Australian Government

Australian Transport Safety Bureau

Engine surge and high vibration involving Airbus A330, VH-EBR

44 km north-east of Gold Coast Airport, Queensland, on 15 April 2018

ATSB Transport Safety Report
Aviation Occurrence Investigation
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Addendum

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Safety summary

What happened

On 15 April 2018, a Qantas Airways Airbus A330, registered VH-EBR, departed Brisbane Airport, Queensland, for a regular public transport flight to Auckland, New Zealand. Shortly after departure, the crew received an advisory notification indicating excessive vibration from the left engine.

The crew reduced thrust on the left engine to idle, and the noise and vibrations ceased. The crew elected to return to Brisbane, and landed uneventfully. The thrust on the left engine remained at idle during the air turn back.

What the ATSB found

The General Electric CF6-80E1 engine utilises rows of variable stator vanes (VSV) between each of its high-pressure compressor (HPC) stages for optimal airflow. Worn bushings led to fretting damage on a lever arm in the fourth-stage VSV system. The lever arm fractured, allowing the VSV to become off-schedule (misaligned), affecting the airflow entering the stage four HPC.

The airflow disturbance resulted in abnormal aerodynamic loading and ultimately, fatigue failure of a fourth stage compressor blade. The downstream turbomachinery was then damaged due to the progression of blade debris through the engine.

Three non-mandatory VSV lever arm inspections were carried out prior to the occurrence but were not effective in detecting the bushing wear.

General Electric intended that replacement of the complete set of bushings was required when more than half of the accessible bushings were worn. However, the operator had proactively replaced worn bushings individually when found during maintenance. As a result, the threshold to replace the complete set would not be reached and inaccessible bushings would not be replaced.

What's been done as a result

As a result of this occurrence, Qantas inspected all CF6-80E1 engines in the A330 fleet for similar defects. No defects were identified. Additionally, Qantas issued a maintenance memo to service personnel, highlighting the maintenance actions for the VSV system and precautions to be aware of when carrying out work in this area.

Safety message

When maintenance organisations carry out additional activities to what is required, they should consider checking with the manufacturer to confirm that no unintended consequences could be introduced.

Contents

The occurrence

At about 0905 Eastern Standard Time[1] on 15 April 2018, Qantas Airways flight QF123, an Airbus A330-202 aircraft registered VH-EBR, departed Brisbane Airport, Queensland, for a regular public transport flight to Auckland, New Zealand.

About 4 minutes later, while climbing through 9,000 ft, the electronic centralised aircraft monitor displayed an ENG 1 N2 VIBRATION[2] advisory notification, indicating excessive vibration on the left engine. The crew carried out actions in accordance with the abnormal and emergency procedures checklist, reducing thrust on the left engine. The aircraft continued its climb at reduced thrust.

After several minutes, while climbing through flight level 190,[3] two loud bangs occurred and continuous airframe vibrations commenced. The crew reduced thrust on the left engine to idle and the noise and vibrations ceased. The thrust on the left engine remained at idle for the remainder of the flight. The crew declared a PAN PAN[4] and returned to Brisbane, landing safely at about 0945.

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1 Eastern Standard Time: Coordinated Universal Time (UTC) + 10 hours.

2 N2: the rotational speed of the high-pressure compressor in a turbine engine.

3 Flight level: at altitudes above 10,000 ft. in Australia, an aircraft's height above mean sea level is referred to as a flight level (FL). FL 190 equates to 19,000 ft.

4 PAN PAN: an internationally recognised radio call announcing an urgency condition which concerns the safety of an aircraft or its occupants but where the flight crew does not require immediate assistance.

Context

Aircraft description

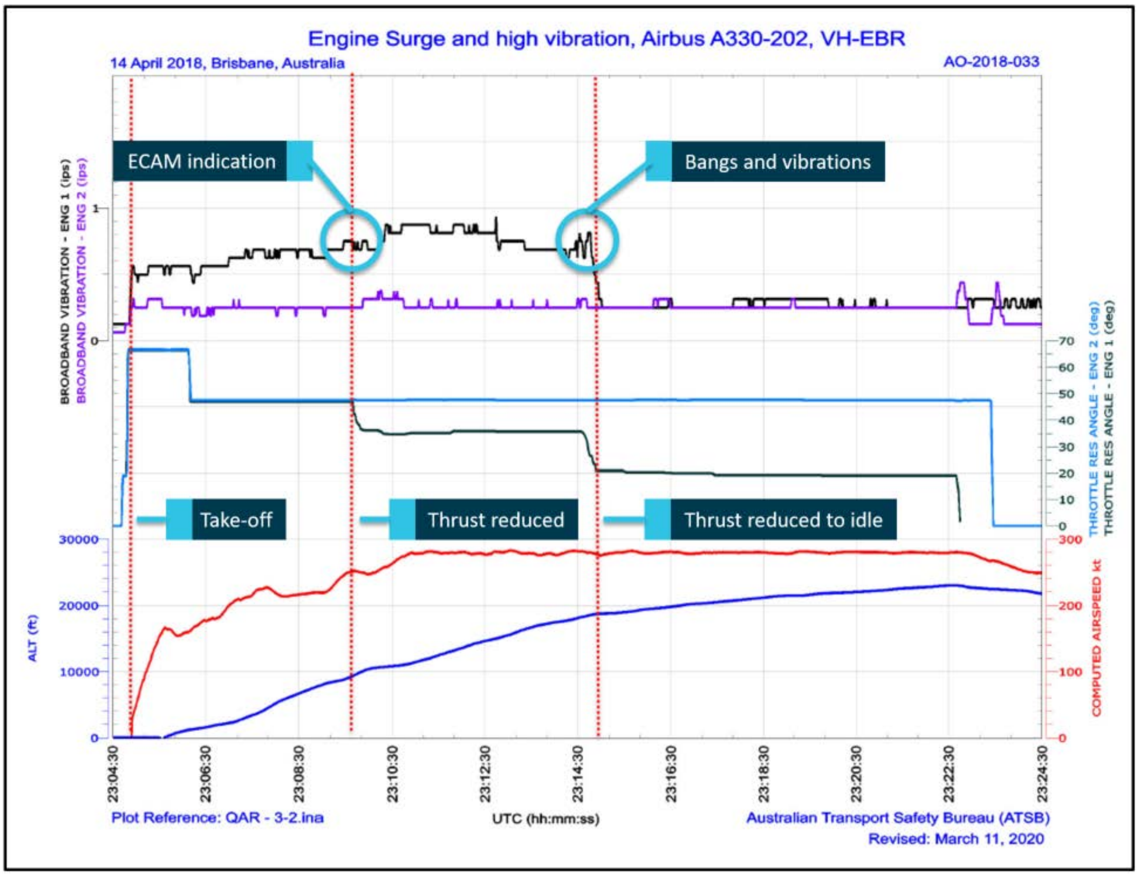
The Airbus A330 range of aircraft is a twin-engine, wide-body airliner. It is available with three different engine installation options. VH-EBR was fitted with General Electric (GE) CF6-80E1 (CF6) engines. Other engine options available for the A330 were the Pratt & Whitney PW4000, or the Rolls-Royce Trent 700 engines.

Recorded data

Figure 1 shows a plot of the data that was obtained from the quick access recorder (QAR). During the take-off roll, the left engine vibrations (black line) increased to a higher than normal level for the CF6. The vibrations continued to increase, resulting in the ENG 1 N2 VIBRATION message displaying on the electronic centralised aircraft monitor (ECAM) at about 0909. The left engine thrust was reduced in response. About 5 minutes later, two left engine vibration spikes were recorded, consistent with the loud bangs and airframe vibration reported by the crew. The left thrust lever was then reduced to idle.

The ATSB also downloaded data from the previous five flights. The recorded data showed that on each of those flights, the vibration level of the left engine was higher than normal, but had not reached the limit to trigger the ECAM notification.

Figure 1: Plotted data from QAR showing vibration levels and thrust lever positions during the occurrence flight



Source: ATSB

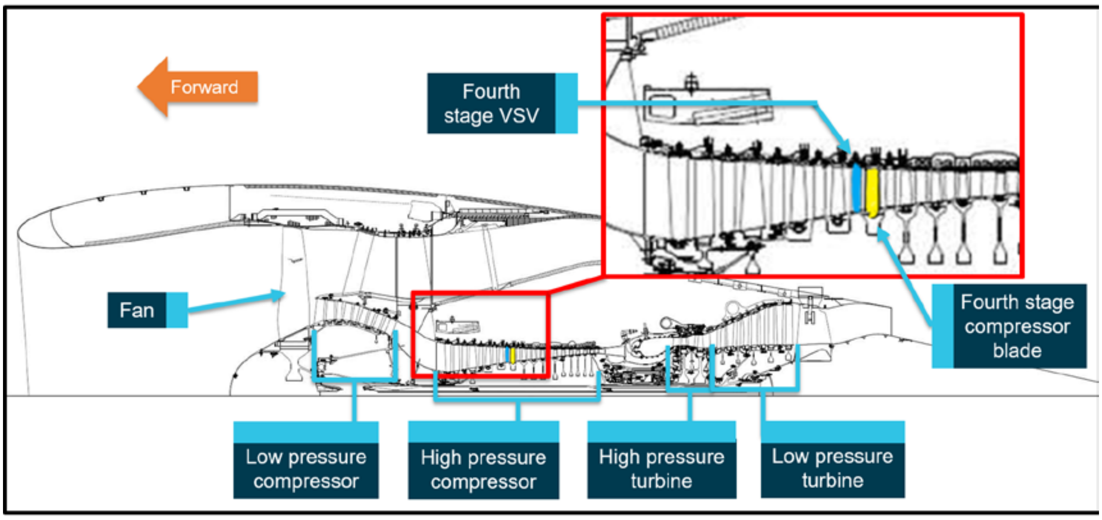
Engine information

Post-flight engineering examination

A post-flight engineering inspection of the left engine identified metal fragments in the tail pipe and two missing fourth stage high-pressure compressor (HPC) blades. Figure 2 shows a cross-section of the GE CF6 engine, with the location of stage four of the HPC highlighted.

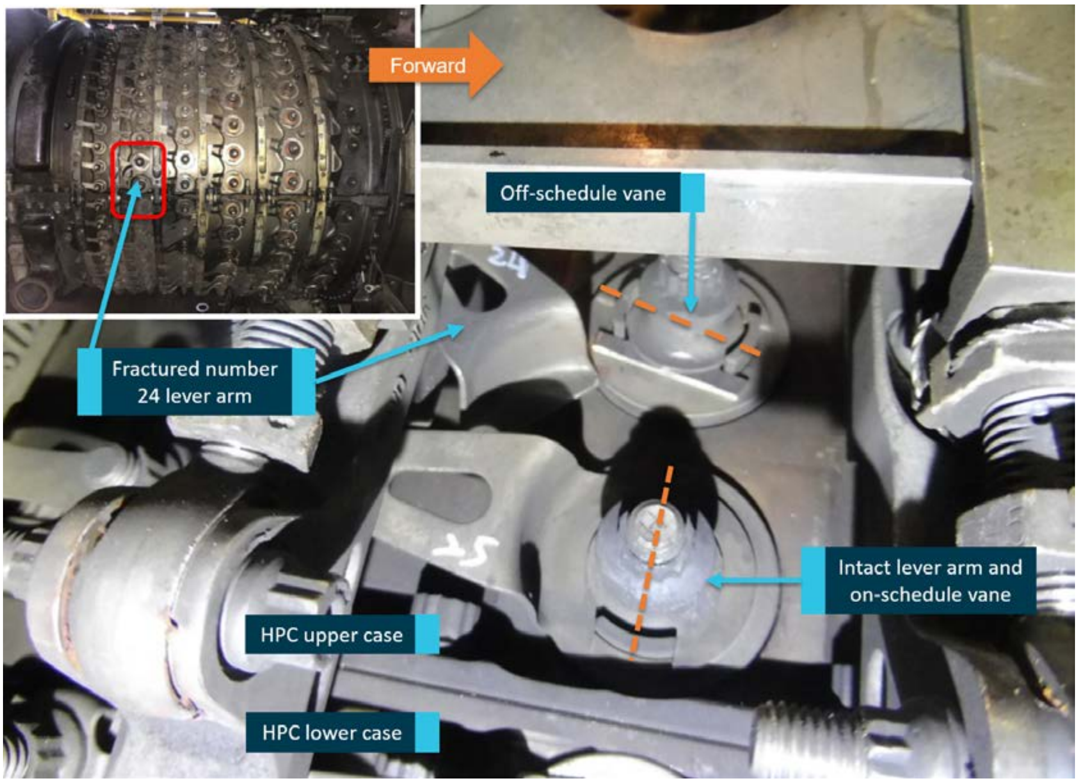
The inspection also identified that several variable stator vane (VSV) lever arms were bent and one was broken (Figure 3). The engine was subsequently shipped to an overhaul facility, where it was disassembled and inspected under the supervision of the engine manufacturer.

Figure 2: GE CF6 cross-section showing a detailed view of the HPC



Source: General Electric, annotated by ATSB

Figure 3: Section of the fourth stage variable stator vanes showing the fractured number 24 lever arm and resulting off-schedule vane. Inset shows location on engine at 3 o'clock position.



Source: Evergreen Aviation Technologies Corporation, annotated by ATSB

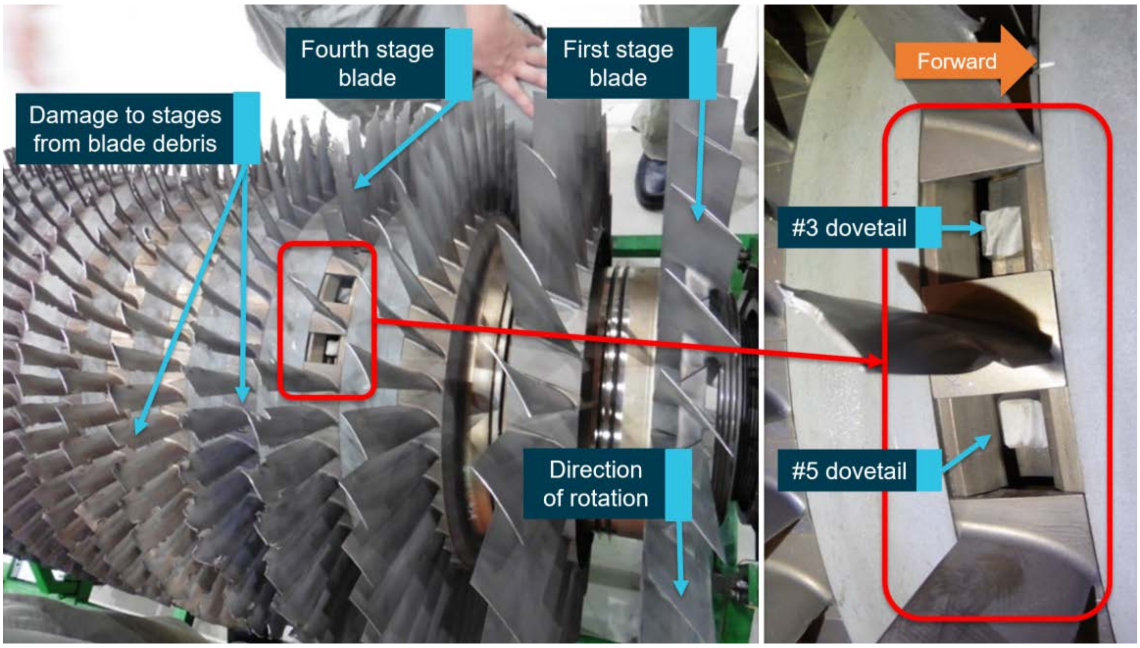
Engine disassembly and inspection

The engine disassembly and inspection revealed:

- there was no damage to the first three HPC stages
- two of the fourth stage HPC blade assemblies, number 3 and number 5, had separated at the dovetail-mounting portion of the blade root (Figure 4)
- of the 50 fourth stage VSV lever arms, eight were distorted and the number 24 position was completely fractured
- the separated blades had damaged the rear face of the fourth stage vanes with the distorted lever arms
- the compressor and turbine sections downstream of the separated HPC blades were damaged from progression of the blade debris through the gas path.

All of the fourth stage compressor blades, variable stator vanes and lever arms were sent to the engine manufacturer's materials examination laboratory for analysis.

Figure 4: Disassembled engine showing fractured dovetails within fourth stage



Source: Evergreen Aviation Technologies Corporation annotated by ATSB

Component failure analysis

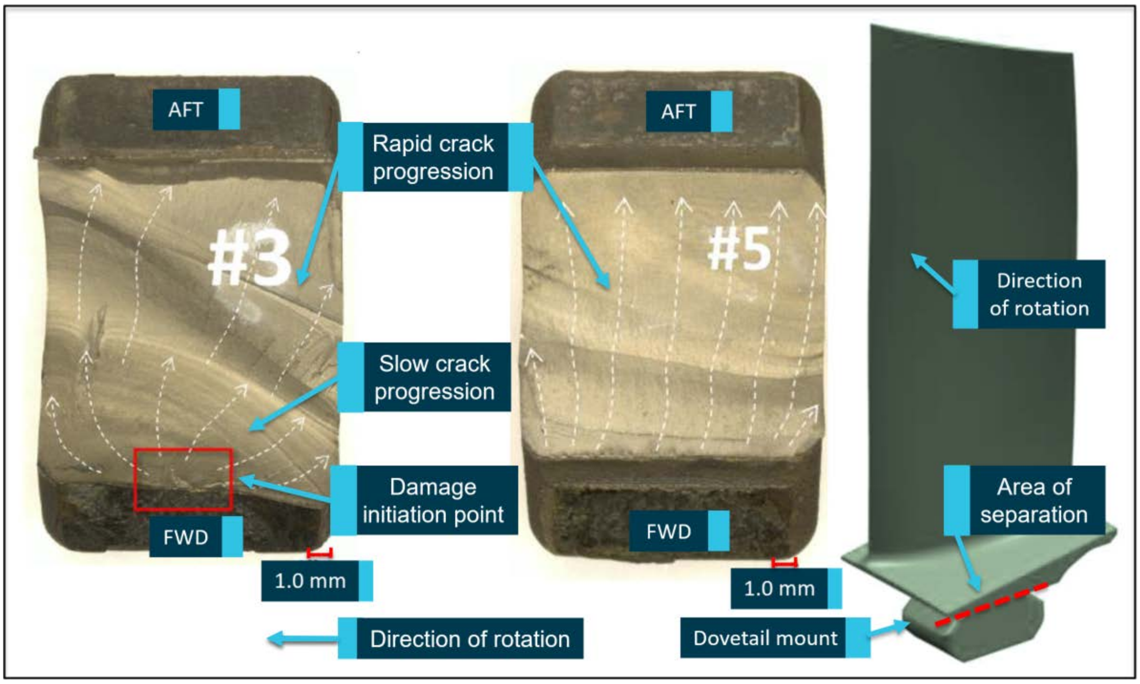
Fourth stage blades

A laboratory examination by GE found that the blade fitted to the number 3 position failed due to the propagation of a high-cycle fatigue[5] crack that initiated in the blade root at the forward edge (in the direction of rotation). Other failures of the stage 4 blades have been reported previously, where the deterioration of the blade coating was identified as an important factor. There was no significant deterioration of the blade coating on this engine.

The blade in the number 5 position failed as a result of more rapid fatigue crack progression cracking (Figure 5). The examination found that this was due to secondary damage, likely from impact by the released number 3 blade. One other fourth stage blade was cracked.

5 High-cycle fatigue develops from repeated elastic (non-permanent) deformation of the material and is associated with a very high number of low-stress cycles.

Figure 5: Detailed view of fractured blades

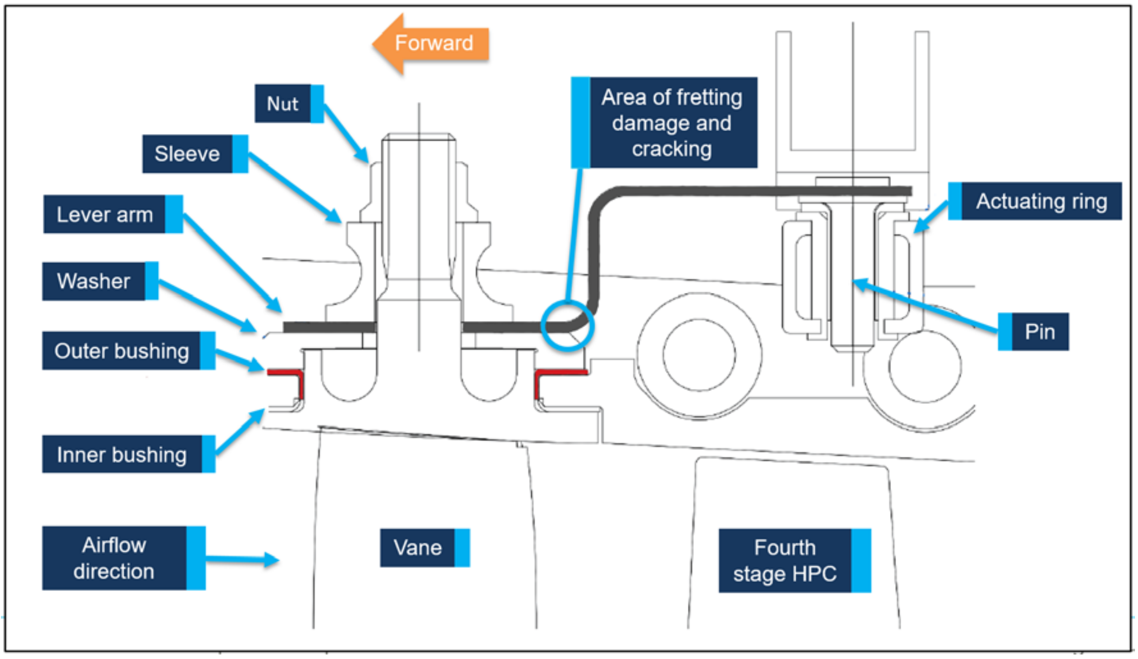


Source: General Electric, annotated by ATSB

Variable stator vane lever arm

The VSV lever arm fractured as a result of fatigue crack progression that originated at an area of fretting[6] wear between the lever arm and washer (Figure 6 and Figure 7). The fretting on the lever arm was determined to have resulted from wear to the composite bushings fitted under the VSV lever arm. As the bushing wore, the VSV was allowed to tilt, placing a bending and twisting moment into the lever arm.

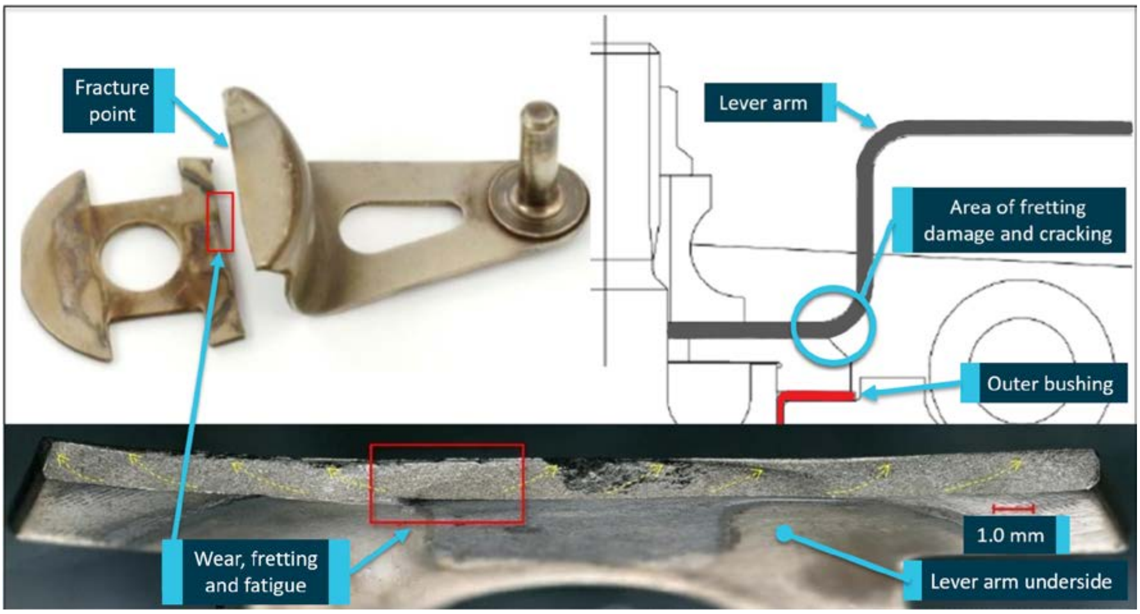
Figure 6: VSV design and component locations, highlighting outer bushing and lever arm



Source: General Electric, annotated by ATSB

6 High frequency, low amplitude relative motion between surfaces in contact.

Figure 7: Fractured VSV lever arm, its location and a close-up picture of the fracture surface showing fretting damage and high-cycle fatigue cracking



Source: General Electric, annotated by ATSB

Once the lever arm was broken, the vane rotated freely, which disrupted airflow into the fourth stage compressor. This created vibratory aerodynamic loading of the blades, which resulted in the fatigue cracking.

The bending damage in the nine VSV lever arms was determined to be secondary damage from contact with the separated compressor blades.

Engine maintenance history

The engine involved in this incident had accumulated 43,635 hours, 7,815 cycles since new and 13,047 hours, 3,352 cycles since its last overhaul. Since the last lever arm inspection, the engine had accumulated 2,474.46 hours and 551 cycles.

During the last engine overhaul, a number of fourth-stage compressor blades, including blade 3, were inspected, assessed as being serviceable and refitted. Others, including blade 5, were installed new at that time.

Variable stator vane inspections

Aircraft maintenance manual

VSV lever arm inspections were recommended by the engine manufacturer, but not mandatory. The inspection had an interval of 1,000 cycles between inspections. Qantas had opted to conduct this inspection, although in a modified form, due to a history of broken fifth stage lever arms experienced by other operators (see *Related*).

The aircraft maintenance manual (AMM) required inspection of the VSV:

> stages 1, 2, 3 and 4 for vane trunnion metal touches stator case metal (MTM - metal-to-metal)

The manufacturer and operator both stated that lever arm looseness was identified through a *wiggle check*, which would indicate worn outer bushings. The AMM went on to state that if the engine had:

> greater than 50% of the vanes in the stage with MTM

then the maintainer must:

> replace outer bushings with new flanged outer bushings (this repair returns these parts to a serviceable condition).

This rectifying work could either be performed at the time of the initial inspection or postponed for a period, based on flight hours or cycles. The permitted extension was in place to allow time for maintenance action to be scheduled at the earliest opportunity.

Inspection accessibility

The ATSB examined a different CF6 engine fitted to an A330 undergoing maintenance and found that access to some VSV lever arms, at all stages of the compressor, was difficult.

About 75 per cent of the fourth stage VSV arms could be examined without engine removal and further disassembly of engine ancillary components. The remainder were not accessible due to the fitment of a large external gearbox covering the six to nine o'clock[7] position of the engine. The number 24 lever arm was situated at the three o'clock position and was therefore accessible.

The ATSB asked the engine manufacturer how a maintainer could determine when 50 per cent of the lever arms were worn, if a quarter of them were not able to be accessed. The engine manufacturer advised that the determination was 50 per cent of the number accessible. The engine manufacturer also advised that the intent of the rectification requirements was that when the 50 per cent threshold was met, the bushings were to be replaced as a complete set on that compressor stage.

The engine manufacturer surveyed five other A330 operators on current inspection practices and common findings. Some operators did not carry out bushing inspections on-wing, due to the inspection being non-mandatory. They were only inspected during shop visits or if found during other maintenance. The operators did not report that the lever arm bushings wore preferentially in any location around each compressor stage.

Operator inspections

The operator proactively replaced any VSV bushing that was found worn, prior to the engine reaching the 50 per cent limit. Stage four bushings had been replaced on other engines where, a portion were replaced at any one time. They advised this was to improve the overall condition of the vane stages. They sought clarification from the engine manufacturer prior to the occurrence, regarding the suitability of individual replacement, but reported they had not received a response.

The engine involved in this incident had undergone three inspections of the VSV system since its last overhaul. No defects resulting from these inspections were noted, and no bushings had been replaced.

Related occurrences

In November 2017, a Qantas A330 experienced similar inflight vibrations. The flight continued to its destination, where an inspection found that number 24 lever arm was fractured and one HPC blade had separated. GE reported that there had been no other fourth stage lever arm occurrences of this type in over 23 million flight hours and 4.7 million flight cycles accumulated by the CF6-80E1 world fleet as at March 2018. There were a number of failures of HPC stage 5 lever arms prior to 2002, however that issue was resolved through redesigned lever arms and bushings.

The manufacturer analysed the November event and determined the lever arm and blade had failed in the same manner as the subject occurrence. There were no commonalities found with

[7] O'clock: the clock code is used to denote the direction of, or the location on an aircraft relative to the observer's position. In the case of an engine, when viewed from the rear.

engine hours or cycles, and no indication that the event engines had been operated significantly differently from the fleet. The manufacturer therefore determined that the two events were most probably related to maintenance in the area.

The ATSB reviewed the maintenance work packages for the engines involved and considered, for example, whether the lever arms at the number 24 position had been unintentionally damaged during a particular maintenance practice, causing accelerated bushing wear. However, there were no aspects identified with respect to personnel or work practices that may have linked the two occurrences.

Safety analysis

Engine vibration

The combination of worn outer bushings and fretting wear on a fourth stage high-pressure compressor (HPC) variable stator vane (VSV) lever arm resulted in a fatigue crack, leading to a fracture of the lever arm. The associated stator vane rotated into an off-schedule position and created turbulent airflow that acted like a cyclic pulse on the fourth stage HPC blades, as they passed the off-schedule vane. This aerodynamic cyclic loading resulted in initiation of a high-cycle fatigue crack in at least two compressor blades, until one blade separated at its root, causing damage to the downstream engine components and a noticeable increase in measured engine vibration.

Periodic maintenance

Qantas inspected the VSV system in accordance with the manufacturer's non-mandatory inspection, with the exception of the individual replacement of worn bushings, as they were discovered. The inspections were generally effective in that assemblies accessible for inspection had previously been found to be loose and were replaced. However, while the failed (number 24) VSV lever arm was also accessible, no issues were found in the most recent inspections. Noting that the engine was approximately halfway between the 1,000 cycle inspections, it was possible that the looseness was not apparent at that time. Nevertheless, the inspections, as conducted, were not effective in detecting the worn bushing and thereby preventing this occurrence.

A consequence of the individual replacement of worn bushings, as opposed replacement of the entire set on a threshold of 50 per cent worn bushings, was that the inaccessible bushings would not be replaced while the engine was in service. While this would not have affected the outcome in this occurrence, modifying the replacement criteria reduced the overall effectiveness of the inspection.

Previous occurrences

This was only the second engine failure of its type on CF6-80E1 engines. The occurrences were within five months of each other, involved the same operator and failure of the VSV arm in the same position. In the absence of commonalities in engine hours, cycles or service history, the engine manufacturer determined that the failures were most probably related to maintenance in the area of the VSV arm. The ATSB review of the associated maintenance work packages did not find any evidence to positively link the occurrences.

Findings

From the evidence available, the following findings are made with respect to the engine surge and high vibration involving an Airbus A330, registered VH-EBR, 44 km north-east of Gold Coast Airport, Queensland, on 15 April 2018. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing factors

- A worn stator lever arm bushing resulted in fretting damage, initiation of a fatigue crack, and fracture of the lever arm.
- The fracture of the lever arm led to an off-schedule variable stator vane, which created turbulent airflow within the engine compressor section. This turbulent airflow led to the failure of a compressor blade at the blade root, due to high-cycle fatigue.
- The operator had conducted three non-mandatory inspections of the variable stator vane system since the engine's last overhaul. Despite these inspections being conducted, the outer bushing and lever arm at the number 24 position was able to wear, undetected.

Other findings

- The engine issue was one of two identified worldwide. Both occurred within 5 months of each other, in the same operator’s fleet and in the same number 24 position, and both on the left engine. The engine manufacturer, operator and the ATSB were unable to establish fully the reason for the timing, fleet, and position commonalities in the context of worldwide historical data.

Safety actions

Additional safety actions

Whether or not the ATSB identifies safety issues in the course of an investigation, relevant organisations may proactively initiate safety action in order to reduce their safety risk. The ATSB has been advised of the following proactive safety action in response to this occurrence.

Qantas Airways

Qantas has taken proactive safety actions, including performing a once-through fleet inspection of variable stator vane (VSV) lever arms in the number 24 position, across the A330 fleet. No defects were identified as a result of this inspection.

Qantas also issued a VSV system awareness maintenance memo to engineering staff. The purpose of this memo was to highlight the importance of the inspection of VSV lever arm system for worn bushings and precautions to be aware of when carrying out work in this area.

General details

Occurrence details

Date and time:	15 April 2018 – 0905 EST	
Occurrence category:	Incident	
Primary occurrence type:	Engine failure or malfunction	
Location:	44 km north-east of Gold Coast Airport, Queensland	
	Latitude: 27º 52.07' S	Longitude: 153º 47.95' E

Aircraft details

Manufacturer and model:	Airbus A330-202	
Registration:	VH-EBR	
Operator:	Qantas Airways	
Serial number:	1251	
Type of operation:	Air Transport High Capacity - Passenger	
Departure:	Brisbane, Queensland	
Destination:	Auckland, New Zealand	
Persons on board:	Crew – 11	Passengers – 266
Injuries:	Crew – 0	Passengers – 0
Aircraft damage:	Minor	

Sources and submissions

Sources of information

The sources of information during the investigation included:

- Qantas Airways
- General Electric Aviation
- aircraft Quick Access Recorder.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), the Australian Transport Safety Bureau (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 Qantas Airways, General Electric Aviation, National Transportation Safety Board, Bureau d'Enquêtes et d'Analyses and the Civil Aviation Safety Authority.

Submissions were received from General Electric Aviation. The submissions were reviewed and where considered appropriate, the text of the draft report was amended accordingly.

Australian Transport Safety Bureau

The ATSB is an independent Commonwealth Government statutory agency. The ATSB is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within ATSB's 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 operations involving the travelling public.

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 identify and reduce safety-related risk. ATSB investigations determine and communicate the factors related to the transport safety matter being investigated.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, 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 initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

Terminology used in this report

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, current risk controls and organisational influences.

Contributing factor: a factor that, had it not occurred or existed at the time of an occurrence, then either:

(a) the occurrence would probably not have occurred; or

(b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or

(c) another contributing factor would probably not have occurred or existed.

Other factors that increased risk: a safety factor identified during an occurrence investigation, which did not meet the definition of contributing factor but was still considered to be important to communicate in an investigation report in the interest of improved transport safety.

Other findings: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which ‘saved the day’ or played an important role in reducing the risk associated with an occurrence.