Australian Government

Australian Transport Safety Bureau

Engine vibrations and in-flight shutdown involving Airbus A330, VH-QPI

Near Sydney Airport, New South Wales, on 1 June 2018

ATSB Transport Safety Report

Aviation Occurrence Investigation
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Addendum

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Safety summary

What happened

On 1 June 2018, a Qantas Airways Limited Airbus A330 aircraft, registered VH-QPI (QPI), was operating a scheduled passenger flight from Sydney, New South Wales to Bangkok, Thailand. On board were 13 crewmembers and 297 passengers.

Shortly after take-off, a ‘pop’ sound was heard, followed by light airframe vibration and a reduction in the rotational speed of the right engine. A cockpit advisory message relating to the right engine’s vibration level was also displayed to the crew.

The flight crew discontinued the climb and consulted the ‘High Engine Vibration’ checklist, which directed them to reduce the right engine’s thrust to idle. With the reduction in thrust, the vibration on the right engine reduced but remained relatively high. To prevent further engine damage the flight crew decided to shut the engine down. With the engine shut down, the airframe vibration ceased.

Following an uneventful descent and return to Sydney Airport, an overweight landing with one engine inoperative was conducted.

Initial inspection by engineering staff revealed visible damage to the right engine low-pressure turbine, and engine debris generated impact damage to the aircraft’s wing flap lower surfaces and body fairings. The engine was removed and sent to the operator’s overhaul facility for detailed examination and repair.

What the ATSB found

Technical examination identified that the effects of oxidation and deterioration of the protective coating of the low-pressure turbine stage 4 nozzle guide vane segments, led to intergranular oxidation, crack development and loss of an aerofoil from the No. 5 segment. The liberated aerofoil impacted downstream rotating components, resulting in a loss of turbine blade material, rotor imbalance and subsequent airframe vibration.

What’s been done as a result

In response to the loss of the aerofoil from the No. 5 nozzle guide vane segment, the operator initiated a borescope inspection program to identify segments that exhibited evidence of cracking. Affected engines were removed from service. The operator also specified that at engine overhaul, all nozzle guide vane segments that had cracks were to be replaced, and that only new (rather than overhauled) segments were to be installed.

The engine manufacturer made a change to the type of protective coating used on the nozzle guide vane segments to reduce oxidation. Service instructions were issued in mid-2019 to implement the coating replacement.

Safety message

This incident illustrates that, despite the high reliability of modern turbine engines, flight crews can still be faced with malfunctions that require their combined judgement and expertise to safely manage the situation.

The occurrence

What happened

On 1 June 2018, a Qantas Airways Limited Airbus A330 aircraft, registered VH-QPI (QPI), was operating a scheduled passenger flight from Sydney, New South Wales to Bangkok, Thailand. On board were 13 crewmembers and 297 passengers. The flight crew consisted of the aircraft captain who was the pilot flying (PF), the first officer as the pilot monitoring (PM) and a second officer.[1]

QPI departed Sydney at 1219 Eastern Standard Time.[2] As the engine thrust was being reduced from the take-off setting, the PM heard a 'pop' sound and the flight crew recalled receiving a flight deck advisory message, followed by light airframe vibration. A reduction of about 5 per cent in N_1[3] revolutions per minute of the right (No. 2) engine was also noticed. The advisory message from the aircraft's electronic centralised aircraft monitor (ECAM) indicated that the No. 2 engine's vibration level had reached the maximum recordable level of 10 units. A later review of quick access recorder[4] data showed that the ECAM message was generated at 1220:25 as the aircraft climbed through an altitude of 1,696 ft.

The PF reported that, despite the right engine vibration and reduction in N_1, no yawing[5] was present. The aircraft was configured with the undercarriage retracted, and autopilot engaged. As the aircraft gained altitude, the PF retracted the wing flaps and leading edge slats. The flight crew then responded to the advisory message and referred to the aircraft's quick reference handbook, which directed them to the 'High Engine Vibration' checklist.

By 1224:22, the flight crew had discontinued the climb and were maintaining an altitude of 7,000 ft in order to complete the 'High Engine Vibration' checklist. The PF reported that in accordance with the checklist, the No. 2 engine's thrust lever was reduced to idle, and the No. 1 (left) engine set to maximum continuous thrust.

With the No. 2 engine at idle, the vibration level reduced to 6.5 units. However the advisory message remained displayed as the threshold to remove the advisory was 5.7 units. The flight crew considered this level of vibration to be excessive, and discussed shutting down the No. 2 engine to prevent further damage. No additional alerts or advisory messages from the ECAM that related to engine parameters were presented to the flight crew for the remainder of the flight. Given the 'pop' sound heard immediately prior to the onset of vibration, the 'Engine Stall' checklist was actioned. At 1231:47, about 12 minutes after take-off, the PF shut down the No. 2 engine.

With the No. 2 engine shut down, the airframe vibration ceased, and a holding pattern over Richmond, New South Wales was initiated. While holding, the flight crew communicated with air traffic control, appraised company representatives of the event, and briefed the cabin crew and passengers on the situation. The decision was made to return to Sydney and perform an overweight landing. The aircraft was not equipped with a fuel dump system and company procedures required that, when an aircraft was damaged, an overweight landing was to be performed to allow the aircraft to land as soon as practicable.

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1 Pilot Flying (PF) and Pilot Monitoring (PM): procedurally assigned roles with specifically assigned duties at specific stages of a flight. The PF does most of the flying, except in defined circumstances; such as planning for descent, approach and landing. The PM carries out support duties and monitors the PF's actions and the aircraft's flight path.

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

3 N1 - The rotational speed of the low pressure compressor of a gas turbine engine

4 Quick Access Recorder (QAR) is an airborne flight recorder designed to provide access to raw flight data, through means such as USB or cellular network connections and/or the use of memory cards.

5 Yawing: the motion of an aircraft about its normal, or vertical axis

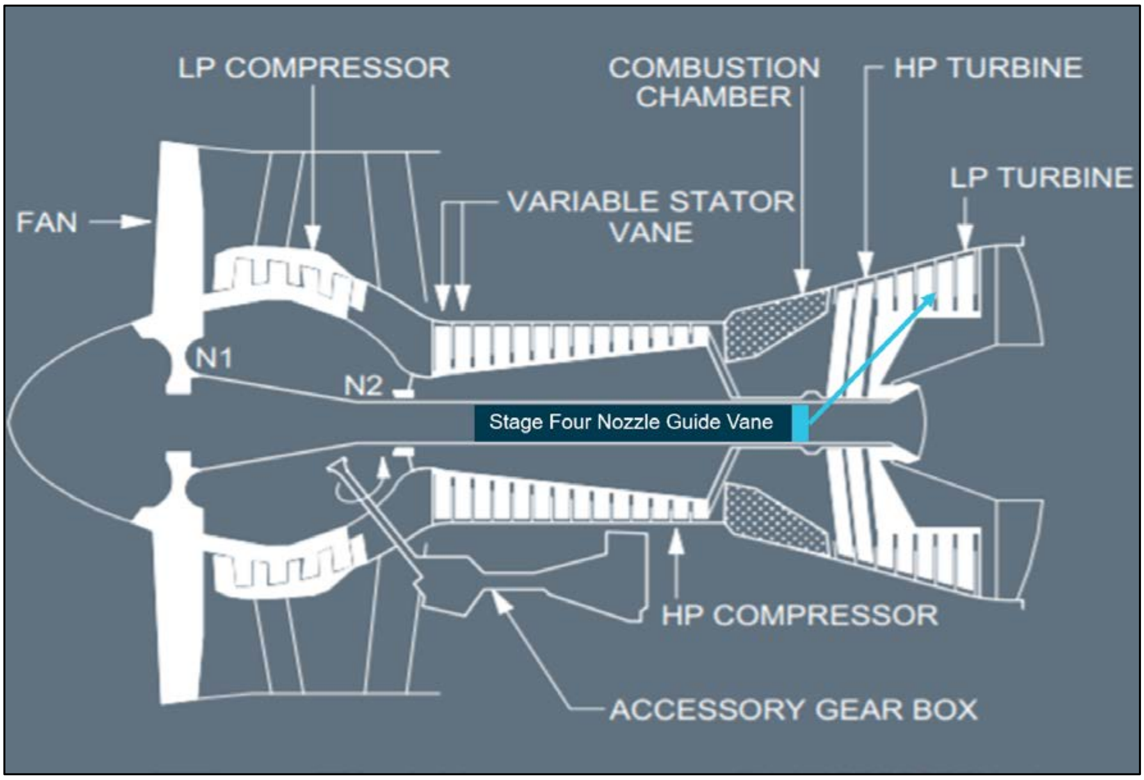
The flight crew referred to the 'Overweight Landing' checklist and discussed how they would conduct a single-engine approach and utilise the aircraft's auto-land system as procedurally required. At 1307, after about half an hour of holding, a descent into Sydney was commenced. The PF reported that the descent was initially unstable, however between 1,000 and 500 ft above ground level, a stable approach was established. At 1317, QPI touched down at Sydney Airport on runway 16R[6]. It was taxied clear of the runway and inspected by airport fire services. On receiving clearance from the fire warden, the aircraft was taxied to the terminal and shutdown at 1319.

An initial inspection by engineering staff revealed visible damage to the No. 2 engine low-pressure turbine stages four and five. It also revealed that engine debris had caused impact damage to the lower surfaces of the aircraft's right wing flaps and body fairings. The engine was subsequently removed and shipped to the engine manufacturer's overhaul facility in Taiwan for detailed examination and repair.

Engine description and examination

QPI was fitted with two General Electric Company CF6-80E1 engines, which are dual-rotor, axial-flow, high by-pass, turbo fan engines. They are capable of delivering in excess of 58,000 pounds of static thrust. A 2-stage high-pressure turbine drives the 14-stage high-pressure compressor (Figure 1). The integrated fan and low-pressure compressor is driven by a 5-stage, low-pressure turbine.

Figure 1**: Profile of General Electric CF6-80 engine showing layout of rotating assemblies and position of stage four nozzle guide vane assembly**



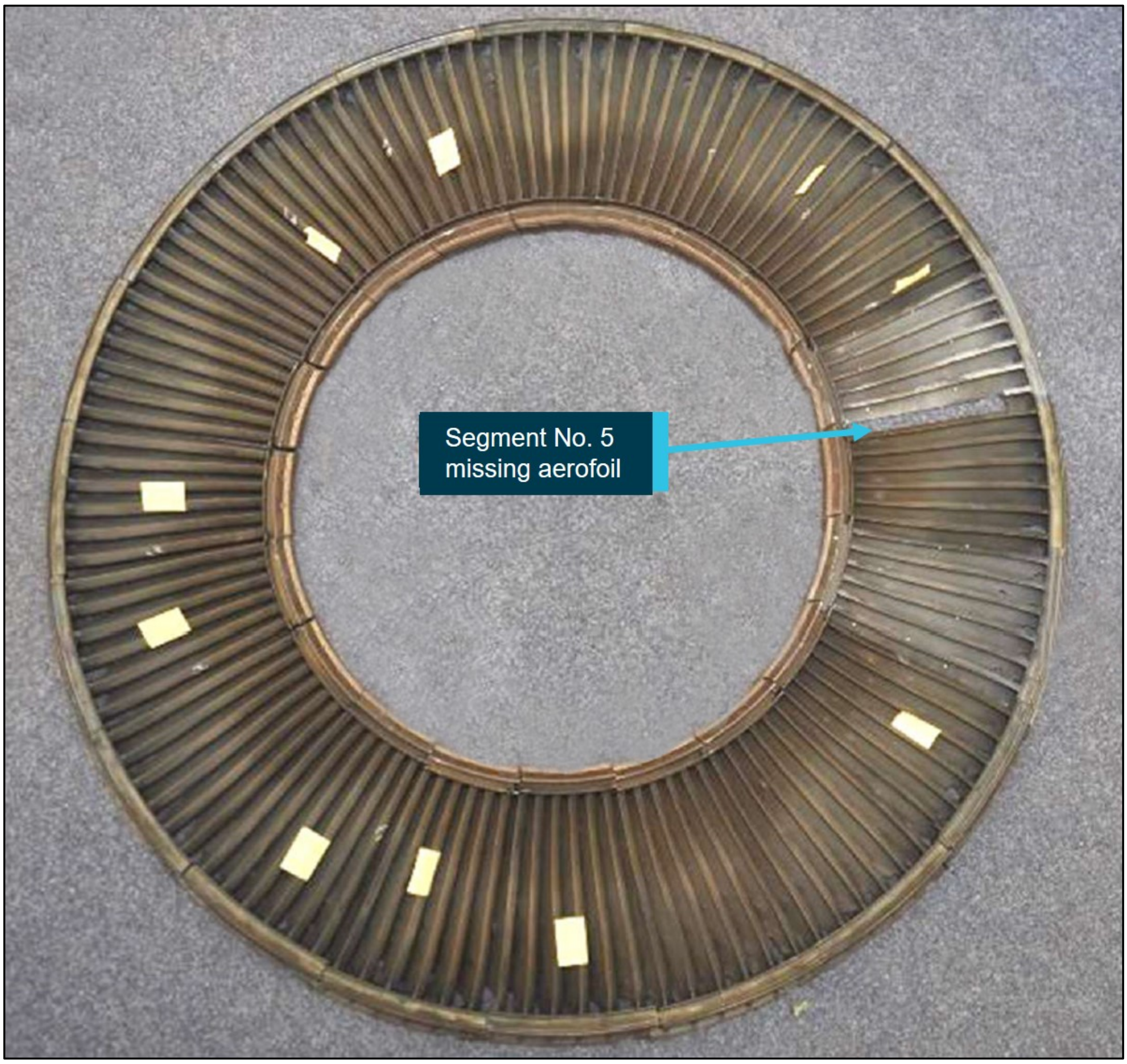
Source: Supplied by operator and annotated by the ATSB

6 Runway number: the number represents the magnetic heading of the runway. The runway identification may include L, R or C as required for left, right or centre

Stationary nozzle guide vanes are fitted ahead of each turbine wheel. Gasses coming from the combustion chamber pass through the nozzle guide vanes, which, due to their convergent shape, accelerate the airflow and drive the turbine at high rotational speed.

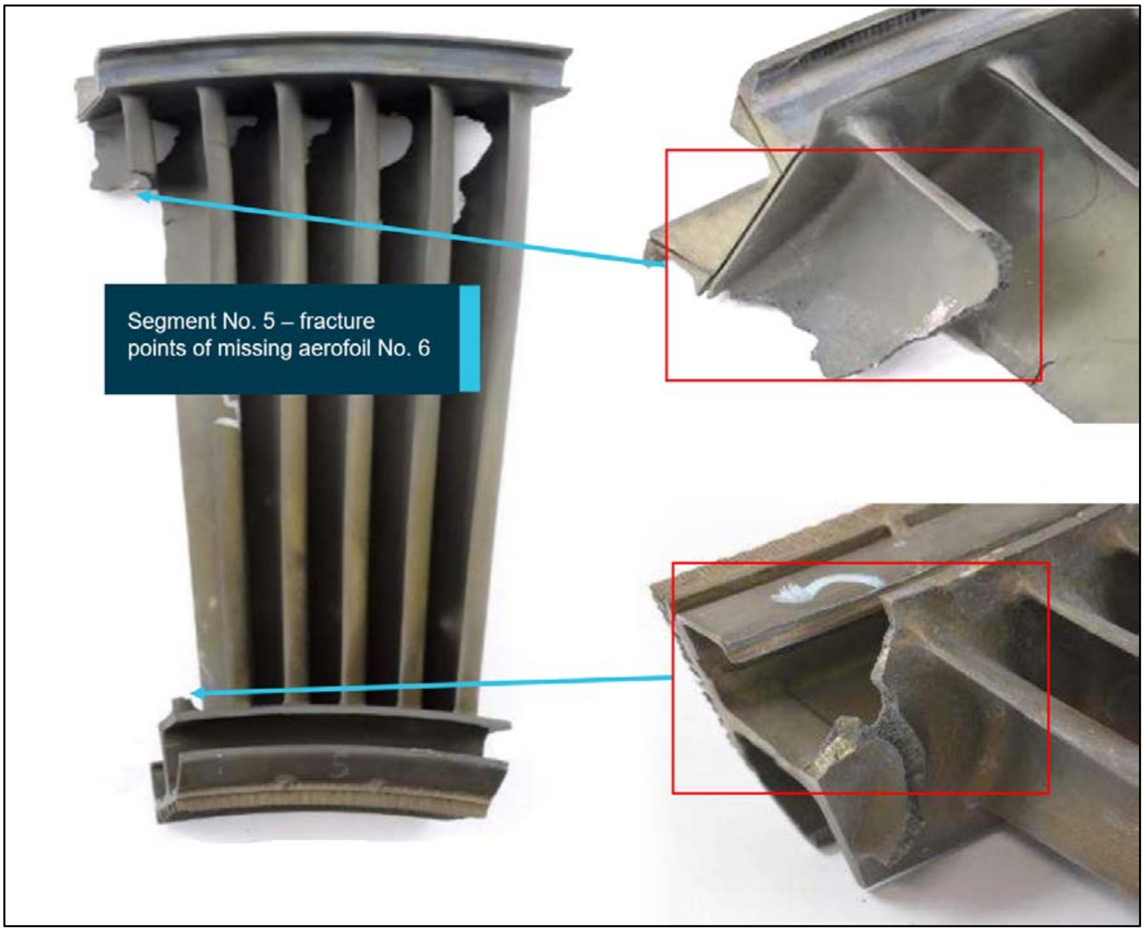
The No. 2 engine from QPI was disassembled and examined at the engine manufacture's repair facility. Examination of the engine's low-pressure turbine stages found that aerofoil No. 6 from the No. 5 segment of the stage four nozzle guide vane (NGV) was missing (Figures 2 and 3). The liberated aerofoil caused downstream damage to the stage four and five low-pressure turbine and the stage five NGV segments. Both turbine stages sustained loss of blade material consistent with impacts from the aerofoil and other liberated fragments. Additionally, while the low-pressure turbine case outer wall was perforated and showed signs of bulging, there was no loss of containment of the fragments via the outer case wall. No damage was found upstream of the stage four NGV assembly.

Figure 2: Low-pressure turbine stage four NGV assembly with segment No. 5 showing loss of aerofoil



Source: Supplied by the operator and annotated by the ATSB

Figure 3: Segment No. 5 showing loss of aerofoil No. 6 and fracture area detail



Source: Supplied by the operator and annotated by the ATSB

Detailed examination of the stage four NGV assembly showed that another three segments exhibited cracks through the entire chord width of various aerofoils. The engine manufacturer identified that oxidation and deterioration of the aerofoil's chromide protective coating had occurred due to engine operating temperatures, stress and time. The deterioration led to the formation of intergranular oxidation in the NGV aerofoil material. As intergranular oxidation levels increased, cracks formed on the NGV leading edges, resulting in eventual failure of the No. 6 aerofoil.

The engine manufacturer also identified that the highest intensity of intergranular oxidation indications was concentrated in the leading edge of aerofoil No. 6, the highest stressed location in segment No. 5 of the stage four, low-pressure turbine, nozzle guide vane assembly.

Additional examination by the manufacturer identified the presence of intergranular oxidation on a number of new NGV segments at their first overhaul shop visit (first run parts), but with less severity than that found on multiple-run parts.

History of stage four NGV aerofoil failures

A review of past occurrences identified that low-pressure turbine stage four NGV aerofoil liberations on General Electric CF6-80E1 engines have occurred on 17 occasions since 2006. The operator experienced seven of those occurrences and was the only operator of CF6 engines to have initiated a consequent engine shutdown in flight.

The engine manufacturer initially assessed that the most likely cause of the failures was associated with movement of the NGV segments relative to each other. This was due to low-pressure turbine case rail wear, resulting in increased stress at the leading edge of aerofoil No. 6. In response, service bulletin CF6-80E1 SB 72-0545 was issued in August 2016, introducing an anti-wear shim to eliminate undesirable nozzle movement.

The manufacturer later recognised that while the anti-wear shim addressed the effects of static stresses and the potential for high cycle fatigue[7] cracking of the NGV segments, it did not prevent intergranular oxidation. The progression of intergranular oxidation was subsequently identified as an additional failure mode for aerofoil liberation. This occurrence was the first liberation in the Qantas fleet, following implementation of the anti-wear shim.

Protective coatings on engine hot section components

To protect against erosion and corrosion, engine manufacturers utilise protective coatings to increase the durability and in-service performance of highly stressed parts. For example, in the fan and compressor areas, erosion-resistant coatings are used to minimise blade wear, and corrosion-resistant coatings are applied to surfaces of turbine blades and nozzle guide vanes.[8]

Oxidation of hot section parts

Oxidation is a form of corrosion in aircraft turbine engines[9] that involves the chemical reaction of oxygen, in the engine core gas stream, with the surface coating or base metal of the part. This chemical reaction creates oxide molecules as it consumes the coating or base metal. The oxides generally build up as an oxide surface film, but can also transition to an intergranular mode, penetrating below the protective coating on the surface and into the base material. Over time, oxidation will consume these materials and in certain cases, cause premature failure of the part.

Thermally induced fatigue can also affect the integrity of the protective surface coating, brought on by repeated application of thermally induced stresses due to rapid and non-uniform heating and cooling cycles during engine power changes.[10] These thermal and mechanical stresses may result in cracking of the surface coating or base metal. Breakdown of the surface coating allows the gas stream to impinge on the base metal and accelerate the overall oxidation process leading to part failure.

Action by the manufacturer and operator

In response to the aerofoil liberation in this occurrence, the engine manufacturer investigated changing the type of protective coating of the NGV segments from chromide to vapour-phased aluminide. The vapour-phased aluminide coating, in use on stage 3 NGVs, has lower instances of intergranular oxidation, and an absence of NGV material deterioration. SB 72-575 was issued in July 2019 to implement the coating replacement.

The engine manufacturer also assessed that the operator's stage four NGVs had higher levels of deterioration when compared to NGVs from other operators. They attributed this to engine thrust settings, reporting that the operator's aircraft spent relatively more time at high thrust, operated at heavier weights, and spent more time in the take-off and climb segments. The manufacturer concluded that the operator's engine duty cycle likely exposed the low-pressure turbine components to higher temperatures and stress.

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7 High cycle fatigue is typically characterised by low-amplitude, high-frequency elastic deflections. An example would be an aerofoil subject to repeated bending

8 G.W. Meetham, (1986), Use of protective coatings in aero gas turbine engines, *Materials Science and Technology,* Vol 2, No.3, p.290-294.

9 AC 33-11, (2014), F.A.A. *Advisory Circular*, U.S Department of Transportation. www.faa.gov

10 AC 33-11, (2014), F.A.A. *Advisory Circular*, U.S Department of Transportation. www.faa.gov

The operator made several changes with respect to treatment of the low-pressure turbine stage four NGV that included:

- replacing all NGV segments that exhibited cracking of the aerofoil leading edge
- introducing a requirement that only new segments were to be installed during overhaul (no multiple run segments)
- introducing a borescope[11] inspection program targeting the low-pressure turbine, stage four NGV assembly. The borescope inspection subsequently identified five engines with aerofoil cracking that warranted engine removal.
- revising the CF6 engine removal plan to reduce the time in service for those engines identified as at-risk of aerofoil liberation.

In-flight engine vibration management

The captain considered that the 'High Engine Vibration' checklist lacked sufficient guidance to address high residual engine vibration, which led the operator to seek clarification from the aircraft manufacturer. The aircraft manufacturer advised that high engine vibration alone did not require an engine shutdown, and crews had the discretion to monitor the engine for other symptoms and to continue operation. However, the manufacturer also advised that the flight crews could consider shutting an engine down if the vibration was considered excessive.

Following review, both the aircraft manufacturer and the operator concluded that sufficient information was available for crews to respond appropriately in an abnormal or emergency situation.

[11] Flexible optical periscope, usually incorporating lighting, capable of being inserted into narrow apertures to inspect interior of machinery

Safety analysis

Gas turbine engine, nozzle guide vanes (NGV) and turbine assemblies are subject to high mechanical loading and temperatures in a corrosive and erosive environment. Detailed technical examination identified that, following oxidation and deterioration of the protective coating on the stage four NGV, No. 5 segment, inter-granular oxidation developed in the base material of the aerofoils. This resulted in cracking of the highly stressed leading edge of the No. 6 aerofoil and its subsequent fracture and liberation.

The lack of damage ahead of the stage four NGV assembly indicated that the liberated aerofoil was the initial event that led to the engine damage. As the aerofoil continued aft in the gas stream, the stage four and stage five low-pressure turbines and the stage five NGV were damaged. The loss of turbine blade material caused a rotor imbalance that was felt as airframe vibration. The airframe vibration was still present following the power lever reduction to idle. Due to the level of residual vibration, the flight crew decided to shut the engine down in flight and return to the departure airport.

Findings

These findings should not be read as apportioning blame or liability to any particular organisation or individual.

- Oxidation and deterioration of the stage four No. 5 nozzle guide vane segment protective coating resulted in the development of intergranular oxidation in the parent material of the No. 6 aerofoil. This led to crack development, fracture and liberation of the aerofoil.
- The loss of the aerofoil led to downstream turbine rotor damage with significant loss of blade material and engine vibration. Due to the vibration, and in consideration of the potential for further engine damage, the flight crew decided to shut the engine down in flight and return to the departure airport.

Safety action

Following this occurrence, the engine manufacturer changed the protective coating on the NVG segments from chromide to vapour-phased aluminide, citing better resistance to oxidation effects.

The operator also worked proactively by ensuring stage four, low-pressure turbine NGV segments that exhibited cracking of the aerofoil leading edge were removed from service, and that only new, not overhauled segments were fitted to the operator’s engines. The operator also introduced a borescope inspection program that was successful in identifying other engines with aerofoil cracking and removed the affected engines from service.

General details

Occurrence details

Date and time:	1 June 2018 – 1220 EST	
Occurrence category:	Incident	
Primary occurrence type:	In-flight shutdown	
Location:	Near Sydney Aerodrome, New South Wales	
	Latitude: S 33º 56.77’	Longitude: E 151º 10.63’

Aircraft other details

Manufacturer and model:	Airbus A330-303	
Registration:	VH-QPI	
Operator:	Qantas Airways Limited	
Serial number:	0705	
Type of operation:	Air Transport High Capacity	
Departure:	Sydney	
Destination:	Bangkok	
Persons on board:	Crew – 13	Passengers – 297
Injuries:	Crew – Nil	Passengers – Nil
Aircraft damage:	Minor	

About the ATSB

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 the 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.

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.

About this report

Decisions regarding whether to conduct an investigation, and the scope of an investigation, are based on many factors, including the level of safety benefit likely to be obtained from an investigation. For this occurrence, a limited-scope, fact-gathering investigation was conducted in order to produce a short summary report, and allow for greater industry awareness of potential safety issues and possible safety actions.