



**Australian Government**

**Australian Transport Safety Bureau**

**ATSB TRANSPORT SAFETY INVESTIGATION REPORT**

Aviation Occurrence Investigation – 200504188

Final

**In-Flight Engine Malfunction  
6km SSE Sydney Airport, NSW  
25 August 2005  
VH-TJX  
Boeing 737-476**





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**Abstract**

On 25 August 2005, while on a scheduled flight from Brisbane, Qld, to Sydney, NSW, a Boeing 737-476 aircraft, registration VH-TJX, experienced an in-flight engine malfunction approximately 6 km SSE of Sydney Airport.

An inspection of the left engine by the operator's engineering personnel revealed damage within the high pressure compressor (HPC). The left engine, a General Electric CFM56-3C1, was subsequently removed and disassembled at the operator's maintenance facility. The teardown revealed that a single dowel pin had come loose from its installed position within stage-three of the HPC and was ingested by the downstream rotating hardware, resulting in damage to the HPC rotor and stator components.

Further examination of the HPC stator components revealed that the dowel pin had come loose due to excessive clearance and recession of the stage-three stator shroud anti-rotation pins.

As a result of this occurrence, the engine manufacturer, General Electric, initiated a number of safety actions that included a redesign of the HPC anti-rotation pin. The manufacturer also released an alert Service Bulletin CFM56-3 S/B 72-1091 to all operators and maintainers of CFM56-3 engines that recommended the introduction of the new pin design into existing engines. Other safety actions taken included amendments to the CFM56-3 maintenance manual for HPC stator shroud component inspections.

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# THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal bureau within the Australian Government Department of Infrastructure, Transport, Regional Development and Local Government. ATSB investigations are independent of regulatory, operator or other external organisations.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

## **Purpose of safety investigations**

The object of a safety investigation is to enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not the object of an investigation to determine blame or liability. However, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

## **Developing safety action**

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.

**#About ATSB investigation reports:** How investigation reports are organised and definitions of terms used in ATSB reports, such as safety factor, contributing safety factor and safety issue, are provided on the ATSB web site [www.atsb.gov.au](http://www.atsb.gov.au).

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## FACTUAL INFORMATION

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### Flight history

On 25 August 2005, during a scheduled passenger flight from Brisbane, Qld, to Sydney, NSW, the left engine of a Boeing 737-476 aircraft, registered VH-TJX, malfunctioned approximately 6 km SSE of Sydney Airport.

While on approach to runway 34R with the landing gear extended, the flight crew heard unusual ‘popping’ noises from the left side of the aircraft. The crew initially suspected a defect with the landing gear and commenced a missed approach.

When both engine power levers were advanced, the left engine did not respond. The pilot-in-command then reduced the left engine power to idle, retracted the landing gear and climbed the aircraft to approximately 2,000 ft. The crew advised air traffic control of a possible engine problem.

The aircraft Captain advised the First Officer to leave the left engine at idle and that a single engine landing would be conducted. The appropriate single engine inoperative checklists were referenced and the aircraft was prepared for landing. At 07:37 EST<sup>1</sup> a single-engine approach and landing on Sydney runway 34R was completed.

Upon landing, Aviation Rescue and Fire Fighting (ARFF) personnel performed an external visual inspection of the left engine area and advised the crew that there were no signs of a fire. The aircraft taxied to the gate without further incident. There were no injuries.

### *Post-flight engine examination*

Shortly after landing, an inspection by the operator’s maintenance personnel revealed that the left engine had sustained compressor turbine damage and metal deposits were found in the engine tailpipe. The left engine was subsequently removed and sent to the company engineering maintenance facility for modular teardown and inspection.

The Australian Transport Safety Bureau (ATSB) requested the recorded flight data from the operator and to be in attendance during the teardown and examination of the left engine from VH-TJX.

### Engine detail

The left engine (serial number 858310) was a General Electric CFM 56-3C1 gas turbine. The engine was divided into four integrated component major modules; the fan, core engine, low pressure turbine and accessory gearbox module. The dual rotor engine consisted of a low pressure (N1) and high pressure (N2) system where

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<sup>1</sup> The 24-hour clock is used in this report to describe the local time of day, Eastern Standard Time (EST), as particular events occurred. Eastern Standard Time was Coordinated Universal Time (UTC) + 10 hours.

each rotor was mechanically independent of the other<sup>2</sup>. Figure 1 shows the locations of the major modules and the low and high pressure systems.

**Figure 1: Illustration of the CFM56-3C1 showing the locations of the major modules and the low and high pressure systems.**

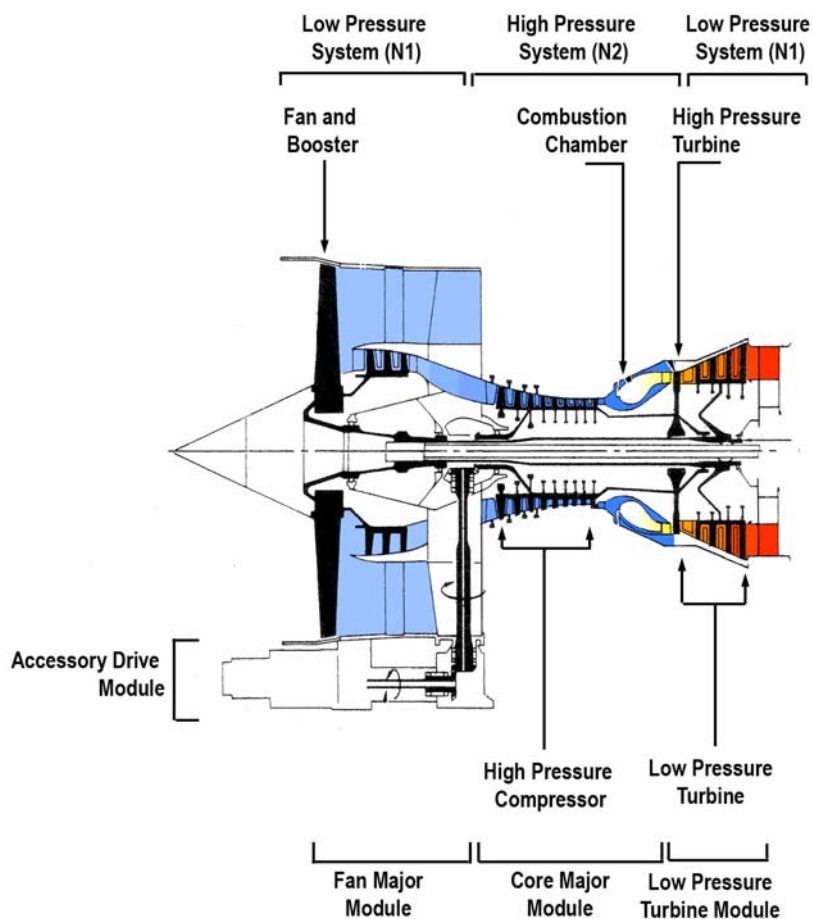


Image source, edited: Boeing 737-300/-400 Maintenance Training Manual, part number 72.00.010.

## Examination of recorded data

The recorded flight data from VH-TJX was examined by the ATSB.

The flight data recorder (FDR) fitted to VH-TJX was an L3 Communications (part number FA2100-4043-00) with input from a Teledyne Flight Data Acquisition Unit (FDAU) (part number 223300-2A). The downloaded information was of good quality and indicated the following:

<sup>2</sup> N values refer to the compressor rotating speeds. N1 represents the low pressure compressor and N2 represents the high pressure compressor.

## Sequence of events

- VH-TJX departed Brisbane Airport (YBBN) on runway 19 at 06:07:34 EST.
- The aircraft reached cruise altitude of 32,000 ft (FL320) approximately 12 minutes after takeoff at 06:19:53. VH-TJX maintained cruise altitude at 270 kts for approximately 37 minutes. During cruise, the engine fan vibration levels for the left engine were higher than the right engine.
- At 06:56:50, the aircraft commenced descent from FL320.
- Approximately 10 minutes later the aircraft levelled off at 5,500 ft and the power levers to both engines were advanced. At this time, the left engine vibration levels were recorded to have increased and were higher than the right engine.
- At 07:18:29, the landing gear was extended at an altitude of 2,412 ft above ground level (AGL).
- At 07:19:57, both power levers were advanced from 18 to 51 degrees, which produced an increase to the right engine parameters; fuel flow up to 4,350 kg/h, the N1 rotor speed increasing to 96%, and the N2 rotor speed to 98%. The left engine parameters, however, showed no increase from the increased power settings with fuel flow remaining constant at 1,355 kg/h, N1 rotor speed constant at approximately 52%, and a marginal increase in N2 rotor speed to approximately 86%.
- At 07:20:23, approximately 6 km SSE of Sydney airport, the aircraft commenced a missed approach and retracted the landing gear. The aircraft then climbed from 861 ft to 2,108 ft AGL and the left engine power lever was retarded.
- At 07:35:05, with reduced power to the left engine, the aircraft commenced its final descent with an uneventful landing carried out at 07:37:18 on Sydney (YSSL) runway 34R.

A plot of the recorded data was prepared showing the five minute period during which time the engine malfunctioned, (Appendix A).

## Engine teardown and disassembly

The left CFM56-3C1 engine from VH-TJX underwent modular disassembly at an approved engine workshop where it was separated into its main assemblies; the fan major module, the core engine major module, and the low pressure turbine (LPT) major module.

An initial borescope<sup>3</sup> inspection of the engine core module (S/N 32X21762) by the operator revealed damage to the internal high pressure compressor (HPC) rotating components. Complete disassembly of the core engine was performed with

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<sup>3</sup> Slender optical inspection tool capable of being inserted into narrow apertures to inspect the interior of machinery.

investigators from the ATSB and representatives from the Civil Aviation Safety Authority (CASA), the operator, and the engine manufacturer in attendance.

When the engine's core high pressure compressor (HPC) front stator assembly was split open and the HPC rotor removed, significant damage to the stator vanes and rotor blades was found, (Figure 2).

**Figure 2: Photograph of the HPC rotor showing damage to the stage-four and -five rotor blades. See also Figure 3.**



### **High pressure compressor rotor**

Examination of the HPC rotor revealed concentrated damage to the airfoil sections of the stage-four and -five blades. Some minor denting of the -six to -nine rotor blades was also observed. It was noted that the forward shoulder surfaces of the stage-four dovetail slot on the -four to -nine spool had been polished from hard rotational contact with another engine element, (Figure 3).

In contrast to the damaged stage-four and -five components, the upstream stage-one to -three rotor blades were undamaged.

The lack of damage to the earlier stages indicated that the blade impact and mechanical battering came from an object or component liberated from stage-three of the HPC that then travelled downstream with the air flow to impact the latter HPC stages.

**Figure 3:** Close-up image of impact damage to stage-four and -five rotor blades. The forward shoulder of the dovetail slot (arrowed) shows polishing damage to the surfaces.



### **High pressure compressor stator**

Similar levels of damage to the stator vanes were observed from stage-three to the latter downstream stages. Like the HPC rotor, no damage was observed upstream of stage-three.

The variable stator vanes (stage-one to -three) were furnished with a segmented interstage shroud and honeycomb seal assembly. Bushings were installed to engage with the inside of each individual variable stator vane. Straight D-head dowel pins were inserted through the ends of each shroud segment to ensure the segments remained anchored during engine operation. To minimise interstage air leakage, segmented honeycomb seals were fitted along to the stage-one, -two and -three shroud rails.

Small anti-rotation pins located at the HPC 3 o'clock and 9 o'clock split lines had been pressed into sockets within the upper rails of the stator shroud to limit the amount of seal rotation and bunching that could occur during service. The engine manufacturer reported that each anti-rotation pin had a 0.001" +/-0.0001" interference with the shroud socket.

Correct locational positioning of the honeycomb seals captured the D-head dowel pins and prevented them from coming loose and entering the air flow during service.

Examination of the stage-three shroud segments and interstage honeycomb seals revealed that a single D-head dowel pin was missing from its prescribed assembly position, (Figure 4 and 5). It was also observed that the stage-three air seals could be easily moved around their station. Normally, honeycomb seal rotation was limited by the presence of two anti-rotation stop pins, but in this case the pin protrusion was such that advanced rotation could occur.

The preliminary on-site assessment indicated that the stage-three honeycomb air seal sections had been allowed to circumferentially shift and bunch together, resulting in the liberation of a single stage-three variable guide vane D-head pin from its assembled position. Once loose, the dowel pin became ingested by the latter stages of the HPC causing considerable impact damage to the rotating components.

**Figure 4: General view of one half of the HPC front stator case. The location of the missing stage-three shroud D-head dowel pin is highlighted. Refer also to Figure 5.**

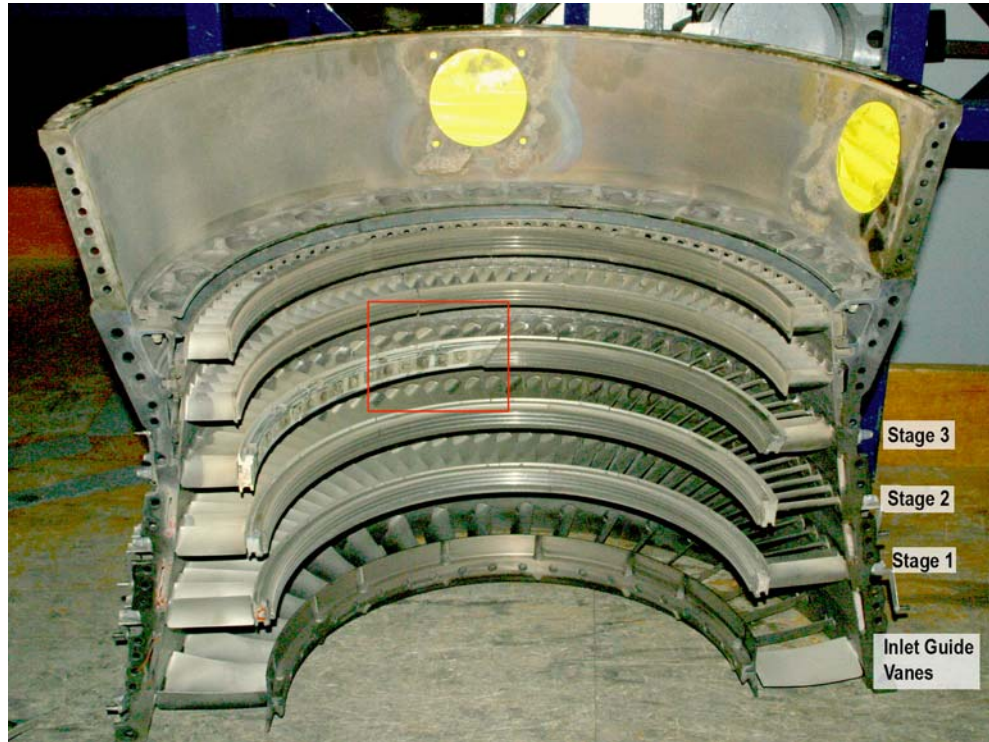
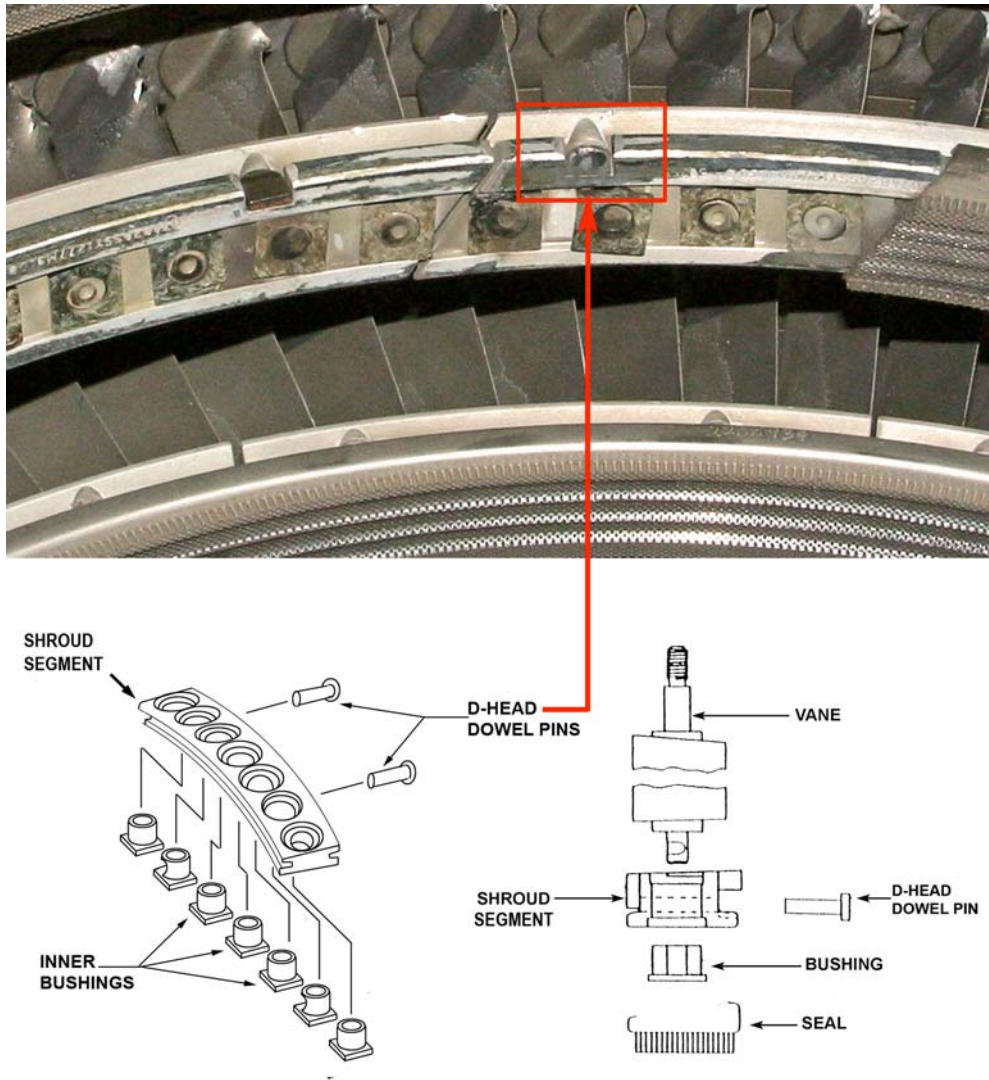


Figure 5: Close view of the stage-three stator showing the missing shroud D-head dowel pin. An assembly illustration shows how the pins were retained.



## ATSB laboratory examination

To establish how the stage-three D-head dowel pin was able to come loose from the installed position, a number of the segmented components from the stage-three HPC were removed. For comparison purposes, several shrouds and honeycomb seals from stage-two were also removed. See Table 1 for the item details.

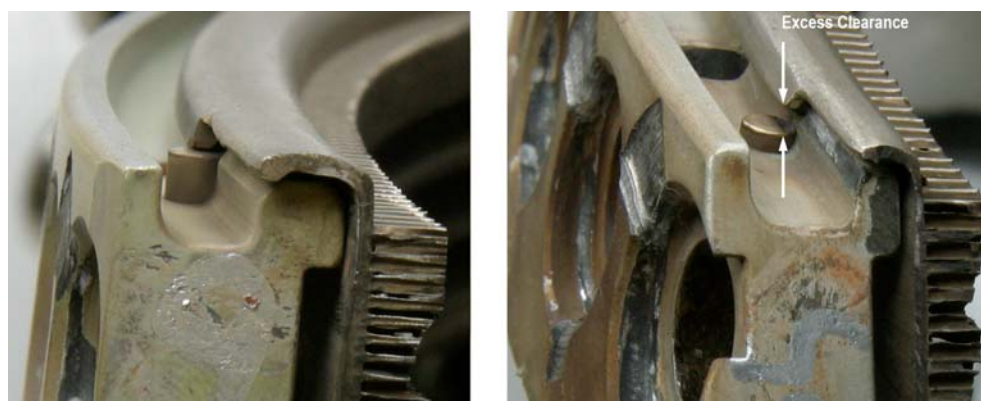
**Table 1: Detail of HPC shroud and seal components examined by ATSB.**

Description	Qty	Manufacturing Identifiers
Stage-two Shroud	2	07482ASSY9994M18G06 50255
Stage-two Honeycomb seal	2	07482ASSY9978M69G44 NA5R060N RW-1 STG 2 21023 2200947 37878A
Stage-two Honeycomb seal	2	07482ASSY9978M69G41 NA5R060N RW-2 STG 2 21023 2200939 37878A
Stage-three Shroud	2	07482ASSY1277M91G04 50255
Stage-three Honeycomb seal	2	07482ASSY1277M90G01 NA5R060N RW-1 STG 3 S/N 9303824-1 4069J
Stage- three Honeycomb seal	2	07482ASSY1277M90G01 NA5R060N RW-2 STG 3 S/N 9303824-1 4069J

When the stage-three components were assembled together, it was evident that the honeycomb seals could slide entirely unrestricted around the rails of each stator shroud. The anti-rotation pins that had been inserted within the rails of the stage-three shroud did not restrict rotational movement.

In contrast, sliding movement of the honeycomb seals around the stage-two shroud rails was stopped by interference provided by the anti-rotation shroud pins, (Figure 6).

**Figure 6: End view of the stage-two (left) and stage-three (right) stator shrouds when fitted with honeycomb air seals.**

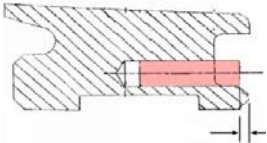


Note the excessive clearance between the stage-three (right image) anti-rotation pin and inner rail of the honeycomb air seal allowing the seals to rotate, compared with zero clearance from the stage-two components (left image).

The unrestricted seal shifting could be explained by the slight difference between the protruded lengths of the stage-three anti-rotation pins when compared with those from stage-two. The manufacturer's specifications indicated that in order to prevent seal segment rotation, the allowable distance between the forward rail axial face and the anti-rotation pin head should measure between 0.76 - 1.02 mm.

Measurements indicated that the stage-three pins were recessed beyond these limits specified by the manufacturer. See Table 2 for these results.

**Table 2: Measurement details of stage-two and -three stator shroud anti-rotation pin clearance when compared with the manufacturer's specification<sup>4</sup>.**

	Manufacturer's Clearance Specification	Measured Clearance			
		Stage-Two		Stage-Three	
	0.76 - 1.02	0.9	1.0	2.0	2.2

All units shown are in mm.

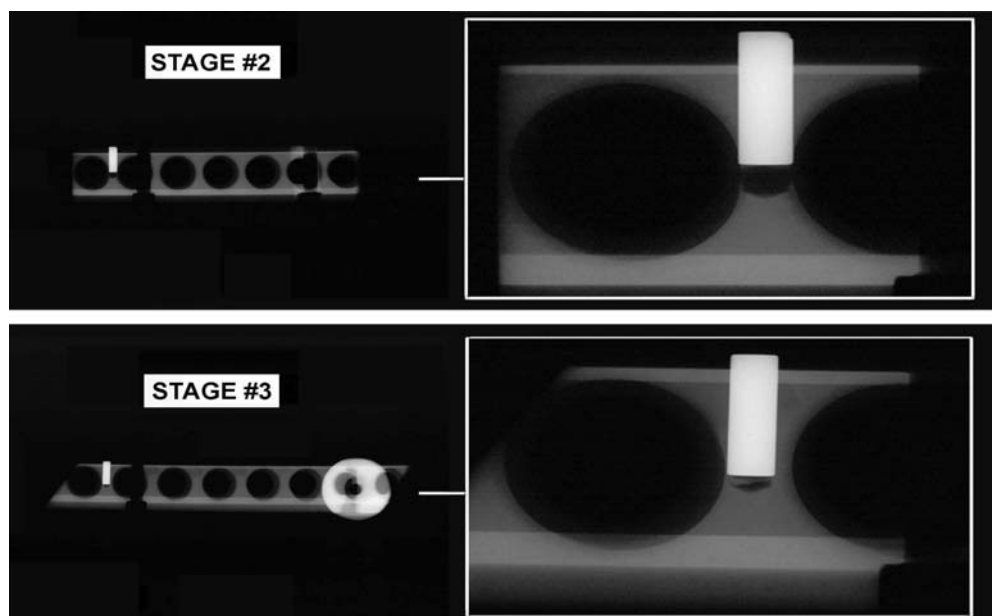
Some wear damage to the faces of the stage-three pins from sliding contact with the lower honeycomb seal rails was found. However, the amount of damage was quite minor with only a slight effect to the pin profile.

### Non-destructive examination

To confirm the dimensional aspects of each anti-rotation pin, the stator shrouds were non-destructively inspected using x-ray radiography. Examination and comparison of the radiographs confirmed that the stage-three pins had been pushed slightly deeper into their socket than the pins from stage-two, (Figure 7).

Measurements indicated that the pins were the correct length and had been manufactured in accordance with the manufacturer's specifications.

**Figure 7: Radiographic detail of the anti-rotation pins showing that the stage-three pins had been inserted slightly deeper into their station than the stage-two pins.**



<sup>4</sup> GE Aircraft Engines, Drawing Number 1277M91 "Shroud, Compressor Stator-Stage 3".

## Previous similar engine shutdowns

As part of this investigation, the ATSB, Civil Aviation Safety Authority (CASA), and the US Federal Aviation Authority (FAA) databases were searched for evidence of similar CFM56 engine failure events. No records corresponding to similar occurrence of this type were identified.

Historical engine reliability data supplied by the engine manufacturer (General Electric) revealed that three CFM56 engines had also experienced in-flight engine failures/malfunctions of this nature. In each case, the liberation of a high pressure compressor shroud D-head dowel pin from the stator assembly had led to the occurrence. Each engine failure/malfunction occurred at a different flight phase.

## Engine servicing and maintenance history

### Maintenance history

The aircraft operator's engine maintenance documents indicated that the stage-three segmented stator shrouds and interstage honeycomb air seals were fitted as new items to the HPC forward case module (P/N CFM56-3EMU32X, S/N 32X21762) in October 1998.

The HPC forward case module had subsequently been scheduled for further maintenance in July 2002. At that time, the maintenance work scope required the front HPC module to be completely disassembled to the piece part level. Each item was visually inspected, repaired or replaced in accordance with instructions listed in the manufacture's engine shop manual<sup>5</sup>.

During that maintenance activity, the stage-three shroud segments were examined for serviceability. The anti-rotation pins integral within the shrouds were inspected for looseness and wear. The parts were found to be in a serviceable condition and were reinstalled back into the HPC forward case module.

### HPC shroud inspection procedures

The inspection procedures outlined in the CFM56-3 engine shop manual<sup>6</sup> required that during engine overhaul, the compressor stator shrouds be inspected using visual and fluorescent penetrant inspection techniques. All surfaces were to be inspected for damage including cracks, nicks, pits, scores and scratches.

It was required that the interstage anti-rotation pins be inspected for looseness. The procedures within the shop manual listed no requirement to dimensionally inspect the pins.

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<sup>5</sup> CFM56-3, Engine Shop Manual 72-32-07 Inspection 001.

<sup>6</sup> CFM56-3 Engine Shop Manual 72-32-01-200-001 -01

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## ANALYSIS

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While on approach to Sydney Airport, the left CFM56-3C1 engine of the Boeing 737-476 malfunctioned. The actions by the crew to reduce the engine power to flight idle and commence a missed approach were appropriate for the circumstances and a successful single-engine return and landing at the airport was carried out.

The engine malfunction was a direct result of a D-head dowel pin that migrated from its stage-three stator shroud installation within the engine's high pressure compressor (HPC). Once the D-pin became entrained within the highly compressed airflow of the HPC, it became ingested by the downstream stages of the HPC. This produced impact and battering damage to the blade and airfoil sections of the stage-three and latter HPC rotor/stator components.

Analysis of the engine's recorded flight data indicated that the damage produced by the liberated dowel pin affected the airflow within the HPC, with reduced efficiency to both the N1 and N2 high and low pressure systems. This reduction was reflected when the pilot-in-command advanced the power levers to both engines. Only the right engine responded to the crew's input. The 'popping' noise heard by the crew was consistent with a compressor stall or surge due to the damaged HPC.

Directly contributing to the dowel pin release was the excessive clearance between the stage-three stator shroud anti-rotation pins and the attached interstage honeycomb air seals. Both the 3 o'clock and 9 o'clock anti-rotation pins at the HPC split line had been pressed slightly too deep into their shroud sockets. This allowed the honeycomb seal segments to shift and circumferentially bunch during engine operation. Once the straight D-head dowel pin became exposed between the seal segments, it was very likely that the dowel pin liberated out through the gap between seal segments. The dowel pin then impacted the downstream HPC rotor hardware resulting in the severe engine damage.

With no requirement from the engine manufacturer to dimensionally inspect the stator shroud anti-rotation pins, it was possible that the anti-rotation pins had been pressed too deep into their shroud sockets from new. Alternatively, each of the anti-rotation pins may have been forced downward into their socket through contact with the honeycomb seals during engine operation. The investigation was not able to differentiate between either of these two possibilities.

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## FINDINGS

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### Context

From the evidence available, the following findings are made with respect to the malfunction of the left CFM56-3C1 engine on a 737-476 aircraft, and should not be read as apportioning blame or liability to any particular organisation or individual.

### Contributing safety factors

- The manufacturer's engine shop manual contained no guidance or instruction to engine maintenance personnel of CFM56-3 engines to dimensionally inspect stator shroud anti-rotation pins from new or during reinstallation of the pins from overhaul. *[Safety issue]*
- Excessive clearance existed between the stage-three stator shroud anti-rotation pins and the segmented interstage honeycomb seals within the left engine's high pressure compressor. This allowed the stage-three honeycomb seals to shift and bunch during engine operation, and permitted a single straight D-head dowel pin from a stage-three shroud segment to migrate from its installed position and be ingested by the engine's rotating hardware.
- The left engine of the 737-476 aircraft malfunctioned while on approach to landing at Sydney Airport.

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## SAFETY ACTIONS

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The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the responsible organisations for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

Depending on the level of risk of the safety issue, the extent of corrective action taken by the relevant organisation, or the desirability of directing a broad safety message to the aviation industry, the ATSB may issue safety recommendations or safety advisory notices as part of the final report.

### **General Electric**

#### ***Safety issue***

The manufacturer's engine shop manual contained no guidance or instruction to engine maintenance personnel of CFM56-3 engines to dimensionally inspect stator shroud anti-rotation pins from new or during reinstallation of the pins from overhaul.

#### ***Action taken by General Electric***

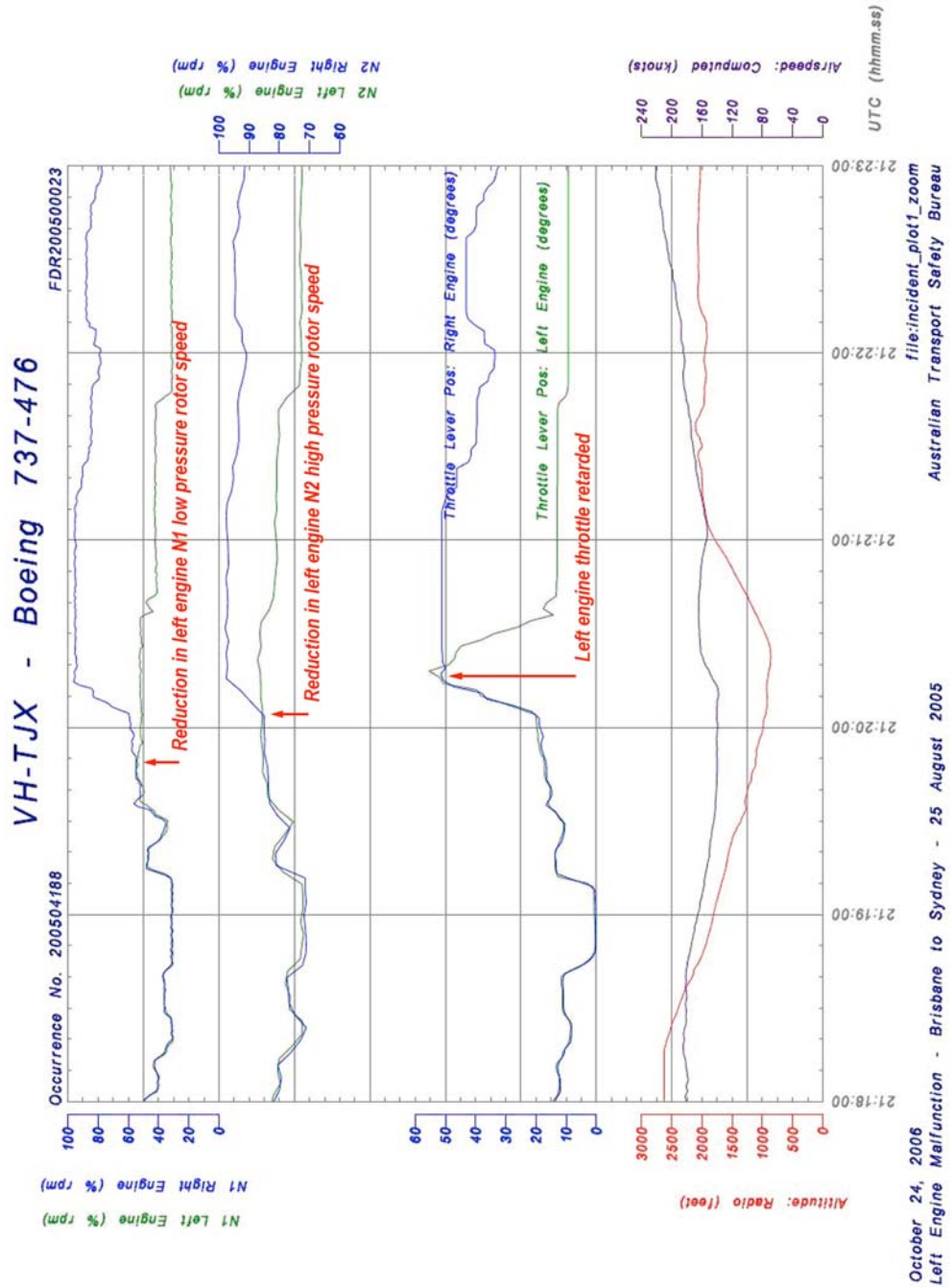
As a result of this occurrence, the engine manufacturer, General Electric, advised that they had taken a number of safety actions. In regard to the CFM56-3C1 engine fitted to the Boeing 737 fleet, the manufacturer:

- consulted with the supplier of the CFM56-3 stator shrouds to determine whether a quality problem existed during the stator shroud manufacturing process
- added an inspection requirement to the current CFM56-3 engine shop manual to verify the stator shroud anti-rotation pin height during piece part inspection
- modified the engine shop manual to include a stator shroud anti-rotation pin height check whenever a new pin was reinstalled into a stator shroud that was being returned to service from overhaul
- redesigned the anti-rotation pin and field released the new part into the CFM56-3 fleet in July 2007
- released a service bulletin (CFM56-3 S/B 72-1091) in December 2007 to all operators and maintenance personnel of CFM56-3 engines to alert that the stator shroud anti-rotation pin design had changed, and recommended

that the old design pins be replaced with the redesigned part into existing engines.

# APPENDIX A

Plot of the flight data recorder data showing a five minute period during which time the engine malfunctioned. Plotted are values of engine rotor speeds (high and low pressure), radio altitude, computed airspeed and the power lever positions.



Note that the flight time scale has been presented in UTC.