



Australian Government

Australian Transport Safety Bureau

Engine power loss and low-speed rejected take-off, involving Airbus A320-232, registered VH-VFF

Brisbane Airport, Queensland, on 23 October 2020

ATSB Transport Safety Report

Aviation Occurrence Investigation (Short)

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Addendum

Page	Change	Date

Safety summary

What happened

On the morning of 23 October 2020, an Airbus A320-232 was being operated by Jetstar Airways on a flight from Brisbane to Cairns, Queensland. As power was being applied for take-off, the crew reported feeling a vibration and hearing a ‘popping’ noise that rapidly increased in frequency and volume. At the same time, the aircraft diverged to the right of the runway centreline despite the pilot flying applying full left rudder pedal deflection. The captain immediately selected reverse thrust and brought the aircraft to a stop.

Some passengers onboard, a Brisbane air traffic tower controller, and flight crew of a following aircraft all reported momentarily seeing flames coming out the right engine. The aircraft was taxied back to the airport gate. Engineers then reported finding metallic debris in the tailpipe of the right engine.

On disassembly of the engine, it was discovered the high-pressure compressor (HPC) had sustained significant damage and a screwdriver tip was found in the combustion section.

What the ATSB found

The screwdriver tip was determined to have been in the engine for over 100 flights. The ATSB concluded the tool bit had been left in the engine after maintenance and when the engine was running, it entered the HPC leaving dents and nicks in numerous rotor blades and stator vanes. At least two of these defects initiated fatigue cracks that resulted in a blade failing during the occurrence take-off. The liberated blade caused greater damage to the HPC and the engine surged.

What has been done as a result

As a result of the occurrence Jetstar Airways issued a Safety Alert to their maintenance engineers, which highlighted the need for all tooling to be accounted for. They also conducted a risk assessment to better understand the on-going risk.

Safety messages

Tool control is an important part of maintenance processes that ensures they do not lead to foreign object damage. Small and seemingly insignificant tool components can, and have, caused significant incidents or accidents. Tool control should extend to pseudo consumable items such as screwdriver tips and drill bits.

Modern training methods include the use of high-fidelity training devices such as full motion flight simulators. Their design aims to maximise the realism of an artificial environment. However, there is a limit to their ability to replicate extreme events. Flight crew should be aware that the noise and vibration from an actual engine failure may be greater than, or different to, that experienced during simulator training and this could contribute to the effects of startle.

The investigation

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 investigation was conducted in order to produce a short investigation report, and allow for greater industry awareness of findings that affect safety and potential learning opportunities.

The occurrence

On the morning of 23 October 2020, an Airbus A320-232 was being operated by Jetstar Airways on a flight from Brisbane to Cairns, Queensland. The first officer was the pilot flying and the captain was the pilot monitoring.¹

After push back, the first officer taxied the aircraft for a planned take-off on runway 01L. The crew completed the pre-take-off checks during the taxi in anticipation of a rolling start to the take-off. After being cleared for take-off on approach to the runway, the aircraft was lined up and, without stopping, the thrust levers were set for Flex.² The crew reported that as both engines spooled up to the requested power setting, a vibration and ‘popping’ noise could be heard that rapidly increased in frequency and volume. At the same time, the aircraft diverged to the right of the runway centreline despite the first officer applying full left rudder pedal deflection. In response, the captain immediately selected reverse thrust and brought the aircraft to a stop. The aircraft reached a maximum ground speed of 30 knots.

Upon returning the thrust levers to idle, the vibration subsided and the popping stopped. The aircraft instrumentation then sounded two master caution alarms and the Electronic Centralised Aircraft Monitoring (ECAM) system³ reported two messages for Engine No. 2 (right) ‘STALL’ and ‘EGT LIMIT EXCEEDANCE’.⁴ The captain called for the cabin crew to move to stations.⁵

The cabin crew relayed to the flight crew that passengers had seen flames coming from the right engine. Both the airport tower controller and the flight crew of a following aircraft similarly reported seeing flames coming from the rear of the right engine for a short period of time. The tower dispatched Airport Rescue and Firefighting services, who observed no apparent abnormalities with the aircraft.

The captain cancelled the flight and the aircraft was taxied back to the airport gate where both engines were shut down. Immediately after the passengers had disembarked, engineers reported finding small balls of metallic debris in the tailpipe of the right engine (Figure 1). A review of recorded data indicated the right engine had surged.

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. The PM carries out support duties and monitors the PF’s actions and the aircraft’s flight path.

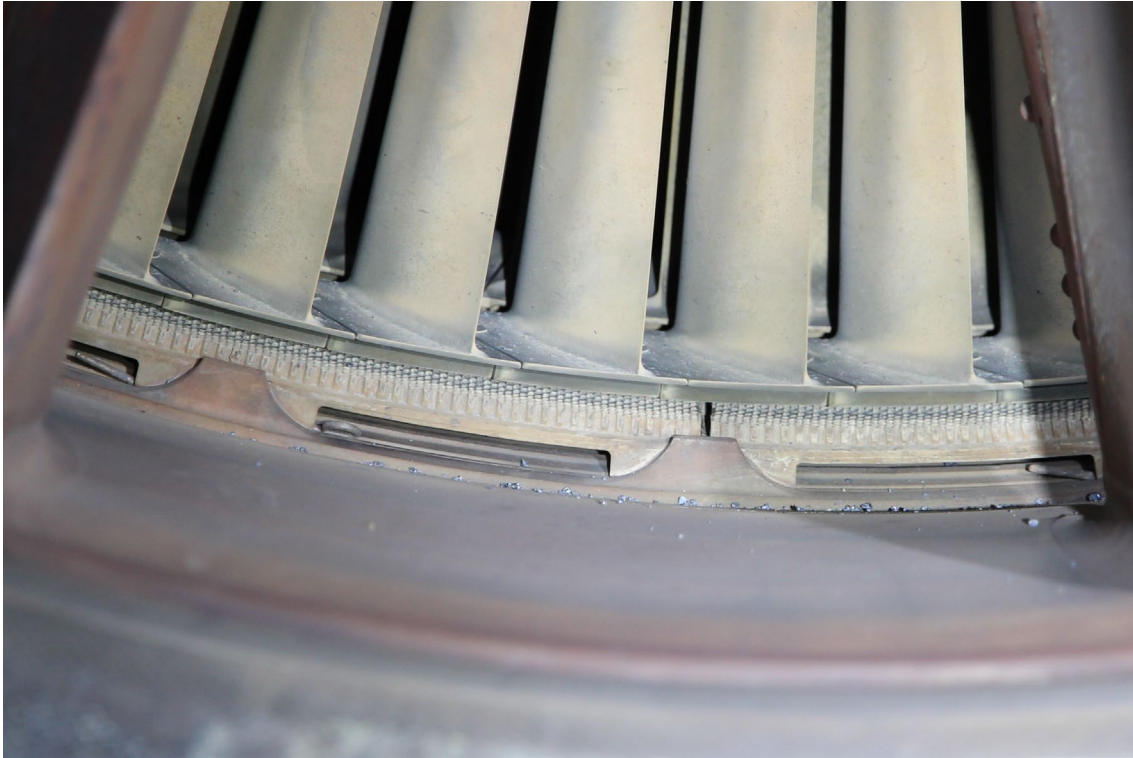
² Flex is an engine thrust setting used for take-off which is below the maximum rated thrust for an engine. The engine thrust requested for a given take-off is calculated based on aircraft weight, flap setting, runway length available and ambient temperature, and is used to reduce engine wear.

³ Electronic Centralised Aircraft Monitoring (ECAM) is a system that monitors aircraft functions and relays their status to flight crew. It also produces messages detailing failures.

⁴ EGT – Exhaust Gas Temperature

⁵ A ‘Call to stations’ is a notification via the public address system from the flight crew to the cabin crew that they are assessing an emergency situation and that an evacuation may be necessary. On receipt of this notification, cabin crew prepare by undertaking actions such as checking conditions outside their assigned door, maintaining control of passengers in the cabin and reporting any abnormal conditions to the flight crew.

Figure 1: Debris in right engine tailpipe



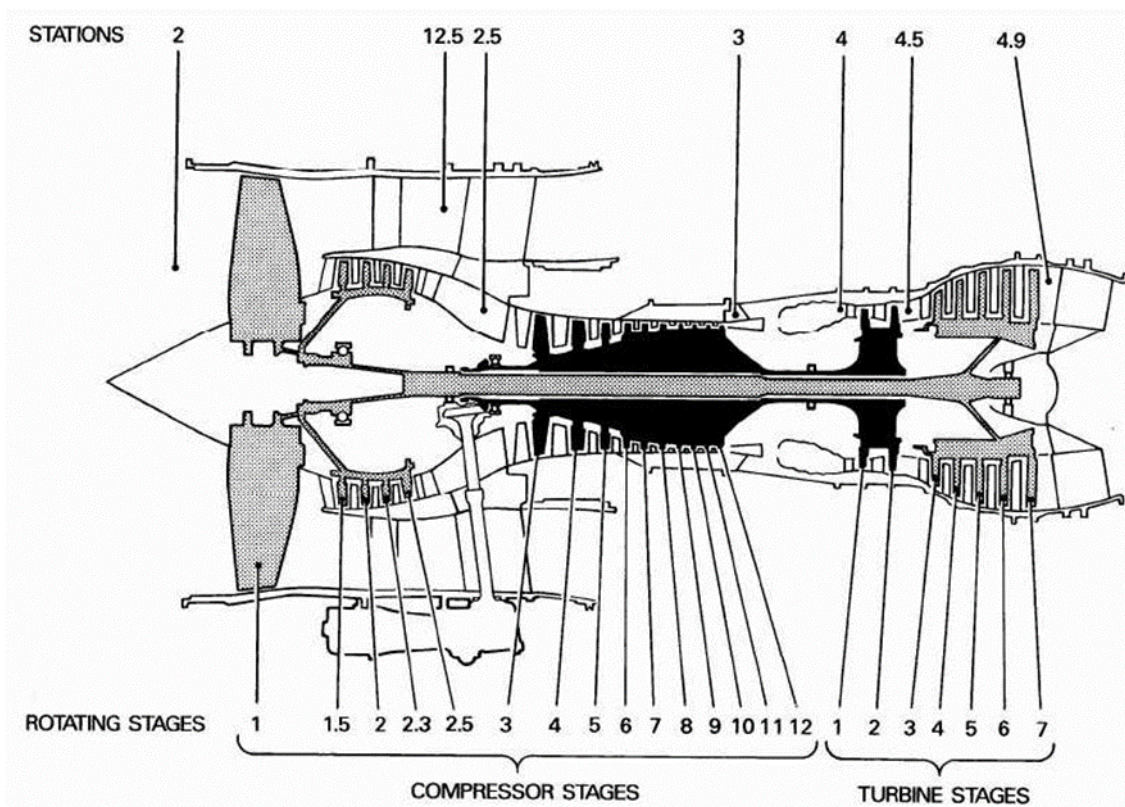
Source: ATSB

Context

Engine Description

The IAE V2527-A5 engine is a variant of the V2500 family of engines. The two-spool, axial-flow, high-bypass turbofan comprises low- and high-pressure stages. The low-pressure section consists of a fan stage and four low-pressure compressor (LPC) stages (labelled booster stages) connected to five low-pressure turbine (LPT) stages. The high-pressure section consists of ten high-pressure compressor (HPC) stages (numbered 3 to 12) connected to two high-pressure turbines (HPT) (Figure 2).

Figure 2: IAE V2527-A5 engine station and stage numbering diagram



Source: IAE Training Manual.

Note: The low-pressure spool is shown in grey and the high-pressure spool in black.

An engine surge is caused by a loss of air compression on the inlet side of the engine. This can be caused by disrupted airflow ahead of the engine, ingestion of foreign matter, excessive thrust changes or an airflow disruption internal to the engine.

Regardless of the cause, the sudden breakdown in compression results in reversal of the flow and violent expulsion of the previously compressed air out the inlet of the engine. The process is often cyclic resulting in a vibratory noise. Additionally, disruption to the airflow can allow unburnt fuel to escape the combustion chamber and ignite in the turbine section or tailpipe.

Post-flight Inspections

On wing inspection

A borescope inspection of the right engine found there was damage to HPC stages 3, 5, 6, 7, 8 and 9 (Figure 3) consistent with foreign object damage (FOD).⁶ As the damage was outside maintenance manual limits, the engine was removed from the aircraft and sent for a teardown inspection.

⁶ Foreign Object Damage (FOD) is any article or substance, alien to an aircraft or system, which could potentially cause damage. The term FOD is used to describe both the foreign objects themselves and any damage attributed to them.

Figure 3: Borescope image of stage 7 HPC and stage 8 stator vanes



Source: Jetstar

Teardown inspection

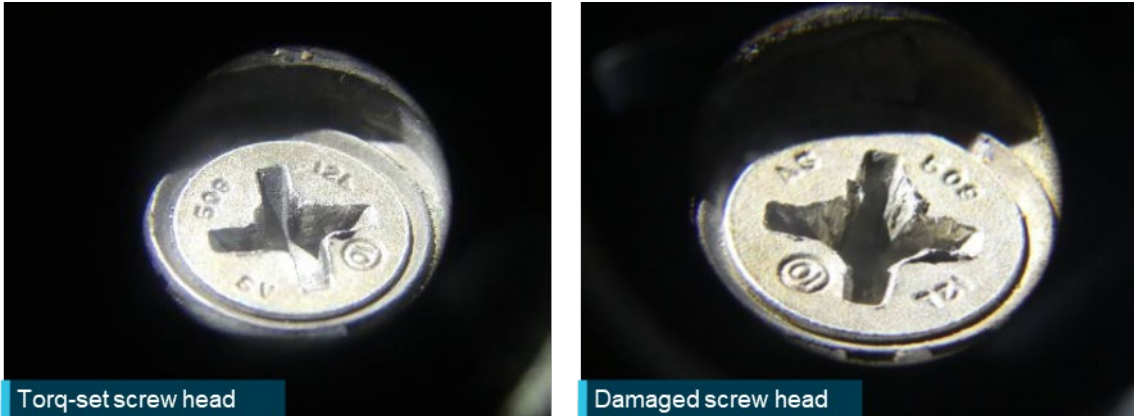
Upon disassembly of the engine, the following observations and anomalies were found:

- The fan blades and LPC contained no visible damage.
- The rear fairing to the LPC bleed valve mechanism was in place but had one Torq-set screw with a damaged head. Although of an incompatible shape, testing showed that due to the damage, the head would also accept a Phillips screwdriver tip (Figure 4).
- In the HPC section, rotor blades (blades) and stators (vanes) in stages 3 and 4 contained dents and minor tears.
- Approximately half of one stage 5 blade (Figure 5) and a whole stage 6 vane (Figure 6) were missing and had failed due to cyclic fatigue. Some of the remaining stage 5 blades exhibited tip curl,⁷ dents and/or missing material.
- Four stage 7 blades and one stage 8 blade were missing and had failed due to overstress. In this section all remaining blades and vanes exhibited hard body damage resulting in severe bending and tearing to both leading and trailing edges. One stage 8 vane contained a distinctive hexagon shaped dent (Figure 7).
- Damage after stage 8 was limited to minor dents and nicks with minimal damage occurring to the final stage components.
- Bleed valve screens at stages 7 and 10 contained large amounts of metallic fragments.

⁷ Tip curl is a signature of compressor or turbine blades making contact with the engine casing.

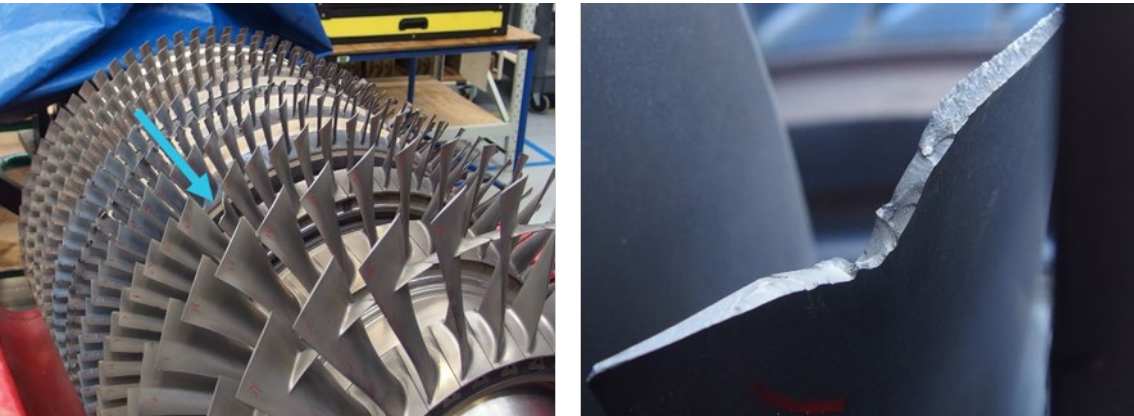
- Small metallic debris and a ¼” hexagon drive screwdriver tool bit (screwdriver tip) was found between the combustion liner and engine case. The screwdriver tip was burnt/discoloured and the tip eroded due to heat and mechanical damage (Figure 7).
- Nozzle Guide Vane (NGV) cooling passages contained small metallic debris.
- Two stage 1 HPT blades contained leading edge nicks attributed to material impacts.
- Small debris was found throughout the LPT.

Figure 4: Interstage screw heads



Source: Jetstar

Figure 5: Stage 5 blade fatigue failure



Source: Jetstar, annotated by the ATSB

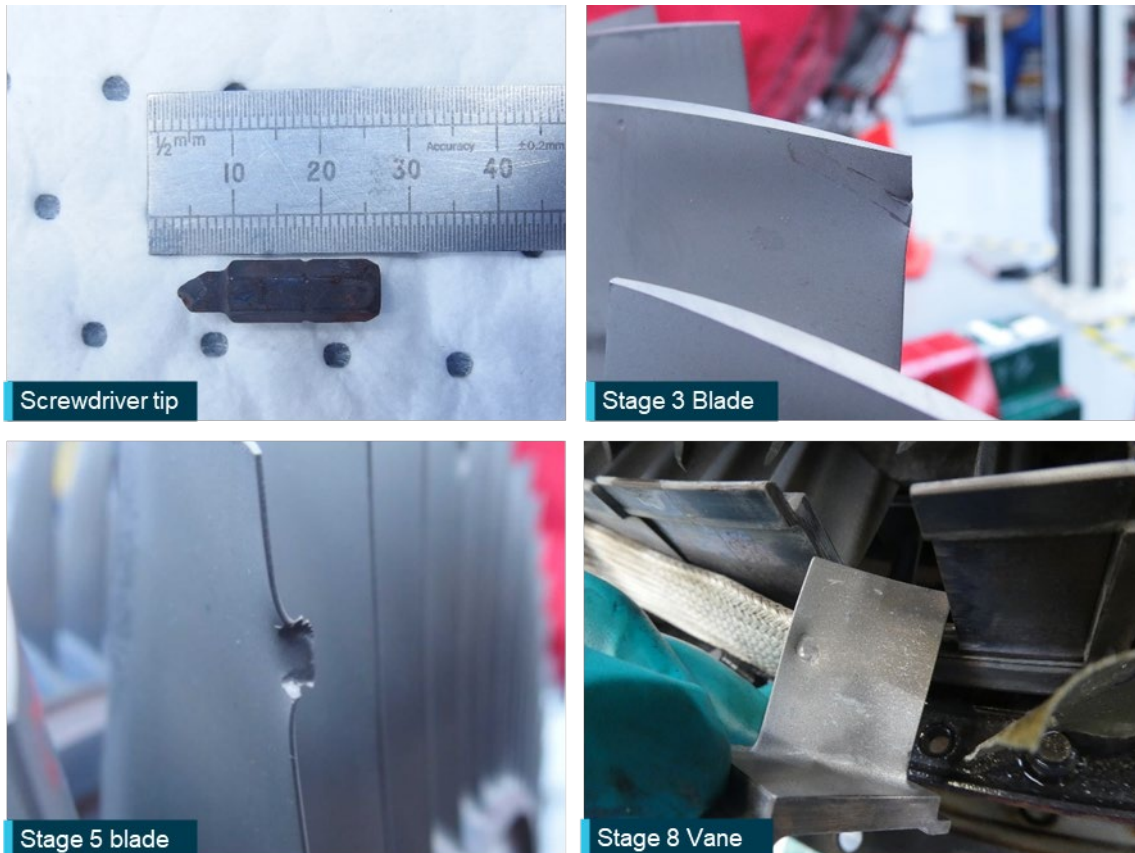
Figure 6: Stage 6 vane fatigue failure



Source: Jetstar, annotated by the ATSB

Witness marks on many components throughout the HPC matched the shape of the screwdriver tip found in the combustion section (Figure 7).

Figure 7: Screwdriver tip and witness marks



Source: Jetstar

A failure analysis was conducted by an engine maintenance facility. The fractured stage 5 blade showed minor leading edge mechanical damage at approximately half span, which initiated a fatigue crack that propagated through approximately two-thirds of the chord. The remaining third of the chord failed in material overstress.

The fractured stage 6 vane sustained a tear near the aerofoil root to a depth of approximately 10 per cent chord. This initiated a fatigue crack that ended 2 mm from the trailing edge with the remaining material exhibiting a material overstress signature.

Both fatigue fracture surfaces displayed fine striations consistent with a high frequency load spectrum, likely from aerodynamic vibrations. While no fatigue growth rate analysis was conducted, based on similar occurrences, it was estimated the components took tens of flight cycles to fail.

Aircraft maintenance program

The aircraft maintenance program required a fairing to be removed in the engine to lubricate the LPC Bleed Valve Mechanism every 4,000 flight hours. The task was last accomplished 112 flight cycles prior to the engine surge. This task occurred with many others as part of preparations to return the aircraft to service after being parked for approximately 4 months.

The LPC Bleed Valve Mechanism task procedures contained specific highlighted caution notes regarding the loss of any screws or other loose objects down the bleed duct. The note highlighted that lost articles would progress to the HPC and break blades and vanes. This occurs because during engine start and idle the bleed valve opens.

Engine failure during take-off

Both flight crew commented that the event startled them due to its unexpected onset, the volume of the popping noise and particularly the levels of vibration. Additionally, the pilot flying reported that, despite the application of full left rudder, the aircraft still diverged to the right of the runway centreline. Both pilots commented that the noise and vibration was far more severe than what they had experienced during flight simulator training sessions when practicing for similar types of events.

Flight crew training includes many different failure scenarios. Being a particularly critical phase of flight, take-off is trained for extensively including engine failures that involve high-speed rejected take-offs (RTO) and post V_1 flight continuations.⁸ One crewmember commented they had never performed a low-speed RTO with engine failure.

For a high-speed engine failure, crews are trained to recognise the failure and maintain runway direction through use of the rudder, which is effective at speeds above V_{MCG} .⁹ The take-off is then either continued or rejected. If rejected, the thrust asymmetry is reduced by idling the remaining engine/s.

Low-speed RTOs are those which occur below V_{MCG} where the aircraft's rudder is not effective enough to counter the large thrust asymmetry and thus the aircraft will diverge from the runway centreline uncontrollably if continued. This situation is countered by differential braking and promptly returning the engines to idle, thereby reducing or nullifying the thrust asymmetry.

Low-speed RTOs, while considered less dangerous because they occur at lower speeds, involve a loss of directional control. Lateral divergence from the runway centreline can be larger than for a high-speed engine failure ($>V_{MCG}$) and can cause considerable damage if the aircraft departs the side of the runway.

Related Occurrences

ATSB investigation (199800615)

On 28 February 1998, at a height of about 100 ft after take-off, the crew of a Boeing 767 reported hearing a series of loud bangs and the right engine exhaust gas temperature indicator rose rapidly into the red range. The right thrust lever was retarded to idle, resulting in the temperature indications returning to normal. ATC also observed a series of flashes from the right engine as the aircraft departed and declared a local emergency. The crew returned the aircraft to the airport and landed without further incident.

An internal borescope inspection revealed extensive damage to blades of the thirteenth compressor stage. The engine was subsequently removed for further inspection, resulting in a replaceable Philips screwdriver tip being found in the core of the engine.

The operator reported that the incident occurred on the first flight after the aircraft had undergone an 'A' maintenance check. The screwdriver tip probably entered the engine through the variable bleed valves, which are open when the engine is not operating.

⁸ V_1 is a decision speed where, thereafter, the pilot can continue the take-off safely using the remaining runway on the remaining engine/s. If a decision to abort the take-off occurs before V_1 is achieved, the aircraft has enough distance to safely come to a stop on the remaining runway available. It can be said that V_1 is the 'commit to fly' speed. V_1 is calculated for every take-off as it is based on aircraft available thrust, aircraft weight, flap setting, runway length and slope, wind conditions, and airport density altitude.

⁹ V_{MC} means the minimum control speed with the critical engine inoperative and the remaining engine/s at maximum power permitted for the situation. V_{MC} can be further separated into V_{MCG} (ground) and V_{MCA} (airborne) which, while both involve engine failure, are limited by different factors.

Safety analysis

The damage to the HPC section and the screwdriver tip found in the cooling cavity were consistent with the screwdriver tip falling into the LPC bleed duct, passing through the interstage duct and into the HPC. The lack of damage to the LPC indicated the tip was not FOD from the runway. The damage to the rear fairing screw meant it was likely the screwdriver tip had been left in the screw or had fallen into the bleed duct during maintenance. At the next engine start-up, it then travelled through the HPC section striking various components, in some cases leaving witness marks, before being held captive adjacent to the combustion chamber.

There was evidence that fatigue cracks initiated from the impact damage in a stage 5 blade and stage 6 vane. These cracks propagated until one reached a critical size due to aerodynamic forces and vibrations, and additionally for the blade, centripetal forces. As the engine surge event occurred during the application of take-off power and acceleration of the engine internal componentry, it is more likely the blade failed first due to the increase in centripetal acceleration.

Regardless of whether the blade or vane failed first, one likely impacted the other and both then caused downstream damage, including the failure of a further five compressor blades. The resulting disruption to aerodynamic flow through the HPC allowed the engine to surge and led to the loss of engine performance.

Findings

ATSB investigation report findings focus on safety factors (that is, events and conditions that increase risk). Safety factors include 'contributing factors' and 'other factors that increased risk' (that is, factors that did not meet the definition of a contributing factor for this occurrence but were still considered important to include in the report for the purpose of increasing awareness and enhancing safety). In addition 'other findings' may be included to provide important information about topics other than safety factors.

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

From the evidence available, the following findings are made with respect to the engine power loss.

Contributing factors

- A screwdriver tip, left in a fairing screw or bleed duct, travelled through the high-pressure compressor (HPC) section of the right engine before becoming lodged in the combustion section. This resulted in impact damage to HPC blades and vanes.
- Fatigue cracks initiated at damaged locations in at least one HPC blade and vane, with one crack propagating to failure. This resulted in secondary damage to the engine and surging on take-off.

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.

Safety action by Jetstar Airways

As a result of this incident, the operator advised the ATSB:

- the Jetstar Aircraft Maintenance Organisation had issued a Safety Alert to maintenance engineers, which highlighted the need for all tooling to be accounted for.
- they had conducted a risk assessment to better understand the on-going risk.

Sources and submissions

Sources of information

The sources of information during the investigation included:

- the flight crew
- VH-VFF direct access recorder
- Jetstar Airways
- Christchurch Engine Centre

Submissions

Under 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. That section 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 following directly involved parties:

- the flight crew
- Jetstar Airways

Submissions were received from:

- Jetstar Airways

The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.

General details

Occurrence details

Date and time:	23 October 2020 – 1000 EST	
Occurrence category:	Incident	
Primary occurrence type:	Engine failure	
Location:	Brisbane Airport, Queensland	
	Latitude: 27° 22.5' S	Longitude: 153° 6.6' E

Aircraft details

Manufacturer and model:	Airbus A320-232	
Registration:	VH-VFF	
Operator:	Jetstar Airways	
Serial number:	5039	
Type of operation:	Air Transport High Capacity	
Activity:	Regular public transport	
Departure:	Brisbane, Queensland	
Persons on board:	Crew – 6	Passengers – 165
Injuries:	Crew – Nil	Passengers – Nil
Aircraft damage:	Minor	