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- independent investigation of transport accidents and other safety occurrences
- safety data recording, analysis and research
- fostering safety awareness, knowledge and action.

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ATSB-Jul10/ATSB113

Released in accordance with section 25 of the Transport Safety Investigation Act 2003

Powerplant/propulsion event Launceston aerodrome – 20 August 2009

Abstract

At approximately 1137 EST on 20 August 2009, a Boeing 737-8BK aircraft, registered VH-VOC, departed Launceston, Tasmania on a scheduled passenger service to Sydney, New South Wales. Following takeoff, several loud bangs were heard from the left engine, consistent with a compressor surge. The left engine was reduced to flight idle and the aircraft returned to land at Launceston.

The compressor surge and damage to the left engine was the result of advanced variable stator vane bushing/shroud wear, which caused a seal retainer to dislodge from the inner shroud segment and move into the compressor gas path. The liberated seal segments then progressed downstream, causing significant impact damage to the remaining stages, resulting in a loss of compressor efficiency.

The manufacturer was aware of the propensity for inner bushing wear, and had previously released a number of service bulletins aimed at eliminating the issue.

The operator had incorporated the relevant service bulletins into their inspection and maintenance program as required; however the event occurred prior to the engine reaching the earliest threshold for inspection.

FACTUAL INFORMATION

The Australian Transport Safety Bureau (ATSB) did not examine the aircraft in Launceston or attend the subsequent engine inspection. The discussion below was prepared principally from information supplied to the ATSB.

History of the Flight

On 20 August 2009, at approximately 1137 EST¹, a Boeing 737-8BK aircraft, registered VH-VOC, departed Launceston aerodrome, Tasmania on a scheduled passenger service to Sydney aerodrome, New South Wales.

Shortly after takeoff, several loud bangs were heard from the left engine, consistent with the effects of a compressor surge. The crew immediately reduced power on the left engine to flight idle and made a PAN² radio call advising of a failure of the number-1 engine. The PAN was acknowledged by air traffic control (ATC) and the aircraft was given a clearance to enter a holding pattern. The crew initiated the appropriate non-normal checklist, and elected to discontinue the flight to Sydney. Once in the holding pattern, the flight crew had discussions with ATC regarding the condition of the runway (wet/dry) at Launceston, and determined that they could return to land safely. The flight crew also advised the cabin crew of the intention to return to Launceston, and made announcements to the passengers during this period. The aircraft landed at 1219.

A walk-around inspection conducted after the earlier arrival at Launceston had shown evidence of a small bird strike on the left wing trailing edge flap lower section. Ground

- 1 The 24-hour clock is used in this report to describe the local time of day, Australian Eastern Standard Time (AEST), as particular events occurred. AEST was Coordinated Universal Time (UTC) + 10 hours.
- 2 Radio code indicating uncertainty or alert, general broadcast to widest area but not yet at the level of Mayday.

staff at Launceston were, however, unable to locate a bird carcass on or near the runway, and further inspection had not identified any impact damage or evidence of bird ingestion into the engines.

Post-flight engine examination

Following the incident, a borescope inspection of the left engine by the operator found damage to the high-pressure compressor (HPC) blades and vanes.

The engine was removed from the aircraft, and shipped to the General Electric (GE) engine facility in Kansas, USA for a full teardown and examination. A representative from the Federal Aviation Administration (FAA) was present at the teardown on behalf of the Australian Transport Safety Bureau (ATSB).

The ATSB also requested that the cockpit voice recorder (CVR) and flight data recorder (FDR) be removed from the aircraft and sent to the ATSB's technical facilities in Canberra.

Examination of recorded data

The recorded data from VH-VOC included information from a number of previous flights, with the ATSB's examination of the data confirming the flight crews' recount of events. The following sequence of events was established primarily from information included on the FDR.

Sequence of events

- VH-VOC departed Launceston aerodrome on runway 32L at 11:37:12.
- At 11:37:41, the left engine N1³ and fuel flow (FF) started to decrease and a slight increase in the left engine exhaust gas temperature (EGT) was recorded.
- Several significant fluctuations were recorded on the left engine N1, N2 and FF parameters between 11:37:41 and 11:37:52.
- At 11:37:49, the crew started to decrease the left engine thrust resolver

angle (TRA), and approximately 15 seconds later at 11:38:05, the left engine parameters stabilised at flight idle levels.

- From 11:52:26 until 12:15:11 the aircraft made a series of left orbits at approximately 3,000 ft.
- The aircraft touched down at Launceston on runway 32L at 12:19:48.

A further review of the FDR data also indicated that the EGT and fuel flow parameters for the left engine had shown a minor increase with respect to the right engine over the preceding two flights. The FDR included data from the previous 16 flights and until the second-last previous flight to the incident flight, the left and right engine parameters had remained almost identical.

Refer to Attachment A for a plot of the recorded data showing a 7 minute interval detailing the engine fluctuations and subsequent reduction in power.

Engine information

The left engine was a CFM International (CFMI) CFM56-7B24, high bypass ratio turbofan (Figure 1), serial number 888952.

Figure 1: Schematic diagram of a CFM56 series engine

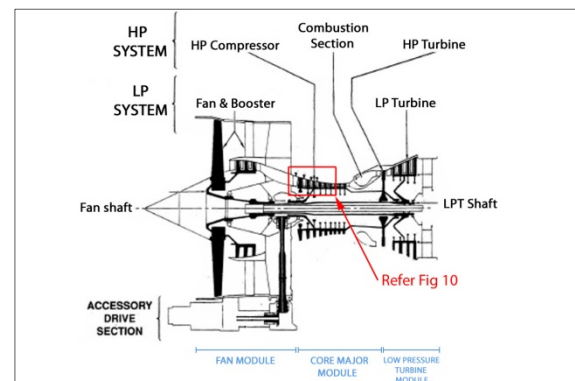


Image Source, edited: Traeger, Irwin, Aircraft Gas Turbine Engine Technology".

At the time of the occurrence, the engine had accumulated 22,978:57 hours time since new (TSN) and 16,798 cycles since new (CSN).

3 N1 represents the low pressure compressor speed, (N2 the high pressure) expressed as a percentage.

The engine was not subject to any open (unaddressed) defect reports at the time of the occurrence.

Engine teardown and inspection

The engine was disassembled at the GE engine facility in Strother, Kansas, USA between 10 and 12 September 2009.

An initial external inspection of the engine revealed no significant damage or defects, with no foreign object damage (FOD) to the inlet fan section. An ultraviolet (black-light) inspection of the spinner cone, fan case and fan blades revealed no indications of recent bird ingestion.

A further borescope inspection was performed at the engine facility, with no anomalies identified in the fan and booster sections.

Following separation of the core module, a visual inspection of the exposed surfaces did not reveal the presence of any impact damage to the high pressure compressor (HPC) inlet guide vanes or stage-1 blades. No evidence of bird remains were detected following an additional inspection with the UV light.

All of the variable stator vane (VSV) lever arms, actuator rings and links were intact and moved freely.

Separation of the HPC forward stator case halves (Figures 2 and 3) revealed damage to the HPC blades, VSV, inner shrouds and honeycomb seals.

Figure 2: HPC rotor following removal of stator. Note the rotated Stage 3 seal segment (arrowed).

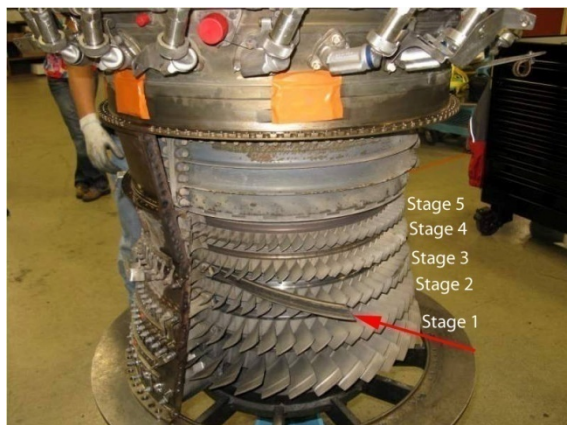
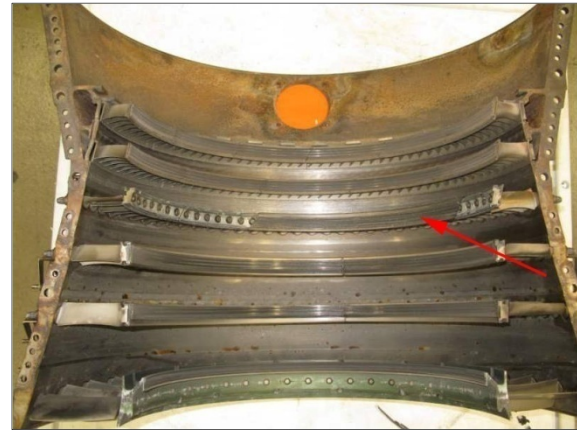


Figure 3: One half of the HPC stator following removal from the core



The HPC rotor damage commenced at the stage-3 blades and continued downstream. There was no evidence of blade fracture and all damage appeared to be consistent with hard object impact (Figure 4).

Figure 4: Example of HPC rotor blade damage.



All stator vane stages appeared to exhibit some degree of damage.

Further examination of the HPC revealed that the stage-1, 2 and 3 inner shroud segments were loose, and the bushings exhibited heavy wear. All straight pins were accounted for. Refer to Figures 5 and 6 for a diagram showing the HPC VSV shroud assembly.

Figure 5: Shroud assembly schematic (from SB 72-0515).

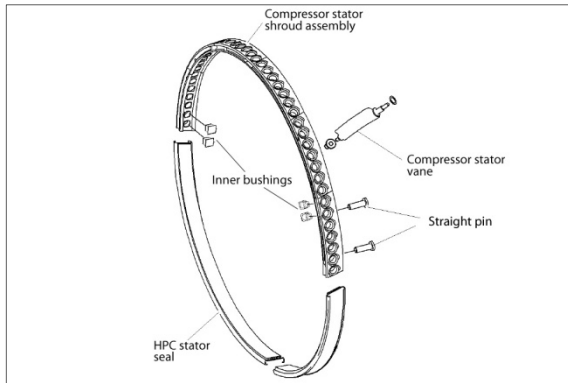
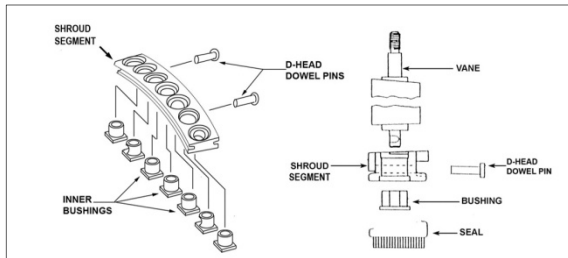


Figure 6: VSV assembly.



Although loose, the stage 1 and 2 inner shroud segments were intact and the honeycomb seals had not rotated. However, the stage-3 honeycomb seal segment located in the 9 - 12 o'clock position looking forward was missing, and the adjacent 12 - 3 o'clock segment had been displaced about 4 inches (102 mm). Two small pieces consistent with the missing seal segment were found in the debris recovered from the engine (Figure 7).

Figure 7: Seal segments found in debris.



The anti-rotation pins at the 3 and 9 o'clock positions (Figure 8) exhibited significant wear in the areas in contact with the seal segments (Figure 9).

Figure 8: Cross section through shroud showing location of anti-rotation pin

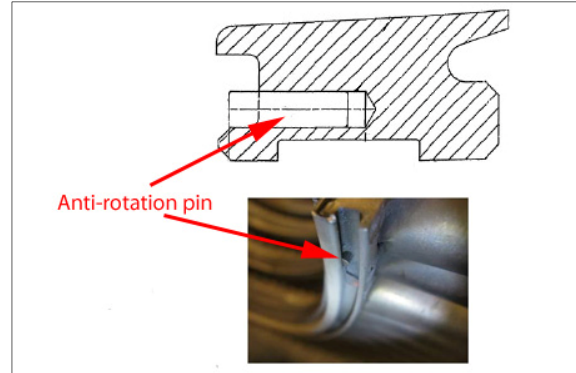
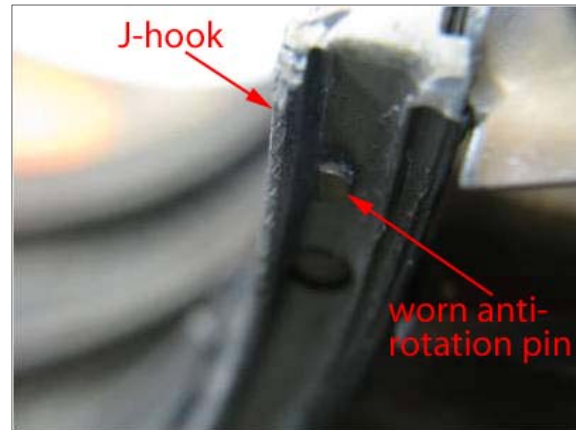


Figure 9: HPC inner shroud with worn stator seal J-hook and anti-rotation pin.



Gouging and impact marks were observed on the outer diameters of the remaining seal backing plates. Heavy rub marks were also observed on the stage 3-4 seal land.

The HPC rear stator cases exhibited impact damage to all stator vanes and moderate rubbing of the blade path liners. The honeycomb seals were intact and did not exhibit any missing material.

Background to the occurrence

The engine manufacturer informed the ATSB that rotor-to-stator contact was a known issue at the time of the occurrence, and that the engine manufacturer had distributed several service bulletins on the subject. The first service bulletin was CFM56-7B SB 72-0515, 'On wing borescope inspection for HPC stator-to-rotor contact' and was originally issued in October 2004. The latest iteration, Revision 4, was issued in February 2009. The service bulletin 'provides instructions and

standards for a borescope inspection (BSI) on high time since new (TSN) CFM56-7B engines in order to detect and monitor wear or rotation of inner shroud J-hooks'. The bulletin stated that wear of the VSV inner bushings allows the HPC inner shrouds to move forward, which in turn allows the vanes and inner shrouds to rotate forward into the rotor hardware (Figures 10 and 11).

Figure 10: Overview of blades and vanes (from SB 72-0515).

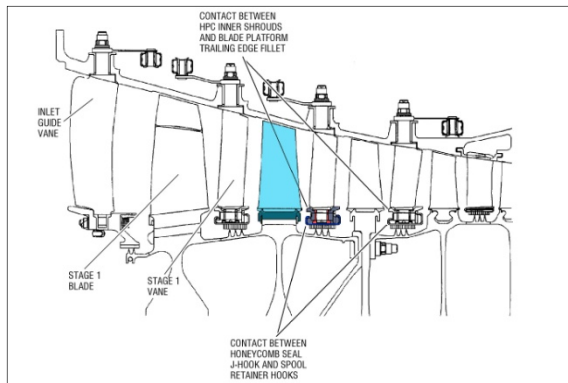
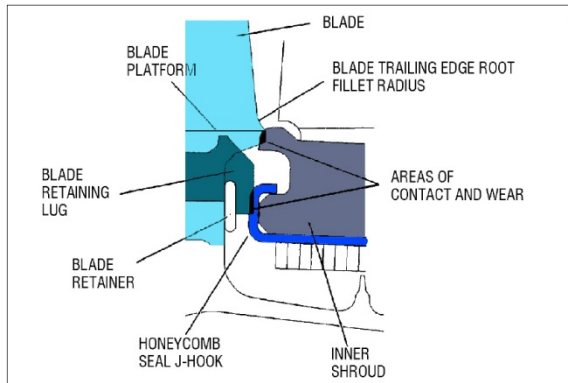


Figure 11: Contact between inner shroud and honeycomb seal and the preceding blade (from SB 72-0515).



The bulletin recommended a borescope inspection after 24,000 hours TSN, or 24,000 flight hours since the HPC inner and outer VSV bushing and outer washers had been replaced with new parts.

Additionally, CFMI issued two later service bulletins, CFM56-7B SB 72-0665, 'Introduction of new metallic-composite VSV Bushing' and SB 72-0581, 'Stage 2 and Stage 3 Improved Inner Bushings, Vanes, Seals and Shrouds', which introduced new components for the HPC. If the engine was fitted with the replacement parts, a

borescope inspection in accordance with SB 72-0515 was no longer required.

Similar service bulletins have been issued for the CFM56-5 models, with borescope inspection at 24,000 hours.

Similar occurrences

Information supplied by GE revealed that there were 34 cases of VSV stage-3 pin and seal liberation events across the entire CFM-56 engine family. Of the 34 identified occurrences, 8 resulted in an in-flight shut down (IFSD) event; compressor surges occurred in 16, but the engine continued to produce thrust, and the remaining 10 had no effect on the flight and were found during inspection (routine, or scheduled due to parameter shifts identified by engine condition trend monitoring).

During the course of the investigation, another Australian operator of Boeing 737 aircraft fitted with CFM56-7B engines advised the ATSB that they had revised their first inspection in accordance with SB 72-0515 to 22,000 hours TSN. This was based on the level of wear observed on some of their engines at the 24,000 hour inspection, which had resulted in a number of unscheduled engine removals.

ANALYSIS

A compressor surge (sometimes referred to as a compressor stall) may occur when a situation of abnormal engine airflow arises from an aerodynamic stall or loss of efficiency of the compressor airfoils. In this situation, a transient reversal of airflow through the engine may occur and is often associated with loud bangs, visible flames and/or smoke, as combustion moves forward within the engine for a short period.

The damage to the left engine of VH-VOC and the associated compressor surge was principally caused by the liberation of a segment of the high pressure compressor (HPC) stage-3 inner honeycomb seal retainer assembly. Analysis by the engine manufacturer concluded that this was brought about in the following manner:

- Wear of the variable stator vane (VSV) bushings and inner shroud had allowed movement between the seal retainer and inner shroud segments.
- This subsequently produced heavy wear of the seal retainer anti-rotation pins.
- A combination of the VSV bushing/shroud wear and loss of effectiveness of the seal anti-rotation feature allowed the seal retainer to make contact with the HPC rotor inter-stage seals.
- The 3 - 9 o'clock seal retainer further rotated on the inner shroud segments and was able to lift above the adjacent seal retainer.
- The seal retainer was then able to further contact the rotor, which dislodged it completely from the inner shroud segments and into the compressor gas path.
- The liberated seal segment then moved downstream, causing significant impact damage to the remaining stages and resulting in a loss of compressor efficiency and the subsequent compressor surge reported by the flight crew.

The short-term increase in the occurrence engine exhaust gas temperature (EGT) levels noted from the flight data recorder (FDR) data was consistent with the effects of the damage developing within the HPC.

FINDINGS

From the evidence available, the following findings were made with respect to the compressor surges experienced by VH-VOC following takeoff from Launceston aerodrome and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- Advanced wear of the Stage-3 variable stator vane (VSV) bushing and inner shroud promoted movement and mechanical interactions that led to the

liberation of a segment of high pressure compressor (HPC) air seal while the engine was operating.

- Liberation of the HPC honeycomb seal into the compressor gas path at the stage-3 blade trailing edges resulted in impact damage downstream, a loss of compressor efficiency and subsequent compressor surge during the takeoff from Launceston.
- The CFM56-7B engine design was susceptible to VSV bushing and shroud wear that can lead to internal mechanical damage and potential in-flight performance difficulties. *[Minor safety issue]*
- The CFM56-7B engine had sustained bushing and shroud wear sufficient to cause rotor-to-stator contact, after a time in service that was less than the minimum threshold period specified by the manufacturer, for an initial inspection targeted at identifying this problem. *[Minor safety issue]*

SAFETY ACTION

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 organisations 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.

CFM International (CFMI)/General Electric

CFM56-7B engine susceptibility to variable stator vane (VSV) bushing and shroud wear

Safety issue

The CFM56-7B engine design was susceptible to VSV bushing and shroud wear that can lead to internal mechanical damage and potential in-flight performance difficulties.

Action taken by engine manufacturer

The engine manufacturer has issued a number of service bulletins (SBs) to operators highlighting the need for on-wing borescope inspection (SB 72-0515) to look for inner shroud / J-hook wear. Additionally, the manufacturer introduced new part numbers (SB 72-0665 and SB 72-0581) that appear to eliminate the cause of the compressor surge.

ATSB assessment of response/action

The ATSB considers the safety action taken by the engine manufacturer adequately addresses this safety issue.

Service bulletin inspection thresholds

Safety issue

The CFM56-7B engine had sustained bushing and shroud wear sufficient to cause rotor-to-stator contact, after a time in service that was less than the minimum threshold period specified by the manufacturer, for an initial inspection targeted at identifying this problem.

Action taken by engine manufacturer

The time since new (TSN) of the subject engine was lower than the 24,000 hour inspection threshold specified in the service bulletin. As such, this engine was not required to have undergone borescope inspection in accordance with the service bulletin. The manufacturer responded to the ATSB that the recommended inspection period is not necessarily set to prevent every event; but is based on the consequence of

that event. The manufacturer used Weibull analysis⁴ to meet a combination of safety goals and operator needs (scheduling, costs etc).

The manufacturer also stressed that only one other of the in-flight shut down (IFSD) events (March 2009) occurred at less than the 24,000 threshold, at 23,700, and went on to state that;

While it may be desirable to prevent every event, a single-engine event is not in itself a threat to continued safe flight, and the aircraft are certified to fly with a single IFSD. Thus, thresholds are set to ensure that dual-engine events are extremely improbable, while not imposing an undue burden on the operators. In this case, the events are being monitored and Weibull's [sic] updated and it is not considered necessary to reduce the inspection threshold at the moment.

ATSB assessment of response/action

The ATSB is satisfied that the action taken by the engine manufacturer adequately addresses the safety issue at this stage. The ATSB will continue to monitor the issue in regard to future related occurrences and the outcome of ongoing updated Weibull analyses by the engine manufacturer. At the same time, in the interests of ensuring awareness of the safety issues identified in this investigation, the ATSB issues the following Safety Advisory Notice to all operators of CFM56-7 and CFM-56-5 engines and their variants.

ATSB Safety Advisory Notice (AO-2009-053-SAN-038)

The Australian Transport Safety Bureau draws the attention of all operators of CFM56-7 and CFM56-5 engines and their variants to the safety issues identified by this investigation. In particular operators should be aware of the potential for premature wear within the compressor variable stator vane bushings and shroud to develop to levels where it may precipitate the failure of the engine while in-service, and within a

⁴ Weibull analysis is a statistical modelling technique commonly used in reliability engineering.

timeframe that is less than the minimum threshold for the initial inspection for the problem (24,000 hours TSN, per SB 72-0515). Operators are encouraged to review their procedures to ensure an appropriate awareness of the issues among maintenance personnel.

Aircraft operator

CFM56-7B engine susceptibility to VSV bushing and shroud wear

Safety issue

The CFM56-7B engine design was susceptible to VSV bushing and shroud wear that can lead to internal mechanical damage and potential in-flight performance difficulties.

Action taken by aircraft operator

As a result of this incident, the operator approached the manufacturer to investigate whether the recommended schedule of 24,000 TSN for the first inspection (as per SB 72-0515) should be reviewed based on this occurrence. They were given a similar response to that provided to the ATSB. The operator was satisfied with the outcome, and on the basis of findings from inspections performed on their fleet of engines, elected not to change the recommended re-work schedule.

The operator advised the ATSB that upon advice from CFMI, they were starting a campaign to replace the bushings and associated hardware on their owned engines (as per SB 72-0581 and SB 72-0665) at the next overhaul, or whenever the engine had criteria that scheduled the next inspection at 800 hours or below (as per the service bulletin).

The operator further stated that at the time of this report release, they had 19 engines in service with the new modified bushings factory installed, and SB 72-0581 had been embodied on one engine during a workshop visit. The majority of workshop visits so far had been for lease engines (i.e. engines returned to the vendor well before 24,000 hours since new/repair), and as such, new pre-modification bushings had been installed

unless the lease company had specifically requested the hybrid or new metallic bushings.

Since the incident, the operator has carried out a significant number of inspections in accordance with SB 72-0515 and observed that the extent of VSV damage appeared to be greater on the higher (thrust) rated engines. As such, the operator has recently implemented a plan which places a higher priority on the replacement of the bushings and associated hardware of these high thrust engines, and includes a schedule for replacement of the VSV components on over 40 engines within their inventory.

ATSB assessment of response/action

The ATSB is satisfied that the action taken by the operator adequately addresses the safety issue.

SOURCES AND SUBMISSIONS

Sources of Information

Aircraft operator

CFM International / General Electric

References

Traeger, Irwin E, "Aircraft Gas Turbine Engine Technology, 3rd Edition", Glencoe Aviation Technology Series, McGraw Hill, 1999, Ohio, USA.

"Powerplant Mechanics' Manual, Study text and guide to the FAA rating", Pan-American Navigation Service Inc, 1975, California, USA.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the Transport Safety Investigation Act 2003, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the operator, the engine manufacturer, the Civil

Aviation Safety Authority (CASA) and the National Transportation Safety Board (NTSB).

Submissions were received from the operator, the NTSB, the engine manufacturer and CASA. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly

ATTACHMENT A: FLIGHT DATA RECORDER PLOT

Plot of the flight data recorder information showing a seven minute period during the time of the compressor surge and immediately after. The plot shows values of the engine rotor speeds (low pressure), altitude, exhaust gas temperature (EGT), thrust resolver angle, magnetic heading, and computed airspeed.

