slope on the belt, the release buckle will sit close to the pubic bone where it is less liable to cause severe damage.

With the lap belt in essentially a horizontal plane when fastened, it was evident that there was a lack of counter traction to the shoulder harness which contributes to the belt riding high up on the abdomen.

This installation exhibits a high risk of the occupant sliding under the lap strap, otherwise known as 'submarining', in the event of an incident with forward g loads.

The bifurcation of the single upper shoulder harness occurred some 6 inches forward of the bulkhead. This configuration does not allow the upper body to be pulled tight onto the seat backrest and leads to chafing of, and/or damage to, the neck due to the narrow strap angle at the neck.

It was found that the upper body could rotate about the single strap anchor point leading to dynamic overshoot of the upper body and consequent magnification of the g loads.

The single anchor point coupled with an excessively long strap, would not prevent the head of the occupant on the left of the seat from striking the door.

A downwards and outwards direction of pull was required to tighten the shoulder straps. This leads to an inability to properly tighten the harness as the body must be arched up into the straps while exerting the download. Similarly, with a door on one side and another FA alongside, the person seated on the left does not have the room to give the required outward pull. The person on the right may be able to give the right strap an outward pull, but not the left, when both seats are occupied.

1.16.5 Uniform considerations

The uniform shirt worn by both FAs was fitted with a left breast pocket. Required to be fastened to the facing of the pocket was a metal half wing, and contained within the pocket were IDs, pens and other discretionary items.

Further examination of the female FA uniform disclosed a metal neck plate fastened to the peaks of the shirt in a manner that would be liable to cause major damage to the throat in the event of an accident with vertical g excursions. A similar situation was noted with the male FA's tie clasp.

There was strong evidence that the rib fractures were the result of a pen being crushed into the ribs by the body moving and coming against the upper body restraint harness strap. There was also the possibility that the straps became hooked under the wings during body rebound.

It was determined that there was no safety assessment of the uniforms during design and manufacture.

1.17 Additional information

1.17.1 Certification issues

1.17.1.1 Flight attendant seat

The FA seat was found to be inadequate in both its size and in its capacity to restrict occupant movement and was found not to have been manufactured and installed to requirements current at the time of manufacture or at the time of certification of the aircraft type.

VH-TAJ was manufactured in 1986 in accordance with the FAA Type Certificate A16WE. The Type Certificate for the B737-300 series aircraft gained FAA approval on 14 November 1984.

Type Certificate A16WE at Revision 17 dated 7 June 1991, states that the Type Certification basis for B737-300 series aeroplanes is FAR 25 to a stated series of amendments.

The seat fitted to VH-TAJ was found to be 30 inches wide. The relevant certification requirement, FAR 25.785, was amended in April 1981 by Amendment FAR 25-51. When this was introduced, an Advisory Circular AC 25.785-1 was issued to clarify the intent of the FAR. Contained within the AC is a recommendation that a dual flight attendant seat have a minimum width of 31 inches. However, paragraphs 6a and 6b of the Advisory Circular state that 'existing flight attendant seats in service are considered to comply with FAR 25.785.'

The FAA and the manufacturer interpret this to mean that as the original B737 was certificated in 1967 and the B737-300 was a derivative of that aircraft, the 1981 rules need not be applied. The manufacturer considers that it is therefore obliged only to comply with those FAR 25 requirements which pertained at the time of original certification of the aircraft type in 1967. This is despite the fact that the B737-300 was type certificated in 1984, and VH-TAJ itself was manufactured in 1986. Consequently, Boeing B737 aircraft in current production are equipped with FA seats not meeting the 1981 recommendation.

1.17.1.2 Restraint harness assembly

The restraint harness assembly was found to be unable to achieve a satisfactory level of restraint in either lateral or forward g situations because it was not installed in accordance with mandatory requirements.

FAR 25.561 and FAR 25.785 between them state that, assuming the maximum inertial loads are 9g forward or 1.5g sideways,

- the harness assembly must be designed to give the occupant every reasonable chance of escaping serious injury in an emergency landing; and
- a shoulder harness must be fitted to prevent the head from hitting any injurious objects.

The injuries to the two FAs in this relatively minor lateral excursion have demonstrated that a doubt exists as to the ability of the installation to meet those requirements.

It is a requirement of CAO 108.42 that the safety harnesses be manufactured to specifications listed in the CAO. For a safety harness, the CAO at paragraph 2.1(c) requires that the British ARB/CAA specification no. 4 (issue 2) be observed.

Paragraph 2.7 of specification no. 4 requires that the lower part of the harness, when fitted to a seat and worn, shall lie across the groins of the wearer in a plane which is approximately at 45° to the plane of the longitudinal and lateral axes of the aircraft.

Paragraph 1.2 of the specification refers to the requirements governing the installation of the harness in an aircraft as contained in BCAR chapter D6.1. At paragraph 3.5.2 of chapter D6.1 the angle of 45° is again specified.

CAO 108.42 issue 1 was approved and dated January 1977. Therefore, the requirement was current in 1986 when VH-TAJ was delivered to the operator. Similarly, this requirement was current in 1984 when the B737-300 received FAA type certification.

2. ANALYSIS

2.1 Cascade assembly

The evidence of fatigue in the forward flanges of the failed and cracked cascades, and of the overload failure in the aft flange of the failed cascade, supports the view that installation and operational stresses were the primary factors in the liberation of the cascade.

2.2 Flight attendant injuries

The underlying movement responsible for FA injuries was due to inadequate restraint by the harness. This allowed the body to move within the harness and exposed it to the effects of rapid deceleration when the slackness in the harness was taken up. The body then rebounded in an opposing direction under the effects of the g-forces and again rapidly decelerated as the slackness in the harness was again taken up.

The FAs' injuries can be attributed to the design of the FA seats they were occupying, the design of the restraint harness and aspects associated with the FA uniform including design and articles carried in the pockets. Due to the inability of both FAs to adequately tighten the upper body restraint harness, they were injured as a result of dynamic overshoot during the rapidly reversing lateral movement generated at the height of the asymmetric reverse thrust.

3. CONCLUSIONS

3.1 Findings

1. The right engine thrust reverser cascade failed due to stresses greater than anticipated during design.
2. The liberated cascade was ingested by the engine concurrent with maximum reverse thrust being attained.
3. The aircraft was shaken and diverged from the runway centreline with low lateral g-forces being generated.
4. Two FAs received minor injuries due to a combination of restraint harness, seating and uniform irregularities.
5. The FAs had not been able to tighten their harnesses properly.
6. The harness assembly did not meet the Australian design requirement current at the time of the aircraft's entry onto the Australian register.
7. Determination by the FAA and the manufacturer of the current applicability of requirements relating to the certification of the original B737 series aircraft currently precludes the introduction of improved seating and restraint systems.
8. Continued inspection or cascade replacement in accordance with the Boeing Service Bulletin should preclude further failures.

3.2 Factors

The following factors were considered relevant to the development of this occurrence:

1. A thrust reverser cascade suffered a fatigue failure shortly after touchdown.
2. The right engine suffered a catastrophic failure when it ingested the cascade.
3. The aircraft was shaken laterally, with the greatest effect being felt at the rear of the aircraft.
4. The FAs located at the rear of the aircraft were not adequately restrained against lateral movement.
5. The relevant FA seat and restraint systems did not comply with Australian design requirements.

4. SAFETY ACTION

4.1 Safety action taken

1. The Boeing Company issued Service Letter 737-SL-78-23 on 13 January 1992 to all operators, advising them of the cascade problem and requiring them to carry out a once-only inspection using the eddy current inspection technique.

2. As a result of inspections completed pursuant to that service letter and further engineering investigation, Boeing issued Service Letter 737-SL-78-27, dated 2 February 1993, detailing a continuing inspection program for installed magnesium cascades. At the time this service letter was issued, eleven operators had reported inspecting 146 aircraft and a total of 73 cracked cascades were found on 38 of those aircraft.

3. The Boeing Company has advised that a cascade manufactured of composite material is available as a replacement for the magnesium cascade. The operator is devising a program to progressively introduce composite cascades into its existing fleet.

4. An inspection program conforming to the requirements of Boeing Service Letter 737-SL-78-27 is in place for those magnesium cascades extant in the fleet.

5. An examination of the aft FA seat fitted to VH-TAJ was carried out with representatives of the CAA, the operator and the FAs' union, along with the two FAs involved in the incident. As a result of that inspection, FAs were advised by both the operator and their union of those clothing adornments that could cause injury during incidents such as this one.

4.2 Recommendations

The following two recommendations were made to the CAA:

1. R930171

It is recommended that the CAA:

(1) review the design and installation of the aft FA seat and harness fitted to VH-TAJ to ensure compliance with Australian requirements current at the time of the aircraft's entry onto the Australian register;

(2) review the practice of accepting 'grandfathering' design requirements with a view to imposing a time limit so that the introduction of improved safety standards is not inhibited; and

(3) formally advise Australian operators of Boeing 737 aircraft of the deficiencies in the FA seat and restraint systems as highlighted by this incident so they may assess their equipment for compliance with both mandatory requirements and sound safety practices.

2. R930176

It is recommended that the CAA, in consultation with operators, evaluate the implementation of initial safety assessments of FA and aircrew uniforms during the design concept stage, prior to their introduction to service. Uniforms currently in service should be similarly assessed for any perceived safety deficiencies.

CAA response

I refer to Air Safety Recommendations R930171 and R930176 regarding an incident involving a B737 aircraft resulting in injury to two Flight Attendants.

In regard to R930171, the requirement for cabin attendant seats and restraint is AD/GENERAL/61 issued in 1983. This parallels the US requirements given in FAR 121.311 (f) and FAR 25.785. None of these requirements specifically address the width of the FA's seat. A recommended width of 31 inches is given in FAA Advisory Circular AC 25.785-1, dated 4 December 1981. CAO 108.42 provides the design standard for seat belts and harnesses. Paragraph 3.3 prohibits a symmetric safety harness from having straps permanently connected to the thigh straps, or straps which do not immediately disconnect from the thigh straps when the harness is released. Although the FA's harness is such that the straps are permanently connected to the thigh straps, the design is considered to provide easy egress for an occupant who is familiar with the harness (in this case a trained FA). The design was therefore given an exemption from this specific requirement.

The Authority concurs with all the recommendations and submits the following responses:

<u>Recommendation 1</u>

As a result of the investigation following this incident, the installation of the FAs seat was found to not provide the best angle for the lap belt. Also the width of the seat was found to be lower than that recommended in the FAA Advisory Circular AC 25.785-1 dated 4 December 1981.

This Authority will take appropriate action but would prefer to have all the details of the formal BASI Report.

<u>Recommendation 2</u>

Any justifiable improvements to the design requirements will be applied retrospectively and actioned through appropriate Airworthiness Directives.

<u>Recommendation 3</u>

The Australian operators of Boeing 737 aircraft were both involved in the investigation and are aware of the problems raised. Full details will be formally advised when the BASI report is released.

In response to the recommendation contained in R930176, both Australian operators of B737 aircraft were involved in the investigation. Following release of details of the BASI investigation, operators will be consulted to ensure safety aspects are considered during the design and development of uniforms.

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