

FINAL REPORT

AIRBUS A330-343, REGISTRATION B-HLM ENGINE FIRE EVENT

16 MAY 2011

AIB/AAI/CAS.074

**Air Accident Investigation Bureau of Singapore
Ministry of Transport
Singapore**

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The Air Accident Investigation Bureau of Singapore

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GLOSSARY OF ABBREVIATIONS

AES	Airport Emergency Service
AOHE	Air oil heat exchanger
ATC	Air traffic control
CVR	Cockpit voice recorder
EASA	European Aviation Safety Agency
ECAM	Electronic Centralised Aircraft Monitoring
EMS	Engine Master Switch
FC	Fire Commander
FDR	Flight data recorder
FMU	Fuel metering unit
FO	First Officer
LPSOV	Low Pressure Shutoff Valve
P/B	Push Button
PIC	Pilot-In-Command
PF	Pilot flying
PM	Pilot monitoring

SYNOPSIS

At about 0112 hours (Local Time) on 16 May 2011, an Airbus A330-343 took off from Singapore Changi Airport on a scheduled flight to Jakarta. While climbing through 33,000 feet at 0129 hours, the No.2 engine stalled and a loud bang was heard and vibration was felt by the flight crew. The flight crew shut down the No.2 engine, following which the vibration reduced, but did not disappear. The flight crew declared an emergency to ATC and flew the aircraft back to Changi Airport.

About 15 minutes after the initial No.2 engine problem, when the aircraft was at 10,500 feet and descending into Singapore, the No.2 engine fire warning indication appeared and the flight crew discharged an engine fire extinguishing bottle. The fire warning indication was cleared but re-appeared after 69 seconds. The flight crew discharged a second engine fire extinguishing bottle but was unsure if the fire had been extinguished as the fire warning light flickered intermittently.

After the aircraft landed, the Airport Emergency Service saw fire at the No.2 engine as they approached the aircraft and proceeded to put it out. No one was injured in this incident.

The No.2 engine vibration was a result of the engine's rotating assembly becoming unbalanced following the loss of a 130 mm tip section of one of the engine fan blades. The failure of the fan blade could be attributed to its mechanical strength having been compromised as a result of the use of an incorrect gas during the manufacturing process.

The interior of the No.2 engine fan case was damaged by the rubbing against it of the fan blades of the engine's unbalanced rotating assembly. The severe rubbing generated heat resulting in the ignition of the Kevlar wrap of the fan case and in fire damage to the accessories on the right side of the engine.

The Air Accident investigation Bureau of Singapore classified this occurrence as a serious incident.

AIRCRAFT DETAILS

Aircraft type	:	Airbus A330-343
Operator	:	Cathay Pacific Airways
Aircraft registration	:	B-HLM
Numbers and type of engines	:	2 x Rolls Royce Trent 700
Date and time of incident	:	16 May 2011, 0129 hours local time
Location of occurrence	:	South-east of Singapore
Type of flight	:	Scheduled passenger flight
Persons on board	:	149

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 flight

- 1.1.1 The Airbus 330-343 aircraft was on a scheduled passenger flight from Singapore to Jakarta on 16 May 2011. It took off from Singapore Changi Airport at 0112 hours. The Pilot-In-Command (PIC) was the pilot flying (PF) and the First Officer (FO) was the Pilot Monitoring (PM).
- 1.1.2 While the aircraft was climbing through 33,000 feet at 0129 hours, a loud bang was heard and severe airframe vibration was felt by the flight crew. The PF observed an Electronic Centralised Aircraft Monitoring (ECAM) message indicating “ENG 2 STALL”. Data from the aircraft’s flight data recorder (FDR) showed that engine vibration spiked up to 10 units¹ for about 12 seconds.
- 1.1.3 At 0130 hours, the flight crew shut down the No.2 engine by putting the Engine Master Switch (EMS) for the No.2 engine to the OFF position. The airframe vibration reduced (to between 0.5 and 4 units) but continued for the rest of the flight.
- 1.1.4 The flight crew declared an emergency (i.e. Mayday) to the Singapore Air Traffic Control Centre (SATCC) and flew back to Changi Airport.
- 1.1.5 The flight crew was informed by the In-flight Service Manager (ISM) that sparks and flames were seen at the rear of the No.2 engine from the cabin windows. The PF informed the ISM that the aircraft was turning back to Singapore and requested for the cabin to be prepared for landing.
- 1.1.6 At about 0145 hours, the No.2 engine fire warning indication² came on. The flight crew discharged one engine fire extinguishing bottle³ and the fire warning indication (i.e. both aural alarm and light) were cleared.
- 1.1.7 The No.2 engine fire warning indication light re-appeared⁴ 69 seconds

¹ This was the upper limit of the engine vibration parameter.

² When an engine fire is first detected, the fire warning indication consists of an aural alarm and a warning light on a guarded Engine Fire Push Button (P/B) located in the overhead panel and the master warning button on the front panel. The warning light is designed to be steady ON when a fire is constantly detected.

³ To discharge the fire extinguishing bottle, the crew has to lift the guard of the Engine Fire P/B, press the Engine Fire P/B (which arms the fire extinguishing system and inhibits the aural warning) and thereafter press the Fire Extinguishing Bottle P/B to discharge the first fire extinguishing bottle.

⁴ As the No.2 Engine Fire P/B had been pressed when the flight crew discharged the first fire extinguishing bottle, the aural warning was inhibited and subsequent fire warning indications would consist of the warning light only.

later and the flight crew discharged the second⁵ engine fire extinguishing bottle.

- 1.1.8 According to the flight crew, after the second engine fire extinguishing bottle was discharged, the fire warning indication light cleared but reappeared flickering and remained flickering for the rest of the flight. The flight crew interpreted the flickering fire warning indication as the No.2 engine fire having been extinguished and they informed SATCC accordingly. Data from the FDR showed that the fire warning indication was on throughout the rest of the flight.
- 1.1.9 At the time of the occurrence, one of the airport's two runways, Runway 02L/20R, was closed for scheduled maintenance and only Runway 02C/20C was open. Other aircraft were still departing from Runway 02C/20C until the emergency aircraft was about seven nautical miles⁶ from landing.
- 1.1.10 The Airport Emergency Service (AES) was notified of the emergency by the control tower and its vehicles were put on standby for the aircraft to land.
- 1.1.11 After the aircraft landed on Runway 02C at 0157 hours, the aircraft vacated the runway and stopped on Taxiway E5. The flight crew then shut down No.1 engine.
- 1.1.12 The AES vehicles were given clearance by the control tower to proceed to the aircraft. When the AES personnel arrived at the aircraft, they noticed that the No.2 engine was on fire and immediately commenced fighting the fire with foam.
- 1.1.13 The flight crew wanted to verify the status of the No.2 engine fire before deciding if an evacuation was necessary and wished to speak to the Fire Commander (FC) of the AES response team directly. They obtained from the control tower the emergency frequency to contact the FC, which was 121.85 MHz⁷. In the meantime, they also informed the cabin crew to stand by in case an evacuation was necessary.
- 1.1.14 The control tower also informed FC to contact the flight crew on 121.85 MHz.
- 1.1.15 The flight crew first attempted to contact the FC on 121.85 MHz at 0201 hours but there was no reply.

⁵ Each engine was equipped with two fire extinguishing bottles.

⁶ From this point, the aircraft took about three minutes to land.

⁷ There was no dedicated frequency channel in Changi Airport for communication between the AES and aircraft during emergencies. There were two frequencies that the control tower may assign for such communication, viz. 121.85 MHz and 121.9 MHz. If requested, the control tower would inform flight crews and the AES the frequency to be used.

- 1.1.16 At 0204 hours, the PM opened the cockpit window and spoke to the FC. The FC informed the PM that the No.2 engine fire had been put out and equipment was being arranged for the disembarkation of the passengers at Taxiway E5.
- 1.1.17 Radio communication between the flight crew and the AES personnel was established at 0206 hours.
- 1.1.18 Below is a summary of the history of the flight.

Time (hours)	Activities
01:00	Runway 02L/20R was closed for scheduled maintenance. Planned closure time was from 0100 to 0700 hours.
01:12	Incident aircraft took off from Runway 02C.
01:29:34	A loud bang was heard and severe airframe vibration was felt by the flight crew.
01:29:52	No.2 engine was put to idle.
01:30:31	The flight crew shut down No.2 engine, which closed both the High Pressure (HP) and Low Pressure (LP) fuel valves. Flight crew declared Mayday and flew back to Changi Airport.
Exact time undetermined	APU was started.
01:45	Tower Controller initiated opening of Runway 02L/20R.
01:45:36	No.2 engine fire warning indication came on for the first time. Flight crew discharged one engine fire extinguishing bottle.
01:46:14	No.2 engine fire warning indication was cleared.
01:47:23	No.2 engine fire warning indication re-appeared. Flight crew discharged the second engine fire extinguishing bottle.
01:54	Runway 02C/20C was reserved for the emergency aircraft when it was about seven nautical miles away.
01:57:41	Aircraft landed on Runway 02C, vacated the runway and stopped at Taxiway E5. The AES vehicles were given clearance by the control tower to proceed to the aircraft. The AES personnel commenced fighting the No.2 engine fire.
01:59	Flight crew wanted to check the status of No.2 engine fire before deciding if an evacuation was necessary. They informed cabin crew to stand by in case an evacuation was necessary.
02:00:55	Based on FDR, the No.2 engine fire warning indication was cleared.
02:01	The flight crew shut down No.1 engine. Flight crew made first attempt (unsuccessful) to contact the FC.
Exact time undetermined	The AES Commander attempted to contact the flight crew but was unsuccessful.
02:04	After various unsuccessful transmissions to contact the FC, the PM opened the cockpit window and spoke to the FC.

02:06	Flight crew and the AES established radio communication.
02:10	Runway 02L/20R was opened.

1.2 Injuries to persons

1.2.1 There was no injury to any person in this incident.

1.3 Damage to aircraft

1.3.1 No.2 engine (See **Figure 1** for the cutaway view⁸ for illustration and comparison purpose)

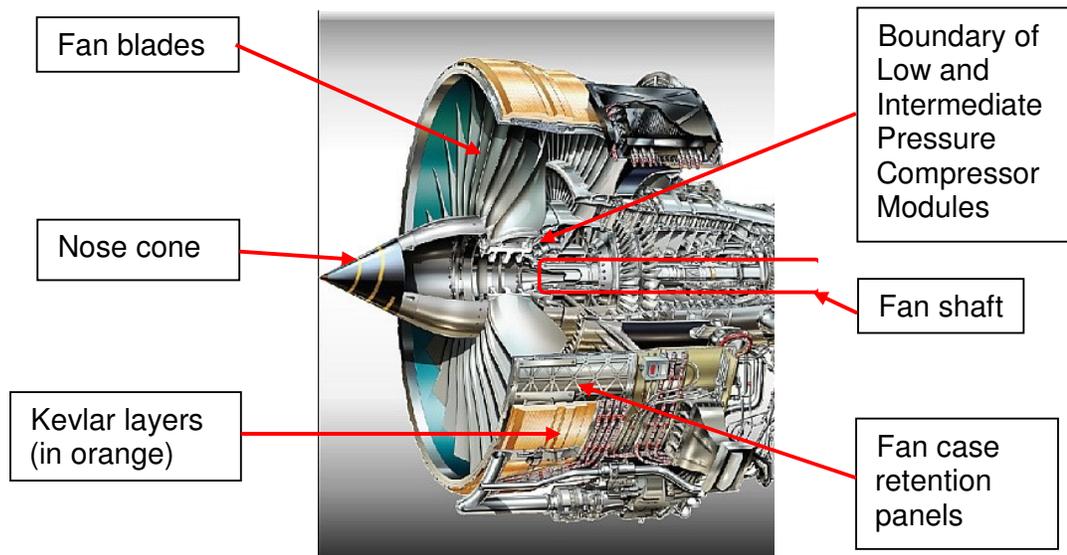


Figure 1: Cutaway view of engine fan case

1.3.1.1 All the fan blade tips of the No.2 engine were damaged, with one of the blades having its tip missing (see **Figure 2**). The missing part was about 130 mm long.

⁸ Source: <http://rustanez.com/Engines.html>

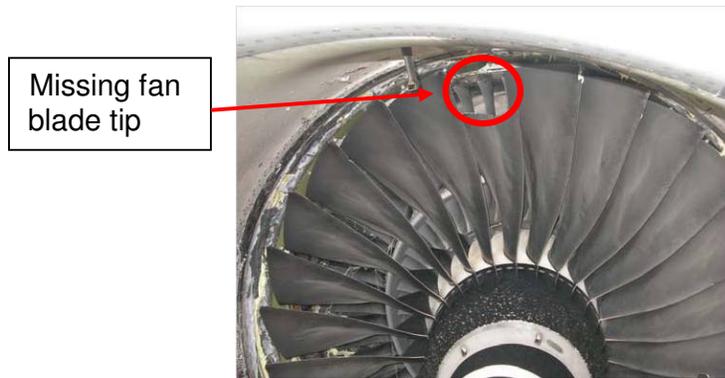


Figure 2: One fan blade had a missing tip section (front view)

- 1.3.1.2 The LP shaft showed evidence of severe contact with the IP front stub shaft with heavy rubbing approximately 40 mm wide and extending 180° circumferentially. The LP shaft was deformed locally and had a significant bend coincident with the heavy rub (see **Figure 3**).

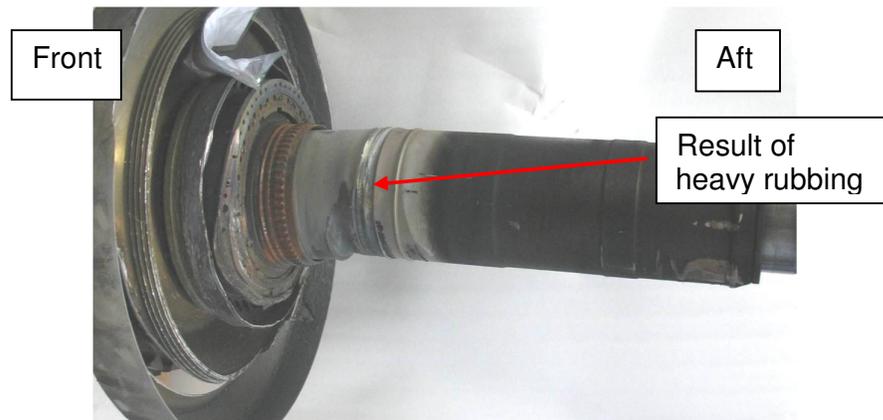


Figure 3: Damaged LP shaft

- 1.3.1.3 There was significant damage to the interior of the fan case (see **Figure 4**). The centre sections on all but two of the fan case retention panels were worn through by rubbing of the fan blades and some of the Kevlar layers were pulled out.

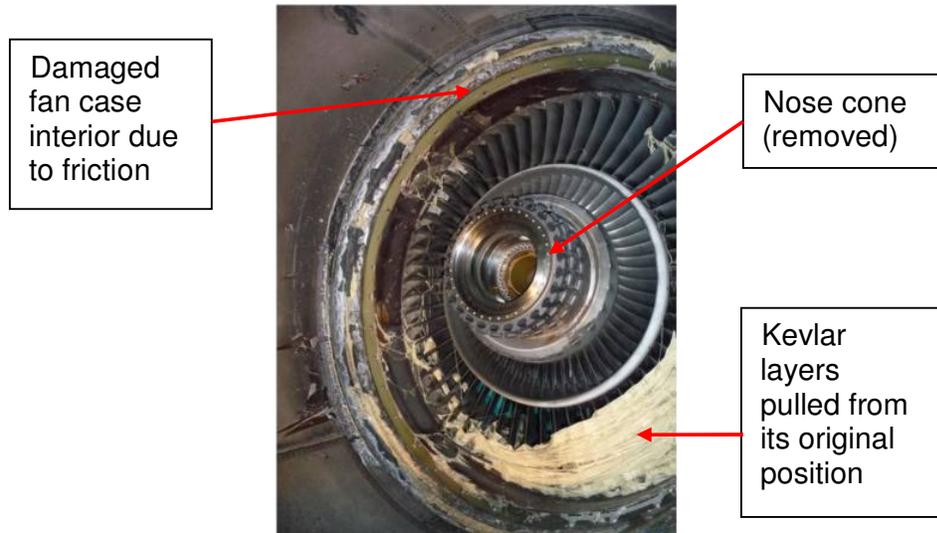


Figure 4: Damaged interior of fan case and Kevlar layers

- 1.3.1.4 The front section of the engine (i.e. the fan case, engine intake and fan cowl door) had shifted forward and left a 30 mm gap between the front section and the thrust reverser unit.
- 1.3.1.5 A crack was found at the boundary of the Low Pressure Compressor Module and the Intermediate Pressure Compressor Module near the nose cone (see **Figure 5**).
- 1.3.1.6 Some nicks and tears were also found on the engine intake cowl acoustic panels (see **Figure 6**). The engine inlet cowl acoustic panel adjacent to the P20/T20 probe had a puncture through the inner and outer skin (see **Figure 7**).

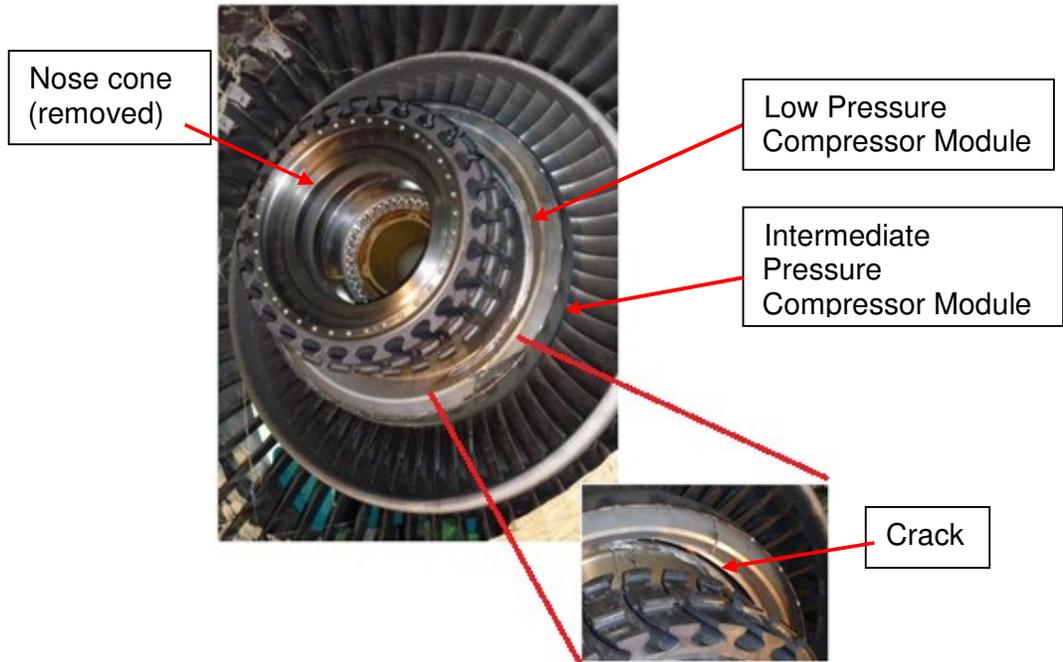


Figure 5: Hole in Low Pressure Compressor rear seal





Figure 7: Puncture on engine inlet cowl outer skin (top view)

1.3.1.7 The pylon on which No.2 engine was mounted was found with several cracks. The pylon was removed and inspection revealed multiple cracks on the forward secondary structure which suggest the presence of high loads level. This damage was most probably consequential and due to the high engine vibration following the partial fan blade release. The pylon primary structure showed no signs of damage.

1.3.2 Fuel line

1.3.2.1 The No.2 engine fuel line next to the engine fuel pump (which supplied fuel from the wing fuel tank to the fuel pump) was found to have a 180° crack around the edge of the tube end-fitting weld (see **Figure 8**). There were signs of fuel spraying onto the surface of a nearby pipe.

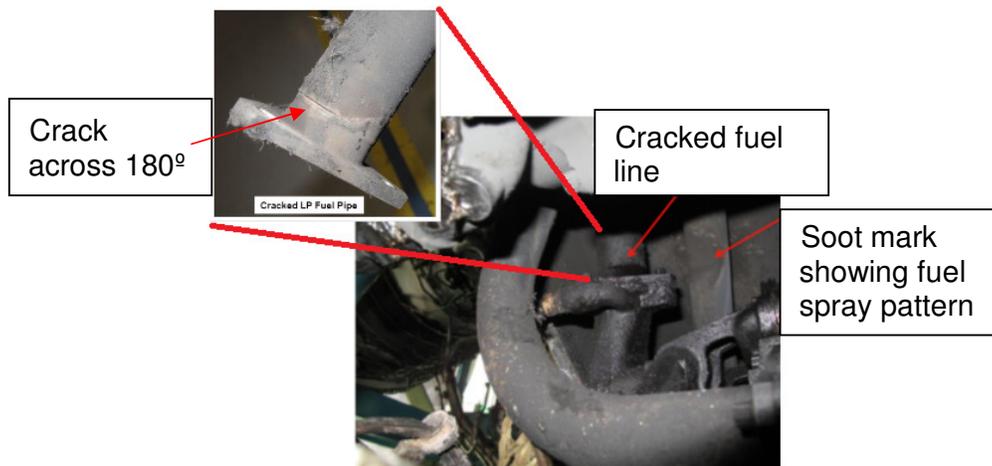


Figure 8: Cracked fuel pump supply line with fuel spray marks in the vicinity

1.3.2.2 Examination of the fracture surfaces of the crack by the engine manufacturer indicated high stress fatigue initiating from multiple sites around the inner surface of the tube towards the outer surface.

1.4 Personnel information

	PIC (Male)	FO (Male)
Age	40 years	41 years
Licence	Airline Transport Pilot Licence issued by the Hong Kong Civil Aviation Department	Airline Transport Pilot Licence issued by the Hong Kong Civil Aviation Department
Total flying experience	8,534 hours	7,385 hours
Flying experience on type	3,632 hours	3,238 hours

1.5 Communications

1.5.1 Data from the cockpit voice recorder (CVR) showed that before the flight crew and the AES established radio communication at 0206 hours, the flight crew had called the FC multiple times on 121.85 MHz over about three minutes (the first transmission by the flight crew to contact the FC was made at 0201 hours) but without receiving any reply. During the flight crew's third transmission, the CVR recording showed that there was a cross talk.

1.5.2 On the part of the FC, he attempted to contact the flight crew on 121.85 MHz while he was in his vehicle⁹. The FC did not receive any reply. The FC then transmitted over the AES Channel¹⁰ via a walkie-talkie, to inform all in the AES Channel that he was not able to contact the flight crew.

1.5.3 At that time, the AES Duty Officer¹¹ was outside his own vehicle coordinating the firefighting activities. He had a walkie-talkie for the AES Channel but did not hear the FC's transmission (that he was not able to contact the flight crew) over the AES Channel because it was very noisy around him.

⁹ AES personnel communicated with flight crews via fixed radio sets in their vehicles. They did not have portable radio sets which could be used outside their vehicles to communicate with flight crews.

¹⁰ The AES Channel was a communication channel for the AES personnel to communicate among themselves and with the control tower via a walkie-talkie. This uses a different frequency than 121.85 MHz.

¹¹ The AES Duty Officer was the second highest ranking the AES personnel on site, after the FC.

- 1.5.4 The FC decided to take over command of the firefighting activities and wanted the AES Duty Officer to try to contact the flight crew instead. The FC left his vehicle to meet up with the AES Duty Officer who then provided the FC with a situation report so as to hand over the command of the firefighting activities to the FC.
- 1.5.5 It was when the AES Duty Officer was handing over to the FC that the PM of the aircraft opened the cockpit window and spoke to the FC. The AES Duty Officer then returned to his vehicle.
- 1.5.6 After the AES Duty Officer had returned to his vehicle, he managed to establish communication with the flight crew on 121.85 MHz. The communication was maintained throughout the rest of the event.
- 1.6 Aerodrome information
 - 1.6.1 At the time of the occurrence, Runway 02L/20R was closed for maintenance and only Runway 02C/20C was operational. When the control tower was informed that the emergency aircraft was returning to land, the Runway Controller took action (at about 0145 hours) to initiate the reopening of Runway 02L/20R. This was done so that there would be another runway available for use if the emergency aircraft could not vacate Runway 02C/20C after landing.
 - 1.6.2 As the emergency aircraft was approaching the airport, other aircraft were still allowed to take off on Runway 02C/20C, then the only available runway. The last aircraft took off while the emergency aircraft was seven nautical miles (about 3 minutes) from touchdown.
 - 1.6.3 Runway 02L/20R was eventually reopened about 13 minutes after the emergency aircraft had landed.
- 1.7 AES Watch Room Officer
 - 1.7.1 The AES Watch Room was manned by one person, viz. the Watch Room Officer, when the incident took place. The Watch Room Officer's primary duties were, among others, to observe all aircraft movements and make journal entries diligently in the Computer Watch Room System or the Occurrence Book. His secondary but important duties included answering all calls (e.g. direct lines, the AES frequency and any assigned emergency frequencies) and redirecting the calls.
 - 1.7.2 The AES Watch Room Officer heard the FC's transmission over the AES Channel that the FC was not able to contact the flight crew. However, the AES Watch Room Officer did not assist the FC and flight crew to establish communication.

1.8 Fire

1.8.1 There was soot on the right side of the No.2 engine (see **Figure 9**) exterior surface, and on the interior surface of the right fan cowl door (see **Figure 10**).

1.8.2 There was fire damage to the accessories located on the right side of the engine, such as pipes, electrical harness under the air oil heat exchanger (AOHE) and the fuel pump, electrical harness near the fuel flow transmitter, and the underside of the fan case (see **Figure 11** to **Figure 14**).



Figure 9: Right side of No.2 engine



Figure 10: Interior of No.2 engine right fan cowl door



Figure 11: Fire damage to the AOHE



Figure 12: Fire damage to the fuel pump



Figure 13: Fire damage to electrical harness near fuel flow transmitter



Figure 14: Fire damage to underside of fan case

- 1.8.3 The Kevlar layers at the bottom of the engine were burnt (see **Figure 15**). The burnt pattern indicated that the burning had started from the inner layers.

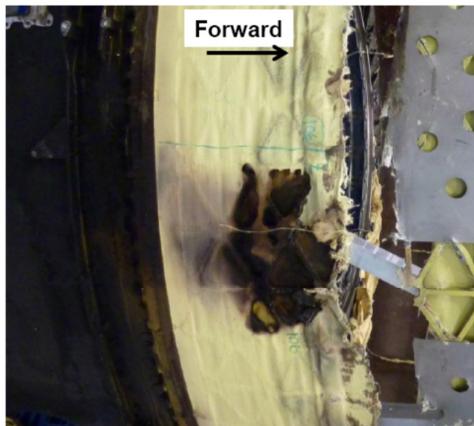


Figure 15: Burnt Kevlar at bottom of engine

- 1.9 Test and research
- 1.9.1 EASA certification specifications - engine certification requirement
- 1.9.1.1 According to EASA CS-E 810 on engine certification requirements, the engine should demonstrate that any failure to single compressor blade or turbine blade will be contained and that no hazardous condition can arise to the aircraft as a result.
- 1.9.2 Fuse system of the engine front bearing housing
- 1.9.2.1 One failure event that the engine manufacturer has envisaged is the 'Fan Blade Off', i.e. when one complete fan blade aerofoil breaks off. Fan Blade Off will result in an unbalanced engine fan assembly, which will in turn result in engine vibration.

- 1.9.2.2 To counter the unbalancing effect of Fan Blade Off on the rotating fan assembly, the engine has two fuses in the front bearing housing. When a blade aerofoil is released, the fuses operate and the fan system will be allowed to rotate about its new mass centre, thereby reducing the degree of imbalance and vibrational loads.
- 1.9.2.3 An inspection of the No.2 engine revealed that only one of the two fuses had operated.
- 1.9.3 Fan blade with a tip section missing
- 1.9.3.1 The fracture surface of the fan blade with the tip section missing was examined by the engine manufacturer.
- 1.9.3.2 According to the engine manufacturer, the fan blade material comprised two types of crystallographic microstructures, viz. alpha phase and beta phase, which are evenly distributed in the material. **Figure 16** shows the microstructure of a normal fan blade material.

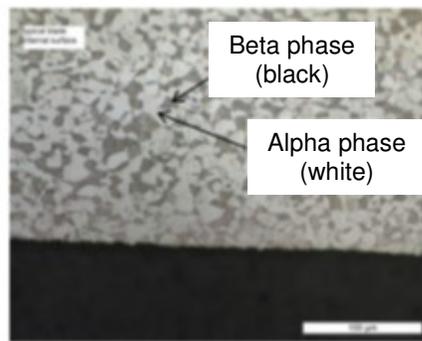


Figure 16: Normal fan blade material's microstructure

- 1.9.3.3 The examination by the engine manufacturer revealed that the material at the surface of the blade's cavity had less beta phase microstructure compared with a normal blade material sample (see **Figure 17**). This phenomenon is known as 'diffused beta-denuded layer' and would weaken the mechanical strength of the material.

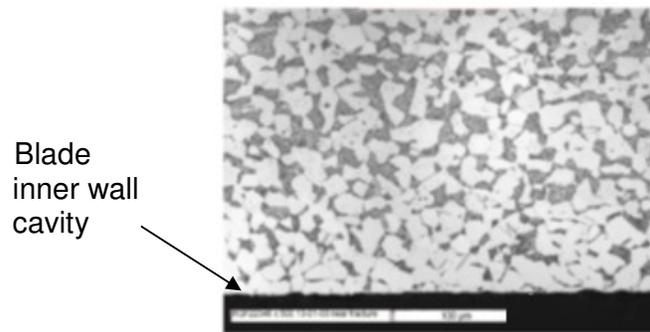


Figure 17: Microstructure at the inner cavity wall of the failed fan blade

1.9.3.4 Investigation by the engine manufacturer revealed that an incorrect gas was used in the manufacture of the failed fan blade. This resulted from the installation of an incorrect gas cylinder during a routine gas cylinder replacement. This gas cylinder was meant for maintenance welding operations and not for fan blade manufacturing. Tests have shown that blades manufactured with this gas resulted in a similar material microstructure to that observed on the failed fan blade.

1.9.4 Fuel supply

1.9.4.1 The fuel for each engine is supplied from the fuel tank to the fuel metering unit (FMU) through the low pressure shut-off valve (LPSOV) located at the wing front spar area (see **Figure 18**). The LPSOV would be closed (i.e. cutting fuel supply to the engine) when either the respective Engine Master Switch (EMS) was put to the OFF position, or when the respective Engine Fire Push Button (P/B) was pressed in the event of a fire alarm to arm the engine fire extinguishing system.

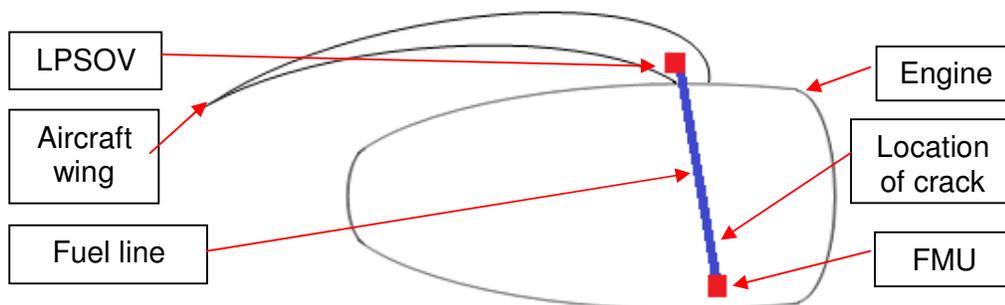


Figure 18: Simplified diagram of fuel line from LPSOV to FMU

1.9.4.2 An inspection after the aircraft had landed confirmed that the LPSOV was in the closed position. Data from the FDR showed that the LPSOV was closed when the No.2 Engine Master Switch (EMS) was put to OFF at 0130 hours during the engine shutdown process.

2 ANALYSIS

The analysis by the investigation team covered the following areas:

- (a) Engine vibration
- (b) Engine fire
- (c) Flight crew's notification to ATC regarding fire warning
- (d) Tower Controller's action
- (e) Emergency communication frequency
- (f) Watch Room Officer's duty

2.1 Engine vibration

- 2.1.1 The No.2 engine vibration was a result of the engine's rotating assembly becoming unbalanced following the loss of a 130 mm tip section of one of the engine fan blades. The failure of the fan blade could be attributed to its mechanical strength having been compromised as a result of the use of an incorrect gas during the manufacturing process.
- 2.1.2 Following the fan blade failure, only one of the two fuses in the engine front bearing functioned. The fuse system was designed and certified for the case of a full fan blade aerofoil being released. It was likely that the loss of a 130 mm tip section of the fan blade aerofoil in this event did not generate sufficient out-of-balance loads to cause the second fuse to function.
- 2.1.3 Since the second fuse did not function, the LP shaft came into contact with the IP stub shaft. Less severe secondary damage, caused by the release of a smaller section of blade, contributed to a slower decay in rotational speed of the LP and IP spools than those occurred in other fan blade loss events. This resulted in higher differential speeds between the contacting shafts for a greater duration, leading to increased localised heating and more severe bending of the LP shaft than had been seen with previous events.
- 2.1.4 The greater than normal bend in the LP shaft seen in this event, resulted in a heavier rub between the tips of the fan blades and the fan case interior around its full circumference, causing damage to the fan case and most of the fan case retention panels.
- 2.1.5 This occurrence showed that, while the fuse system was designed for a full fan blade aerofoil release, a partial fan blade aerofoil release could still generate substantial damages.

2.2 Engine fire

2.2.1 The rubbing of the fan blade tips against the interior of the fan case generated a lot of heat, as evidenced by the burnt Kevlar layers.

2.2.2 The fan blade failure caused severe vibration of the No.2 engine. It was likely that this vibration generated loads in the fuel line supplying the No.2 engine which resulted in a crack forming and subsequently fuel spraying out from the opening in the fuel line (see **Figure 19**).

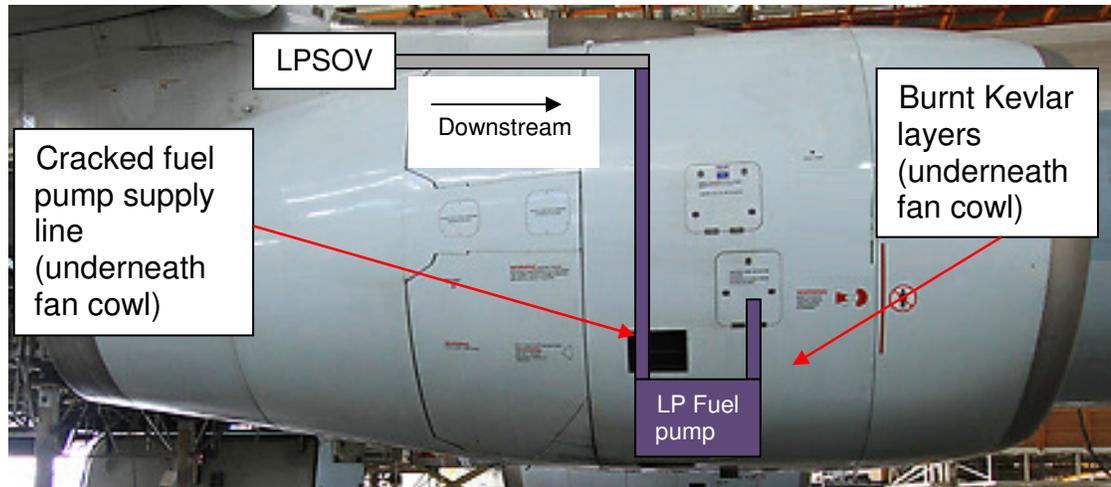


Figure 19: Relative location of cracked fuel line and heat source (block diagram of fuel line from LPSOV viewed from engine exterior, not drawn to scale)

2.2.3 As the rotating fan blades rubbed against the inner circumference of the fan case, the heat generated was high enough to burn through the Kevlar. It was likely that the heat from the burning Kevlar ignited the fuel from the cracked fuel supply line and the burning fuel then caused further fire damage to the engine.

2.2.4 When the flight crew shut down the engine and pressed the Engine Fire Push Button (P/B) to arm the engine fire extinguishing system, the LPSOV was closed. This cut off fuel from the wing tank to the engine. There was about 20-22 litres of residual fuel downstream of the closed LPSOV, an amount which was sufficient to sustain a fire from the onset of the fan blade separation until the aircraft landed (about 28 minutes later), basing on the estimated rate of fuel leak.

2.2.5 The flight crew discharged both the No.2 engine's fire extinguishing bottles. However, the fire was not permanently extinguished (as judged from the data

in the FDR). The 30 mm gap between the thrust reverser units and the fan cowl door, which was a result of the forward shifting of the fan case, could have reduced the effectiveness of the fire extinguishing agent in suppressing the fire. It might also be that the Kevlar continued to provide an ignition source and reignited the leaking fuel after both the fire extinguishing bottles had been discharged.

2.2.6 The presence of the engine fire as a result of the partial fan blade off event created a hazardous condition. The engine did not meet the EASA CS-E 810 requirements that no hazardous condition should arise as a result of engine damage.

2.3 Flight crew's notification to ATC regarding fire warning

2.3.1 After the second engine fire extinguishing bottle was discharged, the fire warning indication light cleared but reappeared flickering and remained flickering for the rest of the flight. Nevertheless, the flight crew believed that the fire, if any, had been extinguished. However, FDR data suggests that fire was still present.

2.3.2 It would have been more prudent for the flight crew to assume that fire was present. While one may consider that, since the flight crew had made a decision to land the aircraft as soon as possible following the engine vibration, whether the flight crew believed correctly or wrongly the fire had been extinguished might not be material. However, if the flight crew had treated that the fire was still present and informed ATC accordingly, this might have aided ATC in planning their emergency actions, such as ceasing operations on the runway (e.g. take-off and landing) well in advance. This would have reduced the risk of the emergency aircraft having to execute a go-around should an abnormal operation (e.g. abort take-off) occurred to a departure or arrival aircraft ahead of the emergency aircraft.

2.3.3 The scenario of a flickering fire indication warning light had apparently been envisaged by neither the aircraft manufacturer nor the operator. It should be included in the aircraft manufacturer's documentation that a flickering fire warning indication should be treated as that a fire is present. Likewise, in the training of its flight crews, the operator should simulate a flickering fire warning indication scenario.

2.4 Tower Controller's action

2.4.1 At the time of the occurrence, Runway 02L/20R was closed for maintenance and only Runway 02C/20C was operational. As the emergency aircraft was

approaching the airport, the Tower Controller continued to allow other aircraft to take off on Runway 02C/20C, with a view to minimising the number of departing aircraft that would be prevented from taking off should the emergency aircraft get stuck on the runway after landing.

- 2.4.2 A concern is that, if any of the departing aircraft had an abnormal operation that makes the runway not immediately useable (e.g. aborted take-off, aircraft parts falling off), the emergency aircraft may have to go-around and come in for another approach while the runway is being recovered. This could mean additional risk for the emergency aircraft.
 - 2.4.3 Tower controllers are trained to reserve the runway for the emergency aircraft when it is on the final approach. In this occurrence case, aircraft were allowed to take off from Runway 02L/20R until the emergency aircraft was about seven nautical miles from landing. However, there is no guideline for the controllers on when to stop aircraft take-offs (e.g. in terms of the distance of the emergency aircraft from the runway threshold). Controllers are left to make such decision on their own. The decision would vary, depending on the experience, knowledge and risk tolerance levels of the controllers. It might be desirable to have a guideline to prevent a controller cutting it too fine.
- 2.5 Emergency communication frequency
- 2.5.1 There was no dedicated frequency in Changi Airport for communication between the AES and an aircraft during an emergency. If requested, ATC may assign *ad hoc* one of two frequencies, viz. 121.85 MHz and 121.9 MHz.
 - 2.5.2 121.85MHz is a standby frequency, for use when any one of the four controlling frequencies in the airport (i.e. Runway1 Controller, Runway2 Controller, Runway1 Ground Controller and Runway2 Ground Controller) is unusable.
 - 2.5.3 If 121.85 MHz was not available, 121.9 MHz would be assigned. 121.9 MHz is the surface utility frequency and was usually used by the control tower to control all vehicular traffic and aircraft towing movements in the maneuvering area. This frequency is heavily used and may not be suitable for use by the AES and the flight crew to communicate between them.
 - 2.5.4 Without a dedicated frequency for communication between the AES and the flight crew, these two parties will always have to check with ATC for the frequency and precious time may be lost.
 - 2.5.5 In the event that both 121.85 MHz and 121.9 MHz are not available to be

used, the control tower will relay messages between the AES and the flight crew. This would slow down communication with an increased probability of miscommunication.

2.5.6 It would be more desirable to reserve a frequency for communication between the AES and the flight crew during an emergency.

2.6 Watch Room Officer's duty

2.6.1 The AES Watch Room was manned by one Watch Room Officer. Although the Watch Room Officer heard the FC's transmission (that he was unable to establish contact with the flight crew) over the AES Channel, he was apparently so busy with his primary duties (i.e. monitoring the communication and logging events) that he did not have time to chip in to carry out his secondary duty, which was to assist the FC and the flight crew in establishing communication between them.

2.6.2 In addition, as the FC did not specifically request the Watch Room Officer to assist in establishing communication with the flight crew, the latter may not have known that he was required to assist the FC in this aspect.

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 Findings

- 3.1.1 The failure of the fan blade with a 130 mm tip section missing was probably due to its mechanical strength having been compromised as a result of the use of an incorrect gas during the manufacturing process.
- 3.1.2 Following the fan blade failure, only one of the two fuses in the engine front bearing functioned.
- 3.1.3 The fire from the rubbing of the fan blade tips and the fan case provided the ignition source and burnt the Kevlar layers.
- 3.1.4 The fuel pump supply line cracked due to high vibrations, resulting in fuel leak. It was likely that the heat from the burning Kevlar layers ignited the leaked fuel.
- 3.1.5 The engine intake cowl and the fan case had shifted forward, resulting in a gap of about 30 mm between the thrust reverser units and the fan cowl door. This gap could have compromised the engine's fire containment capability and reduced the effectiveness of the fire extinguishing agent in suppressing the fire.
- 3.1.6 The hazardous condition of the engine fire following the fan blade failure event did not comply with the EASA CS-E 810 requirement that no hazardous condition should arise as a result of engine damage.
- 3.1.7 After discharging both fire extinguishing bottles, the fire warning indication was flickering intermittently. The flight crew interpreted the intermittent fire warning indication light as the fire had been extinguished.
- 3.1.8 The aircraft manufacturer's documentation and the operator's training did not address the condition of an intermittent flickering fire warning indication which was presented to the flight crew.
- 3.1.9 There was no clear guideline for ATC controllers on when should a runway be reserved for an aircraft that has declared an emergency.
- 3.1.10 The air traffic services provider did not have a dedicated radio frequency for communication between the AES and the flight crew of an emergency aircraft.

- 3.1.11 The Watch Room Officer, who was busy with his primary duties in monitoring the communication and logging events, did not have time to assist the FC and the flight crew in establishing communication. Neither did the FC ask the Watch Room Officer to assist in establishing communication with the flight crew.

4 SAFETY ACTIONS

During the course of the investigation and through discussions with the investigation team, the following safety actions were initiated.

4.1 Engine Manufacturer

4.1.1 All in-service fan blades manufactured in the same batch as the failed fan blade in this incident have been recalled and inspected by the engine manufacturer. There was no similar manufacturing defect found in the recalled blades.

4.1.2 To prevent the use of an incorrect gas during the fan blade manufacturing process, the engine manufacturer has incorporated gas analysers on the gas supply lines to ascertain the nature of the gas in the cylinders prior to using them.

4.1.3 The engine manufacturer has included in its blade manufacturing process an additional laboratory inspection to ensure an acceptable microstructure is present on each fan blade.

4.1.4 The engine manufacturer has launched modification design activities to increase the engine's robustness in the event of a partial fan blade release.

4.2 European Aviation Safety Agency

4.2.1 After the partial fan blade failure occurrence on 16 May 2011, the European Aviation Safety Agency (EASA) issued the following Airworthiness Directive (AD) to address the inspection of affected in-service fan blades:

- AD 2012-0247 (issued on 20 November 2012)
EASA issued AD 2012-0247 to require a one-time inspection of the higher life LP compressor blades.
- AD 2013-0060 (issued on 11 March 2013, which superseded AD 2012-0247)
After AD 2012-0247 was issued, a population of LP compressor blades were identified to be incorrectly inspected, and EASA issued AD 2013-0060 to require re-inspection of the affected blades. Since EASA AD 2013-0060 was issued, the engine manufacturer issued a Non-Modification Service Bulletin (RB.211-72-AH465) providing instructions for a programme of repetitive ultrasonic inspections of the affected LP compressor blades to detect sub-surface anomalies in the aerofoil.

- AD 2014-0031 (issued on 4 February 2014, which superseded AD 2013-0060)
This AD requires repetitive inspections of all affected LP compressor blades and replacement (if required).

4.3 Airport Emergency Service voice recording system

- ##### 4.3.1
- A voice recording system has been installed to automatically record voice communication over the AES Channel and emergency frequency. With this system, the workload of the Watch Room Officer is reduced. This would allow him to chip in to assist the Fire Commander when necessary.

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, as holder of the type certificate, review the engine design to comply with EASA CS-E 810 (Compressor and Turbine Blade Failure) requirements such that no hazardous engine effect can arise as a result of other engine damage likely to occur before engine shut down following a blade failure. [AAIB Recommendation R-2014-010]
- 5.2 The European Aviation Safety Agency require the engine manufacturer, as holder of the type certificate, to review the design of the engine to comply with the EASA requirement CS-E 810 (Compressor and Turbine Blade Failure) requirements such that no hazardous engine effect can arise as a result of other engine damage likely to occur before engine shut down following a blade failure. [AAIB Recommendation R-2014-011]
- 5.3 The aircraft manufacturer include in its documentation that a flickering fire warning indication may imply that a fire is physically present but detected intermittently. [AAIB Recommendation R-2014-012]
- 5.4 The aircraft operator review its operating procedures to ensure that flight crew recognise the risk of an intermittent fire warning indication and that they would interpret it as a fire warning. [AAIB Recommendation R-2014-013]
- 5.5 The air traffic services provider to provide guidelines regarding reserving a runway for the exclusive use by an emergency aircraft. [AAIB Recommendation R-2014-014]
- 5.6 The air traffic services provider assign a fixed frequency for the Airport Emergency Service personnel and the flight crew of an emergency aircraft to communicate between them during an emergency. [AAIB Recommendation R-2014-015]
- 5.7 The Airport Emergency Service improve its communication equipment to ensure that voice transmissions over these equipment can be heard even in a noisy environment. [AAIB Recommendation R-2014-016]