FINAL REPORT

AIRBUS A330-300, REGISTRATION 9V-SSE

ENGINE FAILURE DURING CLIMB

7 FEBRUARY 2018

AIB/AAI/CAS.157

Transport Safety Investigation Bureau
Ministry of Transport
Singapore

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<u>The Transport Safety Investigation Bureau</u>

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<u>**CONTENTS**</u>

GLOSSARY

ATC	:	Air Traffic Control
EASA	:	European Aviation Safety Agency
ECAM	:	Electronic Centralised Aircraft Monitoring
FAA	:	Federal Aviation Administration
FBO	:	Fan blade off
HP	:	High pressure
IP	:	Intermediate pressure
LP	:	Low pressure
NMSB	:	Non-modification service bulletin
PF	:	Pilot flying
PIC	:	Pilot-in-command
PM	:	Pilot monitoring
SEM	:	Scanning electron microscope
SFO	:	Senior First Officer

SYNOPSIS

On 7 February 2018, while flying from Dhaka, Bangladesh, to Singapore, the flight crew of an Airbus A330-300 aircraft heard a sudden loud bang and felt airframe vibrations while climbing through 30,000 feet. The aircraft was flying in Myanmar airspace at that time. The flight crew made a PAN[1] call to Yangon Air Traffic Control. Subsequently, the aircraft diverted to Mandalay International Airport without further incident. There was no injury to any person.

After landing, the fan blades and fan case of the aircraft's No.1 engine (i.e. the left engine) were found to have been damaged.

The Transport Safety Investigation Bureau classified this occurrence as an incident.

AIRCRAFT DETAILS

Aircraft type	:	Airbus A330-300
Operator	:	Singapore Airlines
Aircraft registration	:	9V-SSE
Numbers and type of engines	:	2 x Rolls Royce Trent 700
Date and time of incident	:	7 February 2018, 1630 hours Singapore time
Location of occurrence	:	Over Myanmar while en-route from Dhaka to Singapore
Type of flight	:	Scheduled passenger flight
Persons on board	:	203

[1] The PAN call is a radiotelephony message used by the flight crew to declare that an urgent situation has developed but does not pose an immediate danger to life or the aircraft for the time being.

1 **FACTUAL INFORMATION**

All times used in this report are Singapore times. Singapore time is eight hours ahead of Coordinated Universal Time (UTC).

1.1 History of the flight

1.1.1 The Airbus 330-300 aircraft was on a scheduled passenger flight from Dhaka, Bangladesh, to Singapore on 7 February 2018. It took off from Shahjalal International Airport at 1600 hours. The flight crew comprised two pilots, a Captain, who was the Pilot-in-command (PIC) and a Senior First Officer (SFO). The PIC was the Pilot Monitoring (PM) and the SFO the Pilot Flying (PF).

1.1.2 While the aircraft was climbing through 30,000 feet at 1630 hours, the flight crew heard a loud bang and felt airframe vibrations. In accordance with the operator's standard operating procedures, the PIC immediately took over control of the aircraft and assumed the role of PF, and the SFO assumed the role of PM. The PIC instructed the SFO to carry out remedy actions for the Electronic Centralised Aircraft Monitoring (ECAM)[2] messages. The ECAM remedy actions entailed the shutting down of the No.1 engine (i.e. the left engine). However, even after the remedy actions were completed and the No.1 engine was shut down, the airframe vibrations continued to be felt.

1.1.3 The aircraft was flying in Myanmar airspace at that time. The flight crew made a PAN call to Yangon Air Traffic Control (ATC) and requested clearance to descend to 25,000 feet. Subsequently, the aircraft diverted to and landed in Mandalay International Airport at 1702 hours without further incident.

1.1.4 Immediately after landing, the airport's rescue and firefighting service conducted an inspection of the aircraft and reported an oil leak from the No.1 engine. The aircraft was towed to a remote bay where passengers were disembarked. There was no injury to any person.

1.2 Personnel information

Flight crew details	PIC	SFO
Age	39	39
Licence	Air Transport Pilot Licence	Air Transport Pilot Licence
Total flying experience	9,358 hours	7,578 hours
Flying experience on type	2,740 hours	664 hours
Total flying last 24 hrs	0 hour	0 hour
Total flying last 7 days	8 hours 26 minutes	27 hours 15 minutes

[2] The ECAM is a system that monitors aircraft functions and displays the function status to the flight crew. It also produces messages detailing failures and lists remedy procedures to rectify the problem.

Total flying last 90 days	193 hours 57 minutes	191 hours 58 minutes

1.3 Damage to aircraft

1.3.1 Post-flight inspection of the No. 1 engine revealed damage to all the fan blades, the fan case and the nose cowl of the engine (see **Figure 1** for a cutaway view[3] for illustration and comparison purpose).

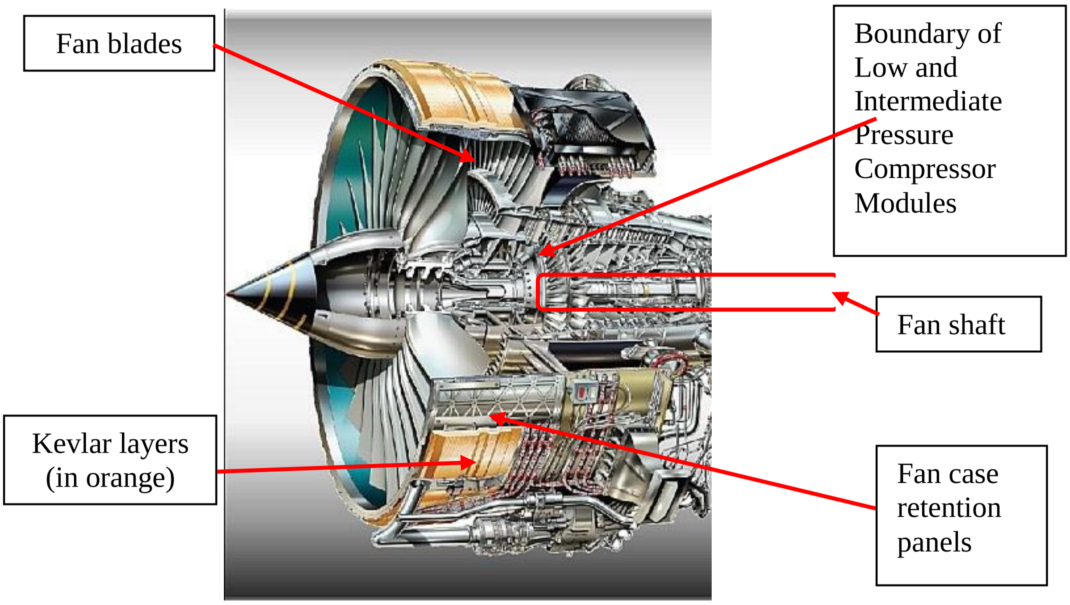

Figure 1: Cutaway view of Trent 700 engine fan case

1.3.2 One fan blade was found broken across the width of the blade, with more than 75% of blade material missing (see **Figure 2**). Two other fan blades were found with impact damage and some blade material missing. The released section of the fan blade (i.e. the one with 75% missing blade material) had penetrated the fan case and was retained within the Kevlar layers[4].

1.3.3 There was no damage found on the aircraft fuselage.

1.3.4 The engine was a three-spooled engine with fan blades attached to the Low Pressure (LP) shaft. External to the LP shaft was the Intermediate Pressure (IP) shaft which was attached to the intermediate compressor stages and external to the IP shaft was a High Pressure (HP) shaft which was attached to the high pressure compressor stages. All three shafts were rotating around each other at differing speeds.

[3] Source: http://rustanez.com/Engines.html

[4] According to the engine manufacturer, in the event of a Fan Blade Off event, the fan case is designed to allow a released fan blade to pass through it but to be retained by the surrounding Kevlar layers (see paragraph 1.5.1).

Figure 2: The missing fan blade (circled in green) with more than 75% missing material

1.3.5 The LP shaft showed evidence of heavy rubbing with the IP shaft which resulted in deformation and bending of the LP shaft, with cracking extending approximately half the circumference of the shaft (see **Figure 3**)[5].

[5] According to the engine manufacturer, fan shaft rubbing and cracking had been experienced previously but the nature of the cracking in this event is different from that seen previously.

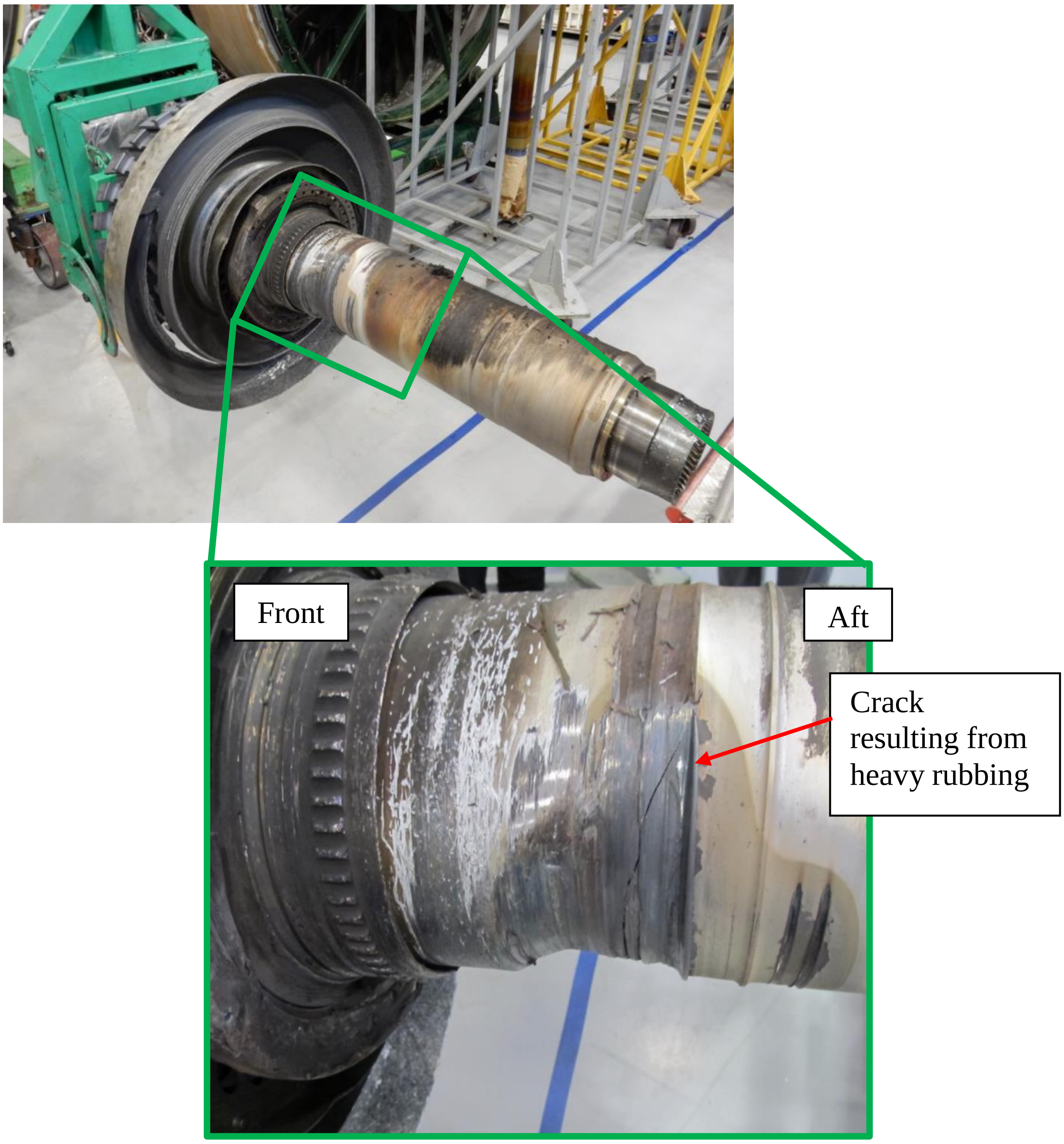

Figure 3: Crack seen on heavily rubbed LP shaft

1.3.6 There was significant damage to the interior of the fan case (see **Figures 4**, **5** and **6**).

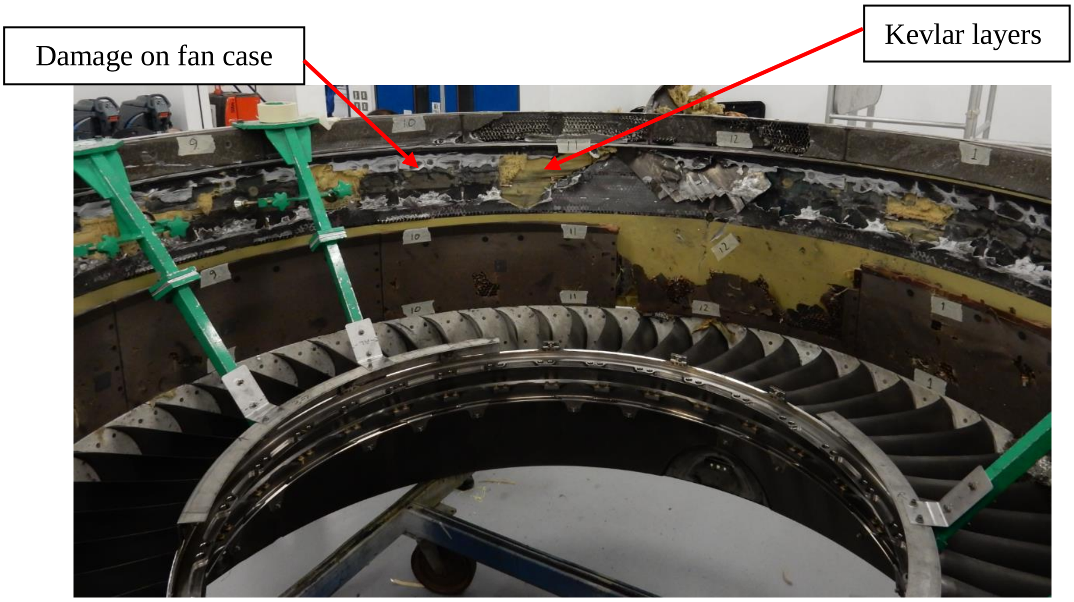

Figure 4: Damage on the fan case (viewed from interior)

Figure 5: Damaged Kevlar layers (viewed from exterior)

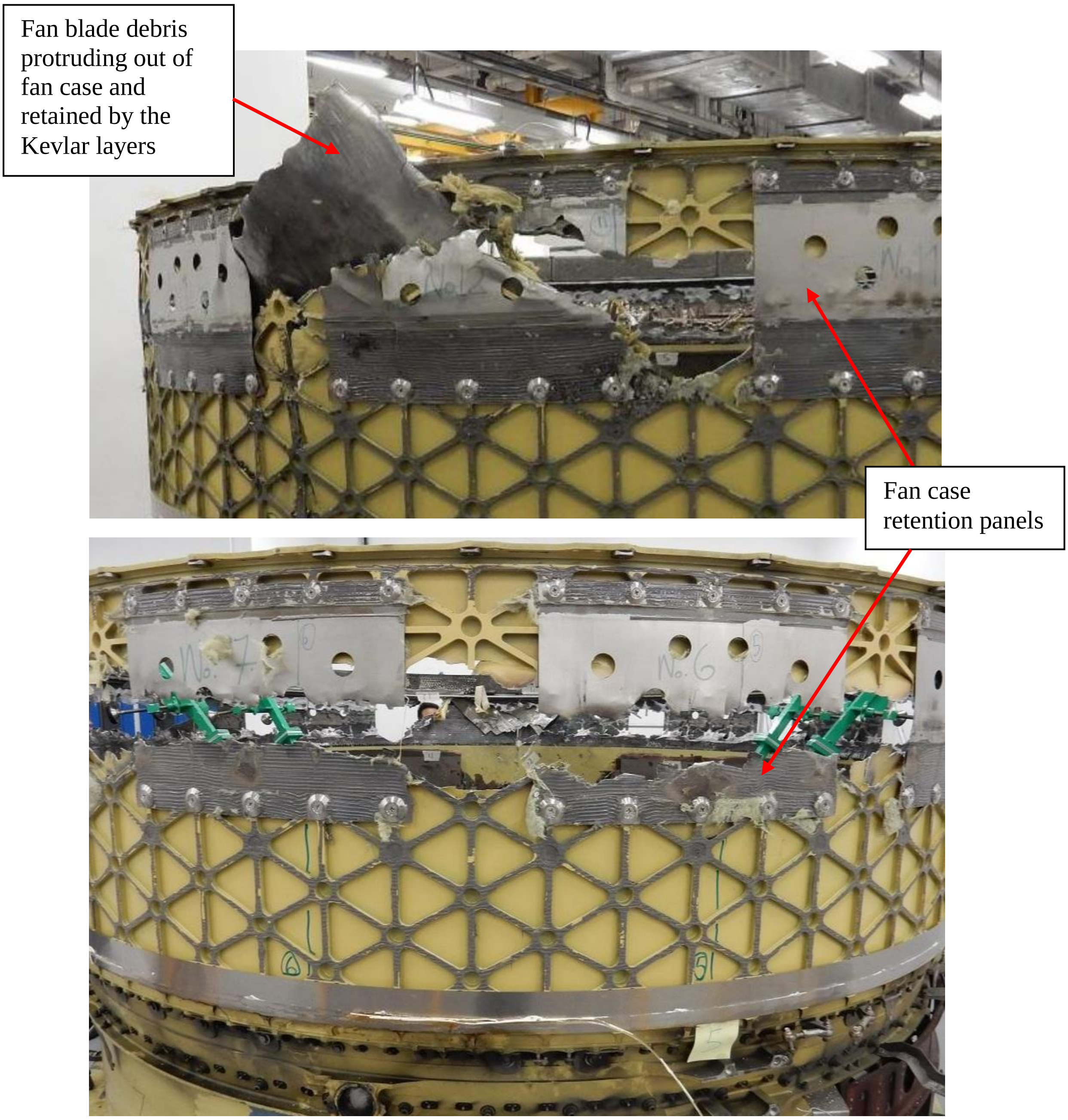

Figure 6: Exterior view of damaged fan case (with Kevlar layers removed)

1.3.7 The fuel pipes at the inlet and outlet of the LP fuel pump were fractured. However, there were no signs of fire (see **Figure 7**).

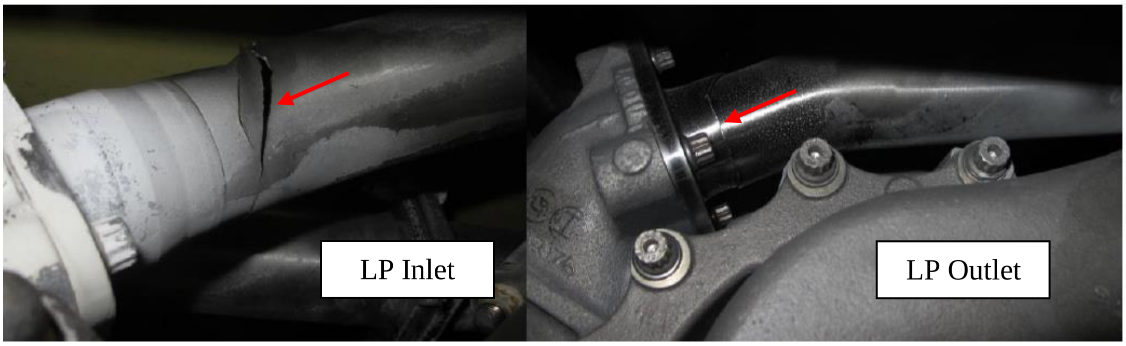

Figure 7: Fractured LP fuel pump inlet and outlet pipes (indicated by red arrows)

1.3.8 The engine inlet cowl suffered damage due to fan blade debris impacting the inner barrel.

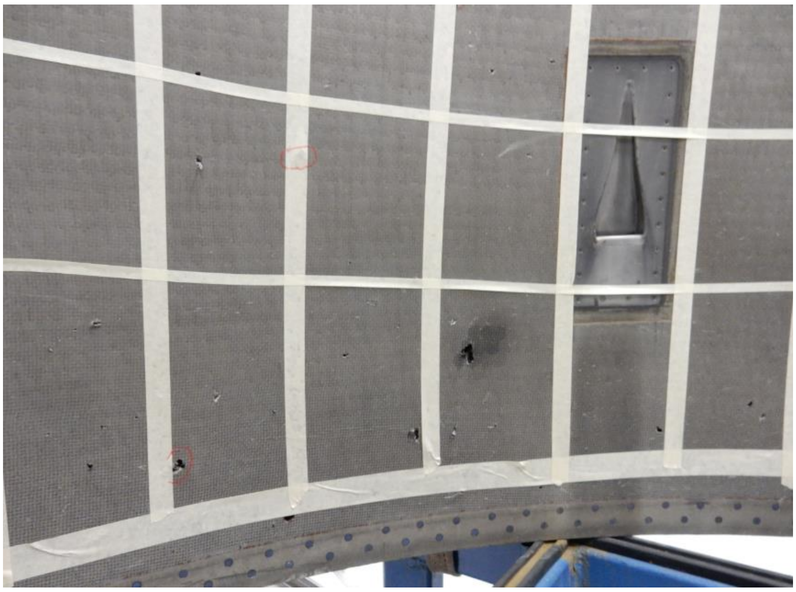
Figure 8: Impact damages on the inner barrel of inlet cowl

1.4 Engine vibration history

1.4.1 The No.1 engine experienced a high engine vibration indication during cruise on a flight on 5 February 2018, i.e. two days before the incident flight. Subsequently, an on-wing maintenance procedure was performed to rebalance the fan disk by replacing all the trim "balancing" bolts[6] previously installed. Vibration levels were checked and found to be normal after the fan disk rebalancing procedure. It cannot be established whether the high engine vibration indication observed on 5 February 2018 was related to the fan blade failure on the incident flight.

[6] Trim balance bolts are installed to assist with balancing the fan disk if it is out of balance.

1.5 Fuse system of the engine front bearing housing

1.5.1 The engine manufacturer had incorporated design features to counter a Fan Blade Off (FBO) failure scenario, i.e. when the entire aerofoil section of a fan blade breaks off from the root section. An FBO event would result in an unbalanced engine fan assembly and thus engine vibration. After the fan blade detachment, the engine would be out of balance and might cause vibrations in the aircraft wing and airframe. The engine manufacturer had designed into the engine a fuse system in the LP shaft front bearing housing to lessen the effects of this engine imbalance during a complete FBO event.

1.5.2 The engine had two fuses[7] in the front bearing housing. If a fan blade aerofoil was released, the fuses would operate and the fan assembly would be allowed to rotate about its new mass centre, thereby mitigating the effect of imbalance and vibrational loads arising from a FBO event.

1.5.3 Post-flight inspection of the No.1 engine revealed that both fuses had operated. According to the engine manufacturer, as a result of the partial release of the fan blade section, the second fuse had operated slower by a few seconds[8].

1.6 Inspection of failed fan blade

1.6.1 The remnant portion of the broken fan blade with more than 75% material missing (as mentioned in paragraph 1.3.2) was removed from the No.1 engine (see **Figure 9**) and sent back to the engine manufacturer for examination.

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[7] A fuse is a linkage in an operating system or structure so designed that, if the system or structure becomes overloaded, it fails at this place.

[8] The engine fuses are designed to operate following a release of a full length fan blade length, which would provide sufficient force for the fuses to operate optimally. In this event, a shorter length of fan blade had been released and there was less force to operate the engine fuses.

Figure 9: Fan blade segment recovered (side and top view)

1.6.2 Detailed examination by the engine manufacturer revealed the following:

(a) The fracture surfaces were inspected under a scanning electron microscope (SEM). The inspection revealed signs of fatigue failure at the acute corner of the inner convex surface bond (known as Bond 6) (see **Figure 10**).

(b) Examination of the acute corner of Bond 6 at higher magnification in the SEM revealed a crack initiation site believed to be in the membrane material adjacent to the diffusion bond (see **Figure 11**).

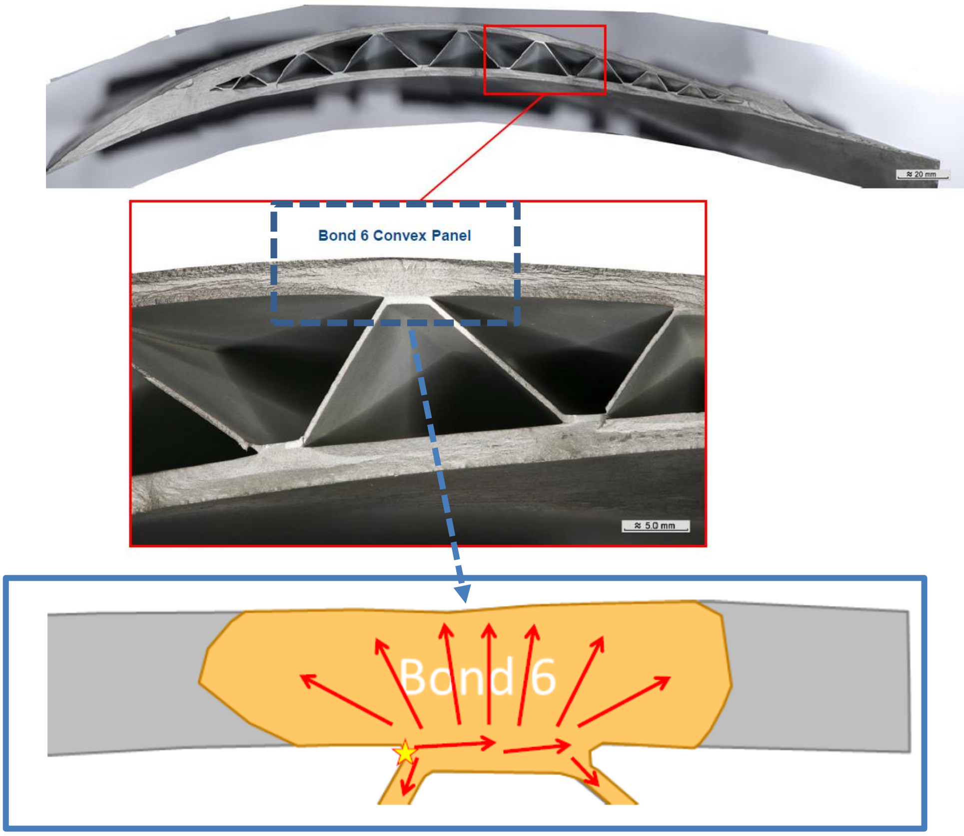

Figure 10: Fatigue failure location (Bond 6) and failure mechanism

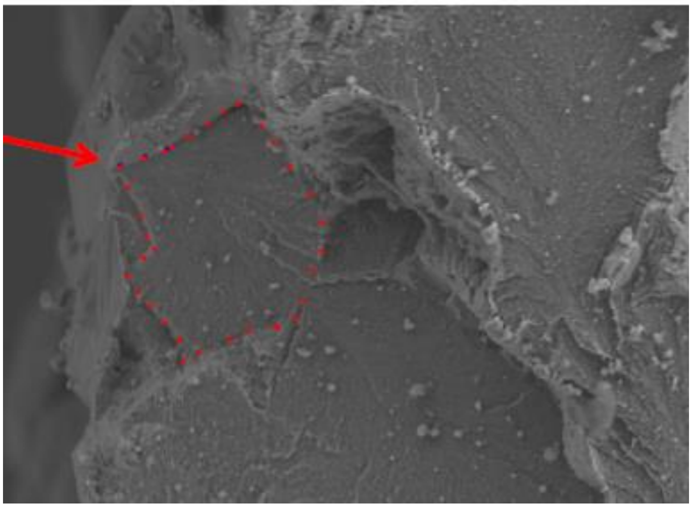

Figure 11: Fatigue failure initiation site in the membrane material adjacent to the diffusion bond (region indicated in red).

1.6.3 The engine manufacturer informed the investigation team that, from its detailed examination of the released fan blade and its reviews into its manufacturing processes, it had concluded that there were no manufacturing anomalies that could have contributed to the fan blade failure.

1.7 Additional information

1.7.1 The engine manufacturer had two separate ultrasonic inspection techniques that could be applied in engine maintenance:

- C-Scan – an automated technique used in overhaul facilities
- Phased array – a manual technique that could be used on-wing

Both techniques could be used to inspect fan blades. A blade would fail the inspection if it had a defect indication that was beyond a rejection threshold size[9].

1.7.2 The fan blade that had more than 75% of the blade material missing was inspected at the engine manufacturer's overhaul facility in June 2016 using the C-Scan method. The defect feature that was detected in the fan blade was below the C-Scan's rejection threshold size, so the fan blade passed the C-Scan inspection.

1.7.3 The engine manufacturer had a non-modification service bulletin (NMSB) 72-AH465 Revision 2 issued on 11 May 2016 requiring an inspection of the fan blades every 2,400 flight cycles, either by using C-Scan in an engine overhaul facility or by using an ultrasonic phased array method on-wing. Subsequently, the engine manufacturer issued NMSB72-AH465 Revision 4[10] to require the inspection to be carried out every 1,200 flight cycles instead. The new inspection interval was applicable from 3 October 2017. The fan blade in question failed during the transition period between inspection interval of 2,400 flight cycles and 1,200 flight cycles. Following this incident, the engine manufacturer issued NMSB72-AH465 Revision 5 to mandate the completion of the inspection of all fan blades under the new inspection interval of 1,200 flight cycles by end of 2018.

[9] The C-Scan technique applies an automated algorithm to identify defect indications, and any fan blade with defect found would be rejected.

[10] EASA issued AD 2017-0241 to require compliance with NMSB72-AH465 Revision 4.

2 ANALYSIS

2.1 The investigation team is looking into the following:

(a) Fan blade failure
(b) Rubbing between LP shaft and IP shaft
(c) History of C-Scan inspection of fan blade
(d) Cracking of LP fuel pump inlet and outlet pipes

2.2 Fan blade failure

2.2.1 The failure of the fan blade could be attributed to a fatigue crack which compromised the strength of the fan blade. This crack originated from an initiation site at the acute corner of the inner convex surface bond.

2.3 Rubbing between LP shaft and OP shaft

2.3.1 As mentioned in paragraph 1.3.5, the LP shaft showed evidence of heavy rubbing with the IP shaft which resulted in deformation and bending of the LP shaft, with cracking extending approximately half the circumference of the shaft. The rubbing was a result of the second fuse in the engine front bearing housing having operated slower than intended.

2.3.2 The two fuses in the engine front bearing housing would operate, as intended by design, to counter the unbalancing effect caused by a fan blade failure. This would allow the fan rotor system to rotate about its new mass centre, and minsimise the chances of contact between the LP shaft and IP shaft. The fuses were designed to operate following a release of a full length fan blade length. In this incident, a shorter length of fan blade was released and there was less force to operate the engine fuses. The resulted in a delay in the operation of the second fuse.

2.3.3 With a delay in the second fuse's operation, there would be a period of time, albeit a very short one, during which the LP shaft and IP shaft could be in contact, the result of which would be damages to the LP shaft and IP shaft.

2.4 History of C-Scan inspection of fan blade

2.4.1 The fan blade that had more than 75% of the blade material missing had passed the C-Scan method of ultrasonic inspection at the engine manufacturer's overhaul facility in June 2016. This was because the defect that was detected in the fan blade was below the C-Scan's rejection threshold size.

2.4.2 In order to ensure effective detection of small defects, a more sensitive inspection technique would have to be developed, or a lower C-Scan rejection threshold would have to be set, to prevent missing detection of a defect which could potentially cause more damage to the engine.

2.5 Cracking of LP fuel pump inlet and outlet pipes

2.5.1 As a result of the fan blade failure, both the inlet and outlet fuel pipes of the engine LP fuel pump were cracked. The cracking of the fuel pipes was due to the vibration that followed the fan blade release.

2.5.2 The investigation team was informed by the engine manufacturer that the inlet and outlet LP fuel pump pipes in the incident engine had been previously redesigned in response to one previous Trent 700 FBO event[11] that led to cracking of the LP fuel pump pipe. The presence of fuel released from the cracked inlet and outlet fuel pipes of the LP fuel pump could be a safety hazard.

[11] The Air Accident Investigation Bureau of Singapore (AAIB), predecessor of the Transport Safety Investigation Bureau, had investigated a Trent 700 fan blade failure event which led to an inflight engine fire (Reference: AAIB Final Report, Airbus A330-343, Registration B-HLM, Engine Fire Event, 16 May 2011). In that incident, the fire was attributed to heat generated by frictional rubbing as the fan blades abraded through the fan case and into the surrounding Kevlar layers, which led to the ignition of fuel that had been released from a cracked inlet pipe of the LP fuel pump.

3 CONCLUSIONS

From the evidence available, the following findings are made. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

3.1 The failure of the fan blade with more than 75% missing material originated from a fatigue crack that initiated at the acute corner of the inner convex surface bond.

3.2 The fuse system in the engine front bearing housing operated fully and separated completely as designed for a Fan Blade Off event, although the second fuse had activated slower than expected due to the release of a partial fan blade section.

3.3 Despite the complete functioning of the two fuses in the engine front bearing housing, significant airframe vibrations persisted due to shaft bending coupled with the engine windmilling effect.

3.4 The C-Scan ultrasonic inspection detected the defect in the event fan blade, but the defect was accepted because the defect feature was below the rejection threshold size.

3.5 Though the inlet and outlet LP fuel pump pipes had been redesigned, cracking in those pipes still occurred. The presence of fuel released from the cracked inlet and outlet fuel pipes of the LP fuel pump could be a safety hazard.

4 SAFETY ACTIONS

During the course of the investigation and through discussions with the investigation team, the following safety actions were initiated by the engine manufacturer and aviation authorities.

4.1 Following the event, the engine manufacturer has issued a non-modification service bulletin NMSB72-AH465 Revision 5 on 26 July 2018 reducing the transition period for operators to carry out mandatory inspection of the fan blades by C-Scan or on-wing using a phased array technique every 1,200 flight cycles.

4.2 European Aviation Safety Agency issued AD 2018-0188R1 on 5 September 2018 to cover the requirements of NMSB72-AH465 Revision 5.

4.3 The engine manufacturer initiated a review of the existing design of the fan blade to address potential contributing factors that could lead to the failure of the fan blade. The review has identified areas for improvement such as reducing the fan blade stresses via local skin thickening and the identification of fan blades more inclined to develop cracks.

4.4 The engine manufacturer has reviewed the existing fuse system and developed a new program logic which can shut the engine down quickly when an FBO event occurs. This will reduce damage to the LP shaft. This program logic modification has been introduced to the fleet.

4.5 The engine manufacturer has initiated activities to develop an enhanced C-Scan inspection process which will identify smaller defects that could lead to blade cracking and fracture.

4.6 The engine manufacturer has initiated further design studies of the LP fuel pump inlet and outlet fuel pipes with a view to ensuring that they remain safe following a fan blade failure event and that they do not pose a safety risk.

5 SAFETY RECOMMENDATIONS

A safety recommendation is for the purpose of preventive action and shall in no case create a presumption of blame or liability.

It is recommended that:

5.1 The engine manufacturer address potential contributing factors associated with the design of the fan blade that could lead to the failure of the fan blade. [TSIB Recommendation RA-2019-003]

5.2 The European Aviation Safety Agency require the engine manufacturer to address potential contributing factors associated with the design of the fan blade that could lead to the failure of the fan blade. [TSIB Recommendation RA-2019-004]

5.3 The engine manufacturer address the current C-Scan ultrasound inspection process so as to improve detection success of potential defect sizes that could lead to the failure of the fan blade. [TSIB Recommendation RA-2019-005]

5.4 The European Aviation Safety Agency require the engine manufacturer to address the current C-Scan ultrasound inspection process so as to improve detection success of potential defect sizes that could lead to the failure of the fan blade. [TSIB Recommendation RA-2019-006]