民航意外調查機構
AAIA
Air Accident Investigation Authority

SYSTEM/COMPONENT FAILURE OR MALFUNCTION

Incident Investigation Final Report

Airbus A330-343

Hong Kong International Airport, Hong Kong

1 February 2018

04-2021

AAIA Investigations

Pursuant to Annex 13 to the Convention on International Civil Aviation and the Hong Kong Civil Aviation (Investigation of Accidents) Regulations (CAP. 448B), the sole objective of the investigation and the Final Report is the prevention of accidents and incidents. It is not the purpose of the investigation to apportion blame or liability.

In October 2018, the then Chief Inspector ordered an inspector's investigation into this event as a serious incident in accordance with the provisions in Cap. 448B. Based on all collected evidence and the subsequent analysis, the event has been reclassified as an incident as per the latest ICAO guidance on occurrence classification.

This incident investigation final report contains information of an occurrence involving an Airbus A330-343 aircraft, registration B-HLN, operated by Cathay Pacific Airways Limited, which occurred on 1 February 2018.

The Bureau d'enquêtes et d'analyses pour la sécurité de l'aviation civile (BEA), being the State of Design and the State of Manufacture, the Air Accidents Investigation Branch of the United Kingdom, being the State of Manufacture of the engine, Rolls-Royce plc (the engine manufacturer), Civil Aviation Department, and the aircraft operator, provided assistance to the investigation.

All times in this Report are in Hong Kong Local Times unless otherwise stated.

Hong Kong Local Time is Coordinated Universal Time (UTC) + 8 hours.

Chief Accident and Safety Investigator

Air Accident Investigation Authority

Transport and Housing Bureau

Hong Kong

December 2021

Synopsis

On 1 February 2018, an Airbus A330-343 aircraft, registration mark B-HLN of Cathay Pacific Airways Limited took off from Hong Kong International Airport at about 2100 hours.

During takeoff, No.1 engine set a stall message with audible surge, N2 and N3 high vibration and low oil pressure ECAM messages. A commanded inflight shutdown (IFSD) was performed per standard operating procedures. The aircraft returned to Hong Kong and landed safely.

During initial troubleshooting, metal debris was reported in the jetpipe and the result of boroscope inspection also confirmed one high-pressure turbine blade fractured.

Based on the safety actions already taken by the relevant parties, no safety recommendation has been made by this report.

Contents

1. FACTUAL INFORMATION

1.1. History of the Flight

(1) On 1 February 2018, an Airbus A330-343 aircraft, registration mark B-HLN of Cathay Pacific Airways Limited took off from Hong Kong International Airport (VHHH) at about 2100 hours.

(2) During takeoff, No.1 (left) engine set a stall message with audible surge, N2 and N3 high vibration and low oil pressure ECAM messages. A commanded inflight shutdown was performed per standard operating procedures and the pilots declared Mayday. The aircraft returned to VHHH and made a safe landing.

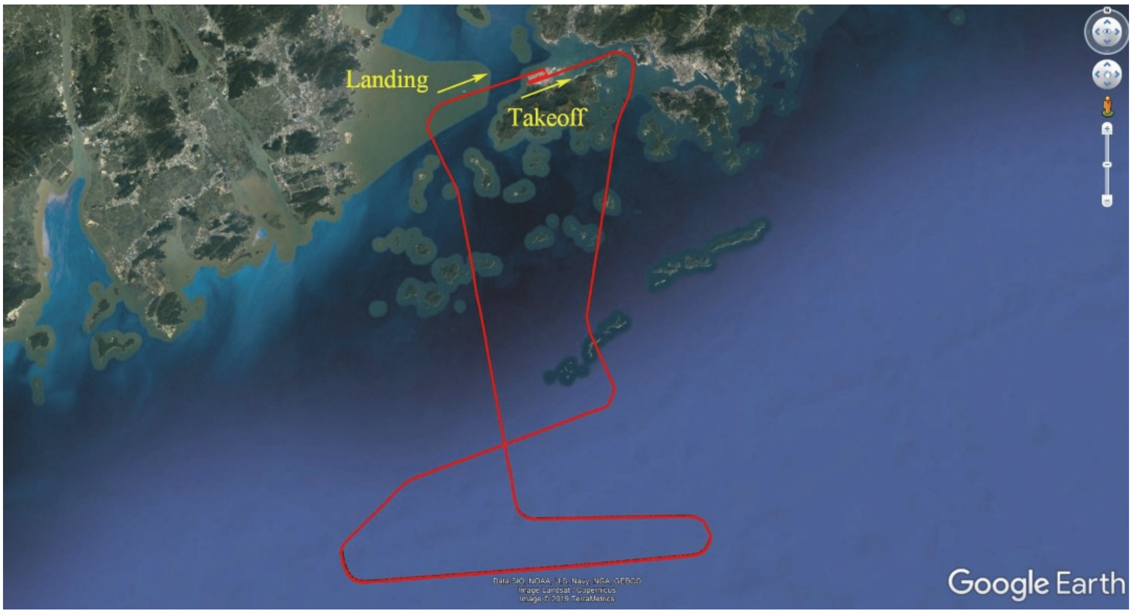

Figure 1: Flight Path

1.2. Injuries to Persons

There were two pilots, eleven cabin attendants, and 272 passengers (including one infant) on board the aircraft. They were uninjured during the incident.

<table>
<tr><td colspan="7">Injuries to Persons</td></tr>
<tr><td>Persons on board:</td><td>Crew (Flight + Cabin)</td><td>13</td><td>Passengers</td><td>272</td><td rowspan="2">Others</td><td rowspan="2">0</td></tr>
<tr><td>Injuries</td><td>Crew (Flight + Cabin)</td><td>0</td><td>Passengers</td><td>0</td></tr>
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Table 1: Injuries to Persons

1.3. Damage - Aircraft

Ground inspection identified metallic debris in the jet pipe of the No.1 engine. The engine was later removed for further investigation.

1.4. Other Damages

Not applicable.

1.5. Personnel Information

(1) The Pilot in Command (PIC) was on the left-hand seat and the pilot monitoring (PM). The first officer on the right-hand seat was the pilot flying (PF).

(2) The crew information is in Section 6.2.

1.6. Aircraft Information

1.6.1. Aircraft

(1) The A330 is a wide-body medium and long-range airliner made by Airbus. It can be equipped with three engine types and the incident aircraft is fitted with Rolls-Royce Trent 700 engines. It can accommodate up to 335 passengers or carry 70 tonnes (154,000 pounds) of cargo.

(2) The aircraft is equipped with the electronic flight instrumentation system (EFIS) including the flight and navigation displays and the electronic centralised aircraft monitors (ECAM). The ECAM presents data from the various aircraft systems on the Engine/Warning Display (EWD), System Display (SD), and ‘Attention Getters’.

(3) The alerts provided by the ECAM are classified in three levels, namely Alert Advisory (Level 1), Cautions (Level 2) and Warnings (Level 3), which reflect the importance and urgency of the corrective actions required. A Level 3 warning has priority over a Level 2 caution, which has priority over a Level 1 alert.

1.6.2. Engine

1.6.2.1. Propulsion System Outline

(1) The Rolls-Royce Trent 772B-60 is in a three-shaft configuration high-bypass turbofan engine. The three-shaft configuration consists of

low-pressure (LP), intermediate-pressure (IP) and high-pressure (HP) compressor and turbine assemblies, producing 72,000 lb of thrust.

(2) The No.1 (Left) engine fitted to this aircraft had completed 4,948 flying cycles since new.

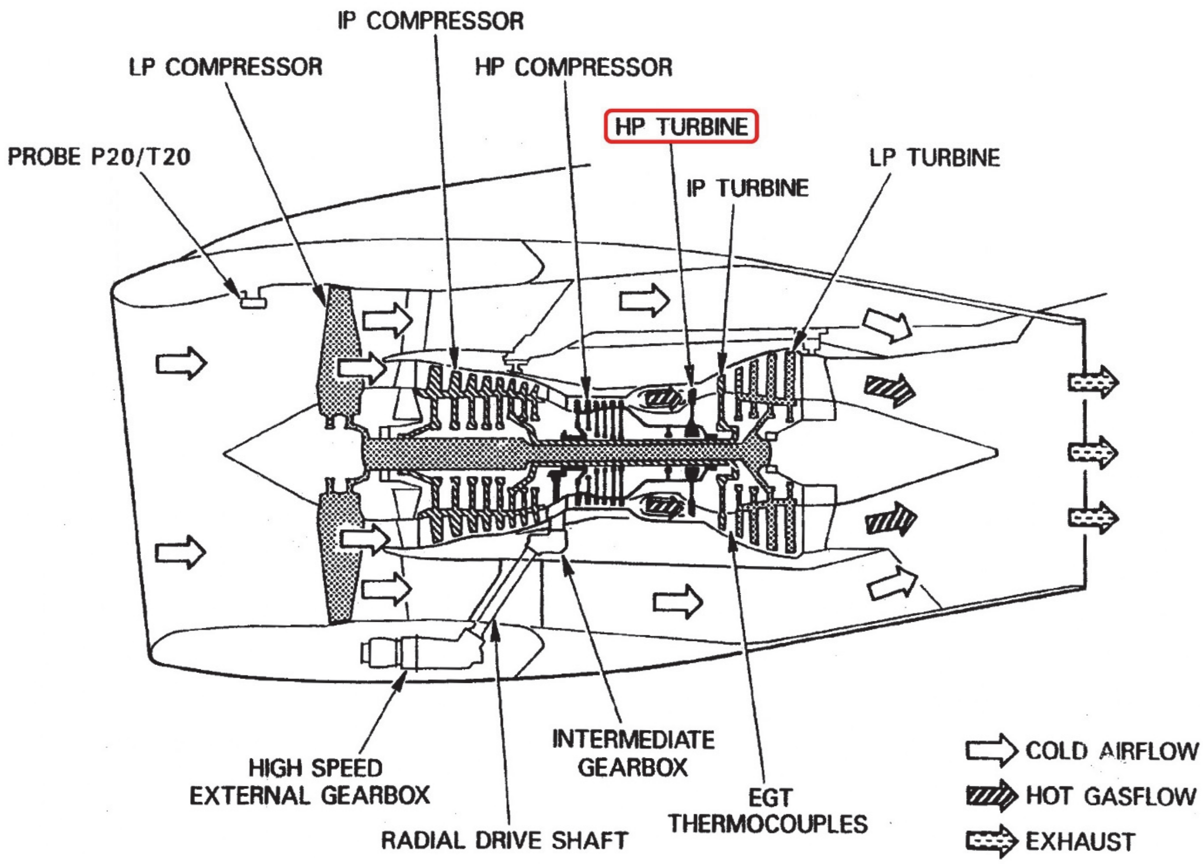

Figure 2: Rolls-Royce Trent 700 Propulsion System Outline

1.6.2.2. HP System Module

The HP system module comprises of HP compressor, combustion chamber and outer case, and HP turbine (HPT). The HPT is a single stage disc connected to a mini disc to the rear of the HP compressor drum. On the front face of the disc there are two sets of seal fins which control the flow of cooling air. The disc has firtree roots for installation of 92 HPT blades.

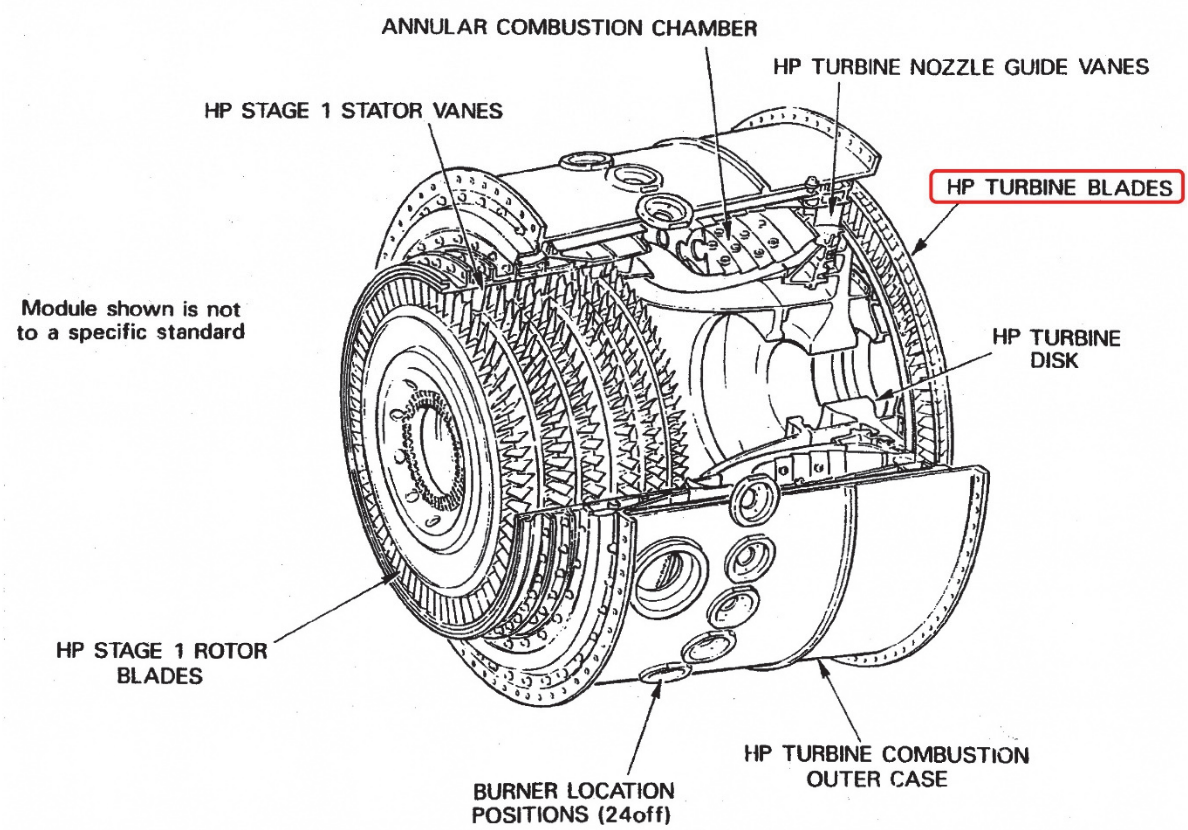

Figure 3: Rolls-Royce Trent 700 HP System Module

1.6.2.3. Engine Internal Cooling

The engine is internally cooled with air supplied by the IP and HP compressors. Air bled from the sixth stage of HP compressor flows around the HP shaft and keeps the front face of the HPT disc cool. It then flows through pre-swirl nozzles which control the level of cooling airflow. The pre-swirl nozzles give the best direction for the air to flow through the HPT blades. The cooling air goes out through holes in the turbine blades into the exhaust gas stream.

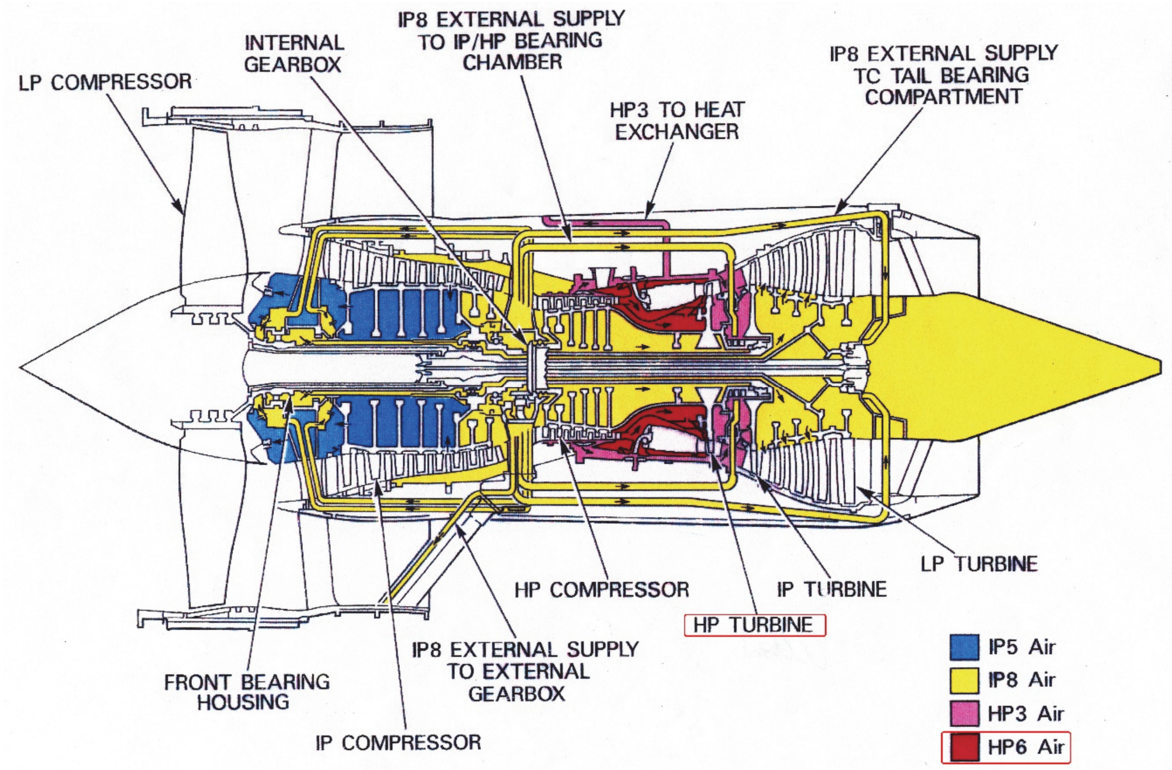

Figure 4: Cooling and Sealing Airflow

1.6.3. Extended Range Operations (ETOPS) Approval

According to European Aviation Safety Agency (EASA) Type-certificate Data sheet No. EASA.A.004, the Type Design, system reliability and performance of A330/Trent 700 aeroplane/engine combination (AEC) was found capable for ETOPS when configured, maintained and operated in accordance with the latest published revision of the ETOPS Configuration, Maintenance and Procedures (CMP) document, LR2/EASA: AMC 20-6/CMP.

1.6.4. Aircraft Details

The aircraft was registered in Hong Kong and had a valid Certificate of Airworthiness. Further details of the aircraft are in Section 6.3.

1.6.5. Maintenance History

The last base maintenance input, comprising C, 2C and 4C checks, was completed on 26 September 2017. Before the incident flight, there were no recorded defects regarding No.1 engine.

1.7. Meteorological Factors

The meteorological aerodrome weather report for VHHH at 2100 hours indicated that the wind was from 40 degrees at 7 knots. The visibility was 10 kilometres and the runway condition was dry. The air temperature was 12ºC, the dew point was 4°C and the QNH was 1,002 hPa. The weather conditions were within the limits for the flight.

1.8. Navigation Aids

Ground-based navigation aids and aerodrome visual ground aids were not a factor in this incident.

1.9. Communications

The aircraft was equipped with VHF radio communication systems. All VHF radios were serviceable. The radio communication systems were not a factor in this incident.

1.10. Aerodrome Information or Remote Incident Location

The information on the arrival and the destination aerodromes is listed in Section 6.4.

1.11. Flight Recorders

The aircraft is fitted with a Digital Flight Data Recorder (DFDR) and a Cockpit Voice Recorder (CVR). A copy of flight data in CSV format was provided to the investigation team by the operator.

1.12. Wreckage and Impact

1.12.1. Engine Dismantling

The engine was stripped down at the engine manufacturer's local overhaul facility. The HPT blade at position 64 had fractured and been released in the aerofoil, just above the inner platform. The inner platform and root section was retained in the turbine disc. Impact damage was noted on other HPT blades, the whole set of IP turbine blades and some of the LP turbine blades. The whole set of HPT blades was sent back to the engine manufacturer for further analysis.

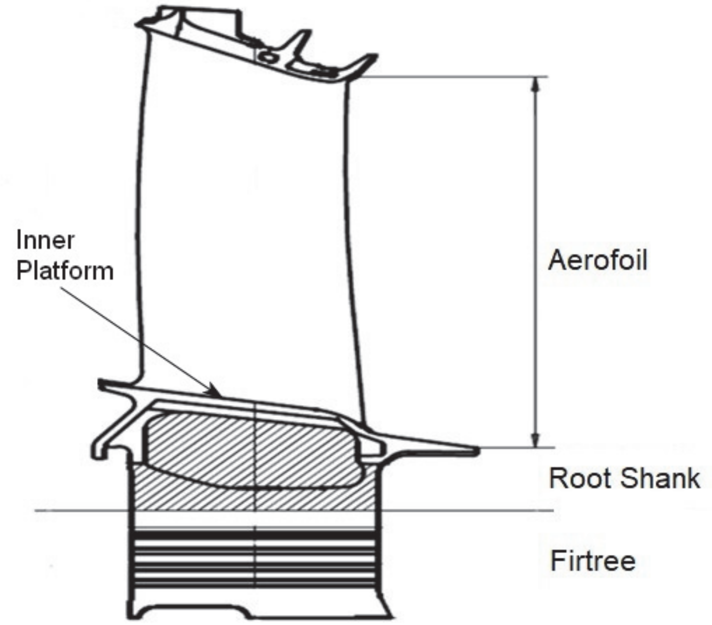

Figure 5: High-pressure Turbine Blade

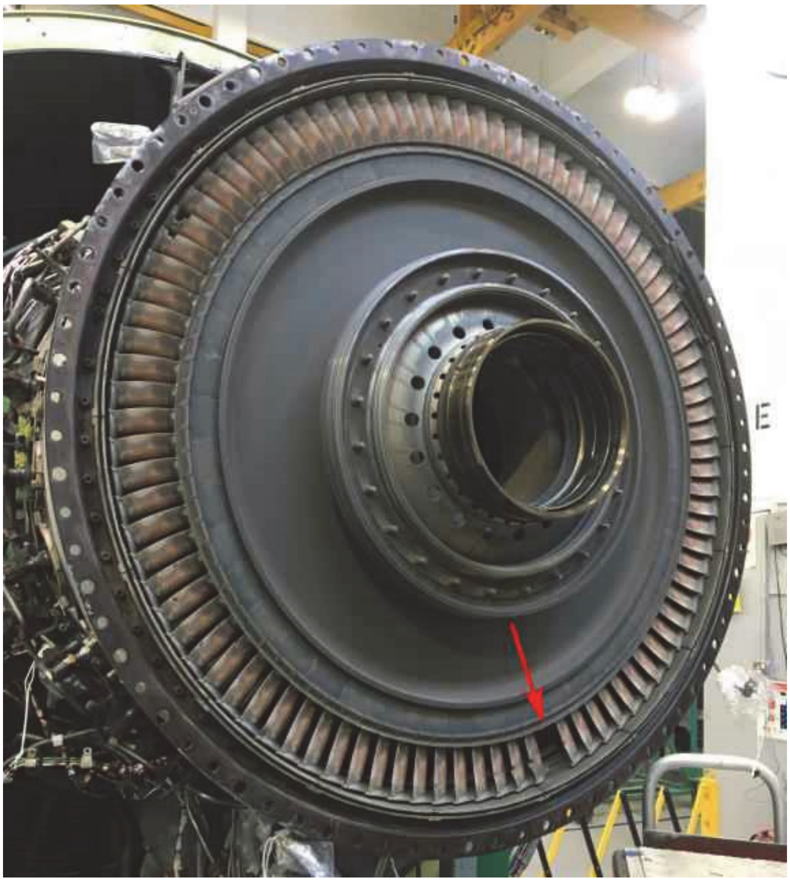

Photo 1: Rear Face of the HPT Rotor Assembly

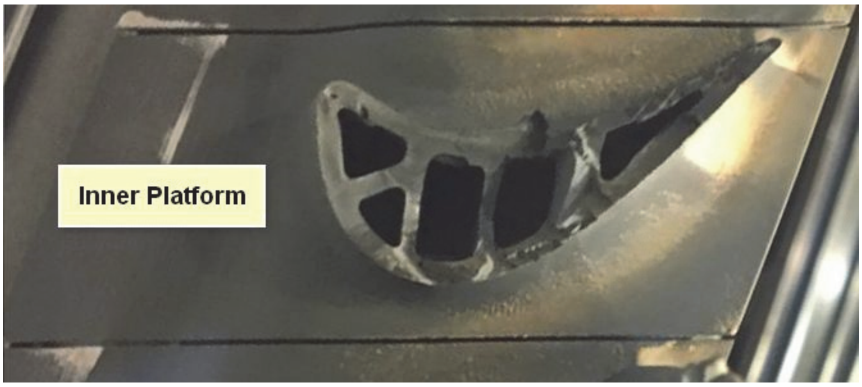

Photo 2: Close-up of the Released HPT Blade

1.13. Medical/Pathological Information

Both pilots were uninjured.

1.14. Smoke, Fire, and Fumes

There was neither fire nor fuel leakage.

1.15. Survival Aspects

The aircraft landed at runway 07L at 2151 hrs and vacated the runway. The pilot reported all operations were under control and no Airport Fire Contingent assistance was required. The aircraft taxied to bay N142 without further incident. The passengers disembarked in a normal manner.

1.16. Tests and Research

No specific tests or research were required to be conducted as a result of this occurrence.

1.17. Organisation, Management, System Safety

1.17.1. Civil Aviation Department

Civil Aviation Department (CAD) regulates Cathay Pacific Airways (CPA) as an Air Operator Certificate (AOC) holder and a maintenance organisation based on the Air Navigation (Hong Kong) Order 1995 (Cap. 448C). CAD is the regulatory authority responsible for the registration and operation of the incident aircraft.

1.17.2. European Union Aviation Safety Agency

European Union Aviation Safety Agency (EASA) is the regulatory authority responsible for the airworthiness and environmental certification of all aeronautical products, parts, and appliances designed, manufactured, maintained or used by persons under the regulatory oversight of EU Member States. It carries out the functions and tasks of the State of Design and State of Manufacture of Airbus A330 aircraft and the State of Design of Rolls-Royce Trent 700 engine.

1.18. Additional Information

1.18.1. Type I and Type II Hot Corrosion[1]

(1) Aircraft gas turbine engine generally uses excessive amounts of air for combustion with a typical air-to-fuel ratio about 100 to 1 at cruising speed. The air-to-fuel ratio corresponds to about 0.12 to 0.18 mole fractions of oxygen in the combustion zone which makes the combustion gas atmosphere highly oxidizing.

(2) The HPT blade in the engine operates under the most demanding conditions of temperature and stress than any component in the engine. The blade experiences not only high temperature and direct stress, but also rapid temperature transients at various points during the engine cycle. The hot gases surrounding the blade are highly oxidizing and contain contaminants like sulphur and chlorine.

(3) During the combustion process, sulphur from the fuel and sodium chloride from ingested air react at high temperatures to form sodium sulphate. The sodium sulphate then deposits on the hot-section components, such as turbine blades, resulting in accelerated sulphidation attack[2]. This is commonly known as 'hot corrosion'.

(4) There are Type I and Type II sulphate-induced hot corrosion. Type I hot corrosion takes place above the melting point of sodium sulphate, generally 800 to 950°C, or 1,470 to 1,740°F. It is believed that the molten sodium sulphate deposit is required to initiate hot corrosion attack.

(5) Type II hot corrosion occurs below the melting point of sodium sulphate, typically 670 to 750°C, or 1,240 to 1,380°F. It is characterised by pitting attack with little or no internal attack underneath the pit.

[1] George Y. Lai, *High-Temperature Corrosion and Materials Applications*, Chapter 9 *Hot Corrosion in Gas Turbines*, ASM International

[2] Sulphidation is the reaction between a metal and a sulphur/oxygen-containing atmosphere to form sulphides and/or oxides. Sulphidation attack is a form of accelerated oxidation resulting in rapid degradation of the substrate material due to loss of corrosion protection.

1.18.2. Corrosion Fatigue

Corrosion fatigue is the sequential stages of metal damage, namely cracking and fracturing, that evolve with accumulated load cycling in a deleteriously chemical environment. Corrosion fatigue damage accumulates with increasing load cycle count (high cycle fatigue and low cycle fatigue) and in four stages: (1) cyclic plastic deformation, (2) micro-crack initiation, (3) small crack growth to linkup and coalescence, and (4) macro-crack propagation.[3]

1.18.3. Phased Array Ultrasonic Testing

(1) Ultrasonic testing (UT) is a non-destructive testing (NDT) method commonly used in the aviation industry. Conventional UT uses single-element transducers or paired element transducers, one for transmitting and one for receiving, to generate and receive ultrasonic sound waves.

(2) Comparing with conventional UT, phased array UT transducers have 16 to 256 individual elements. The utilization of multiple elements on a single transducer provides the inspection system flexibility to electronically control parameters such as focal point, beam size, and incidence angle by pulsing elements in groups to create the desired beams that can be steered, scanned, swept, and focused electronically for fast inspection, full data storage, and multiple angle inspections.

(3) The ability for phased array UT to digitally control numerous ultrasonic elements simultaneously has greatly improved flaw detection and flaw visualization over conventional UT methods.[4]

1.18.4. Rolls-Royce Alert Service Bulletin

(1) Rolls-Royce issued alert non-modification service bulletin (NMSB) RB.211−72−AK165 (*Trent 700 Management of High-pressure Turbine Blades*) on 31 October 2018 to deal with the corrosion fatigue issues of the HPT blades. The SB identified two groups of specific engines to be removed from service for HPT blades replacement by specified dates.

(2) In addition, the NMSB instructed that, from 1 May 2019, HPT blade component life was not to exceed 3,500 flight cycles (for Group 1 engines) or 5,800 flight cycles (for Group 2 engines).

[3] Richard P. Gangloff, *Environmental Cracking - Corrosion Fatigue*
[4] https://www.olympus-ims.com/en/ndt-tutorials/phased-array/

1.18.5. EASA Airworthiness Directive

EASA issued Proposed Airworthiness Directive (PAD) No. 18-161 on 27 November 2018 notifying that they were in the process of issuing an airworthiness directive (AD) 2018-0291 to make NMSB RB.211−72−AK165 mandatory for worldwide operators of specific Trent 700 engines. The AD was formally issued on 21 December 2018 and became effective on 4 January 2019.

1.18.6. CAD Mandatory Occurrence Reporting Scheme

(1) Article of 86 of Air Navigation (Hong Kong) Order 1995 (Cap. 448 sub. leg. C) requires certain categories of persons (or organisations), such as operator or pilot, make a report to the Chief Executive of Hong Kong (in practice to the Director-General of Civil Aviation) of any reportable occurrence as specified in Cap. 448C. CAD monitors these reports through a mandatory occurrence reporting (MOR) scheme and uses the reported information to improve the level of flight safety. Guidance and information on the scheme is published in CAD 382 (The Mandatory Occurrence Reporting Scheme).

(2) The objectives of the MOR Scheme are as follows:

(a) To ensure that the Director-General is advised of hazardous or potentially hazardous incidents and defects (hereafter referred to as occurrences).

(b) To enable knowledge of these occurrences to be disseminated so that other persons and organisations may learn from them.

(c) To enable an assessment to be made by those concerned (whether inside or outside the CAD) of the safety implications of each occurrence, both in itself and in relation to previous similar occurrences, so that they may take or initiate any necessary action.

(3) CPA submitted an MOR to CAD on this engine failure incident in accordance with CAD 382 on 2 February 2018.

1.18.7. Extended Diversion Time Operations

(1) The International Civil Aviation Organization (ICAO) use the acronym ETOPS (Extended Twin Operations) for the operation of twin-engined aircraft over a route that contains a point further than one hour's flying time from an adequate airport at the approved one-engine inoperative cruise speed.

(2) In 2012, ICAO amended Annex 6 (Operation of Aircraft) Part I to introduce the Extended Diversion Time Operations (EDTO) regime in place of ETOPS. EDTO means any operation by an aeroplane with two or more turbine engines where the diversion time to an en-route alternate aerodrome is greater than the threshold time established by the State of the Operator.

(3) The ICAO requirements and recommendations are contained in ICAO Annex 6 Part I Chapter 4 Section 4.7. Further guidance is published in Attachment C to the Annex (Guidance for operations by turbine-engined aeroplanes beyond 60 minutes to an en-route alternate aerodrome including Extended Diversion Time Operations (EDTO)), ICAO Doc 9760 *Airworthiness Manual*, and ICAO Doc 10085 *Extended Diversion Time Operations (EDTO) Manual*.

1.18.8. CAD EDTO Requirements

(1) CAD 360 (Air Operator's Certificates) is a document published by CAD and contains the administrative procedure for the issue and variation of AOCs and the requirements to be met by applicants and certificate holders in respect of equipment, organisation, staffing, training and other matters affecting the operation of aircraft. CAD 360 Part One is about Operation of Aircraft and Part Two is about the arrangements for maintenance support, including the requirements on reliability programmes and system reliability monitoring for the AOC holders' fleet.

(2) CAD 360 further refers to CAD 513 (Extended Diversion Time Operations (EDTO) for criteria and requirements by which AOC holders' EDTO will be assessed.

(3) According to CAD 513, the IFSD target rates for the respective diversion time are:

(a) 120 minutes: 0.027 per 1000 engine hours; and

(b) 180 minutes: 0.022 per 1000 engine hours.

(4) The CPA A330 fleet has a 180-minute EDTO Permission granted by CAD. At the time of this event, the IFSD rate of the fleet was zero.

1.18.9. ICAO Doc 10085 *Extended Diversion Time Operations (EDTO) Manual*

1.18.9.1. Propulsion System Reliability and Monitoring

According to ICAO Doc 10085, when reliability data indicate that the applicable IFSD rate of the propulsion system is no longer being met, the civil aviation authority (CAA) should be notified of the corrective measures taken. If the reliability data show a continual degradation below the applicable target reliability level, a substantiated plan for resolution should be submitted and consideration for a reduction in EDTO capability may be warranted.

1.18.9.2. Tracking of Engine Reliability

(1) The engine reliability should be tracked at two levels:

(a) by the manufacturers and the State of Design as part of the continued airworthiness surveillance of a given AEC (worldwide fleet). The goal of this tracking is to ensure that the EDTO capability of a given AEC is demonstrated and maintained;

(b) by the EDTO operator and its CAA for the fleet (of this operator) of a given AEC. The goal of this tracking is to provide an indicator, but not the only indicator, of the reliability of the concerned operators' EDTO operations.

1.18.9.3. Inflight Shutdown Rate and Monitoring

(1) The commonly retained definition of an inflight shutdown (IFSD) for EDTO is when an engine ceases to function (when the aeroplane is airborne) and is shutdown, whether self-induced, flight-crew initiated or caused by an external influence. Typical examples of engine inflight shutdown causes retained for the computation of the IFSD rate are: flameout, internal failure, flight-crew initiated shutdown, foreign object ingestion, icing, inability to obtain or control desired thrust or power, and cycling of the start control, however briefly, even if the engine operates normally for the remainder of the flight.

(2) The IFSD rate is a statistical indicator and precursor commonly used to assess the reliability of the concerned engine model versus the target rate set by applicable regulations. It is a reliability figure calculated by dividing the chargeable number of inflight shutdowns by the total engine operating hours accrued during the same period. The IFSD rate is usually computed over a 12-month rolling average basis for the concerned AEC; it is, therefore, the count of IFSD(s) over the total engine hours cumulated during the last 12 months.

(3) The State of Design monitors the IFSD rate computed for the worldwide fleet of the concerned AEC to assess its EDTO capability. The CAA of the operator monitors the IFSD rate computed by the operator for its fleet of the concerned AEC as part of the continued reliability assessment of the concerned operators' EDTO operations.

(4) The IFSD alert levels should be provided in the applicable national regulations, which are typically defined for a given maximum diversion time (e.g. 120, 180 minutes and beyond 180 minutes).

1.18.9.4. Continued Validity of EDTO Certification

According to ICAO Doc 10085, the EDTO certification is not granted permanently. It is subject to continued surveillance (airworthiness monitoring) by the State of Design of the in-service reliability of the worldwide fleet of the concerned aircraft/engine combination. This reliability surveillance may result in changes to the EDTO standards for the airframe or engines by means of service bulletins issued by the aircraft and engine manufacturers and maintenance or procedures mandated to restore the reliability. If no solution exists to a major problem, the certified EDTO capability of the aircraft may therefore be reduced, suspended or even revoked.

1.18.10. Rolls-Royce Total Care Programme

(1) Rolls-Royce Total Care programme for airline operators is power-by-the-hour long-term service agreements charged on a fixed amount of money per flying hour basis. Large amounts of engine performance data are gathered under the Total Care and analysed for close monitoring of engine health and reliability.

(2) All the A330/Trent 700 operators in Hong Kong enrolled into this Programme at the time of the incident. The engine performance data is monitored by RR.

1.18.11. Other Terms Used in this Report

The following terms were used in RR's updates to the regulatory authorities and the operators and in this report.

1.18.11.1. Inflight Shutdown Rate

(1) The IFSD rate is a reliability figure which is the count of IFSD(s) over the total engine hours cumulated during the last 12 months over a rolling average basis for the concerned AEC.

(2) The IFSD rate may be computed for the worldwide fleet of the concerned AEC; this is the rate monitored by the State of Design to assess the EDTO capability of a given AEC.

(3) The IFSD rate should also be computed by the operator for its fleet of concerned AEC; this is the rate that may be considered by the CAA as part of the continued reliability assessment of the concerned operators' EDTO operations.

(4) Individual operators may have IFSD rate significantly different from that of the worldwide fleet due to specific operations, etc.

(5) RR uses IFSD rate as a precursor to establish whether they need to assess the Dual Inflight Shutdown (DIFSD) rate and hazard rate to determine if an unsafe condition is present and mandatory occurrence reporting is required.

1.18.11.2. Dual Inflight Shutdown Rate

(1) Dual Inflight Shutdown is considered to be a catastrophic failure which would result in multiple fatalities, usually with the loss of the aeroplane. If the mean fleet rate of catastrophic events exceeds $1x10^{-9}$ /acfh (aircraft flying hour), then mandatory corrective action has to be carried out.

(2) The Dual Inflight Shutdown rate is calculated directly from the square of IFSD rate which varies between different operators.

1.18.11.3. Maximum Individual Aircraft Risk

The maximum individual aircraft risk is $2x10^{-6}$ Catastrophic events in terms of probability. Individual aircraft having a risk beyond this limit must be grounded and corrective action implemented.

1.18.11.4. Maximum Risk Limit / Mean Accrued Risk

For a Catastrophic Event, this equates to 0.1 Catastrophic Events across the fleet, or a mean of $1.5x10^{-4}$ Catastrophic events per aircraft (the use of either limit depends on the size of the fleet). Once a fleet is identified as being above the Continued Airworthiness Threshold of $1x10^{-9}$ /acfh then it begins to accrue risk, this accrued risk is compared against both the 0.1 Catastrophic Events and $1.5x10^{-4}$ limits, the more restrictive reaction time to each limit is then used as the allowable time to implement mandatory corrective action.

1.18.11.5. Mean Fleet Hazard Rate

If the mean fleet hazard rate exceeds the threshold of $1x10^{-8}$ /efh[5], then mandatory corrective action has to be carried out.

1.18.12. Recurrent Flight Training and Proficiency Check

(1) Every six months, all CPA pilots undergo recurrent training in flight simulator which may involve handling of engine failure at some stage of the simulated flight. Such recurrent training is supervised by CAD Approved Person.

(2) The flight crew are also required to undergo a Proficiency Check conducted by an Authorised Examiner in flight simulator every six months for the renewal of pilot's aircraft rating and instrument rating. The handling of engine failure or engine fire is included in every Proficient Check.

(3) The Recurrent Training and Proficiency Check are staggered such that every pilot will be able to practise the handling of inflight emergency and non-normal situations in the simulator approximately every three months.

1.19. Useful or Effective Investigation Techniques

Not applicable.

[5] EASA CS-E (Easy Access Rules for Engines (Amendment 5)) 510 Safety Analysis (a)(3): For Engine certification, it is acceptable to consider that the intent of this paragraph is achieved if the probability of a Hazardous Engine Effect arising from an individual Failure can be predicted to be not greater than 10^{-8} per Engine flight hour (see also CS-E 510(c)).

2. Safety Analysis

The Safety Analysis provides a detailed discussion of the safety factors identified during the investigation.

2.1. Introduction

(1) After engine strip-down, the HPT blade at position 64 was found fractured in the aerofoil, just above the inner platform. Only the inner platform and root section remained in the turbine disc.

(2) The safety analysis will examine the flight operations, the details of the crack and its formation, the assessment against unsafe condition, risk reduction, and regulatory oversight.

2.2. Flight Operations

This incident was not related to operations issues.

2.3. Engineering

2.3.1. Aircraft Maintenance

The maintenance records indicated that the aircraft was equipped and maintained in accordance with existing regulations and approved procedures, indicating that the aircraft had no outstanding defects prior to the incident flight.

2.3.2. Metallurgical Analysis of HPTB Release

(1) The fractured blade exhibited primary corrosion initiation from the exterior of the concave aerofoil which transited into High Cycle Fatigue (HCF) and incidental release of the blade. Energy-dispersive X-ray spectroscopy (EDX) analysis found Calcium-Sulphur rich layer on the exterior of the blade. Small levels of corrosion were also found in the internal passages.

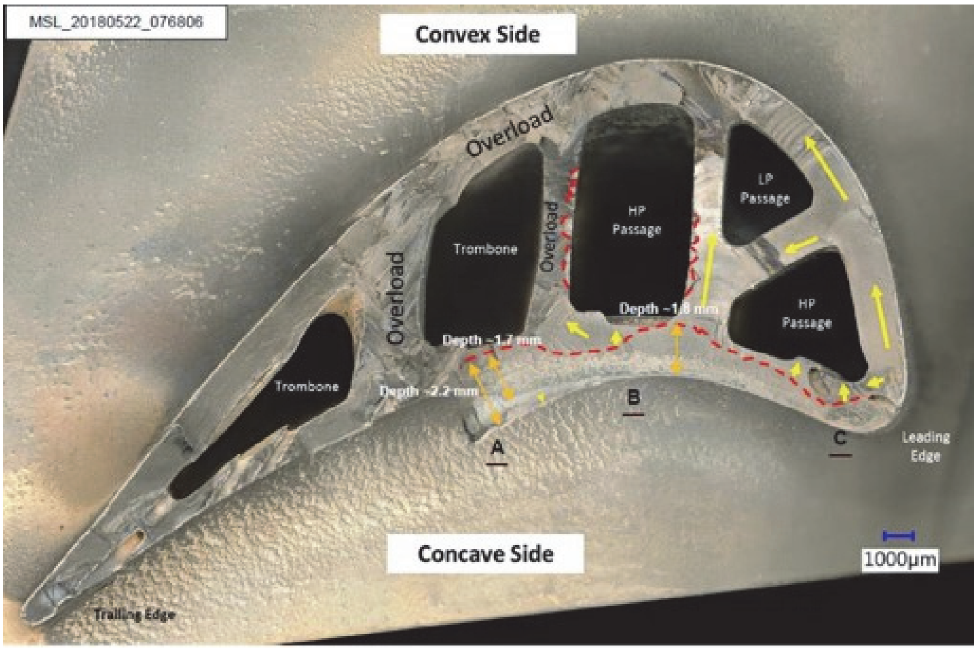

Photo 3: Close-up of the Fractured Blade

Photo 4: The Remaining Firtree and Shank

(2) The failure mode was corrosion cracks in the aerofoil exterior which transited into High Cycle Fatigue and incidental release of the blade. The primary corrosion initiation was considered to be from the concave aerofoil exterior. Sulphates stuck to the blade shank and melt at temperature resulting in chemical attack on the protective oxide on the blade surface. The crack propagation was chemically driven.

(3) The corrosion was associated with Type 1 sulphidation as the temperature of the annulus gas blowing on the aerofoil surface was in the range of 800°C. The root shank pocket was more effectively cooled by HP 6 air and its operating temperature would be susceptible to Type 2 sulphidation.

(4) Up to June 2018, there were 18 worldwide events confirmed sulphidation attack at fracture surface.

(5) According to RR's analysis, different operators have different levels of HPT blade sulphidation. Different engines of the same operator have different levels of the corrosion. Engines paired on the same aircraft also have different levels.

2.4. Assessment against Unsafe Condition

2.4.1. Numerical Risk Assessment

(1) RR undertook Numerical Risk Assessment (NRA) to assess against Probability of Hazardous or Catastrophic events of the complete Trent 700 fleet, CPA and its sister company's fleet, and another Hong Kong operator's fleet. Failure effects were assessed for hazards of High Energy Debris and DIFSD which are catastrophic.

(2) NRA has two main factors:

(a) HPT blade failure rate - Sub fleets (individual or group of operators with similar operating environment) have higher rate than homogeneous fleet.

(b) Ratio of HPT blade failure rate to Hazard rate - Same rate applied to any assessment.

2.4.2. Dual Inflight Shutdown Rate

(1) Prior to issue of NMSB 72-AK165 the DIFSD rate was shown to be below the Continued Airworthiness Threshold for the worldwide Trent 700 fleet (and all sub-fleets). Hazard rate was also shown to be below the Continued Airworthiness Threshold for the worldwide fleet, but was above the Continued Airworthiness Threshold for some specific sub-fleets (including Hong Kong based operators). Mandatory action was therefore taken in the form of NMSB issue and the associated EASA AD.

(2) Subsequent analysis has shown that mandatory action is no longer required. However, the life limitations set out in the NMSB will remain in place until blade modification has been embodied on the specific engine groups.

(3) At the time of writing this report, the Trent 700 worldwide fleet and all sub-fleets remain below the Continued Airworthiness Threshold for both DIFSD rate and Hazard rate.

2.4.3. Obtaining the DIFSD Rate and Hazard Rate for Individual Operators

(1) Whether an operator enrols onto the RR Total Care programme or not, engine reliability data is still collected and analysed by RR. Any related fleet safety advice or recommendations will apply equally to all operators regardless of the type of service agreement that is in place. Operators with engine and reliability experts are in a better position to understand how RR uses the rates to monitor the safe operation of the engines and proactively interact with RR in reliability monitoring.

(2) For operators with less technical competence, they may not be so familiar with the DIFSD rate and the hazard rate and what these rates may mean for the safe operations of their fleet.

(3) DIFSD and hazard rate are not monitored by Rolls-Royce and are only calculated when the IFSD rate becomes unacceptably high, to determine if an unsafe condition is present.

2.4.4. Oversight by CAD

(1) CAD published requirements and guidance in CAD 360 and CAD 513 on reliability of aircraft and engine. Operators are required to arrange scheduled reliability review meetings with the participation of CAD.

(2) The IFSD rate is a key reliability indicator used by the manufacturer to demonstrate the fleet health and continued ability to support the established ETOPS (EDTO).

(3) Operators also need to monitor their IFSD rate to maintain ETOPS (EDTO) compliance and acceptable levels of aviation safety.

2.5. Risk Mitigation of Blade Fracture

Typically, the mitigation to the risk of blade fracture of this nature includes design change, maintenance action, and operation limitation.

2.5.1. Design Change - Modification of HPT Blade

To improve HPTB reliability, RR has developed a modified HPT blade by introducing a revised blade shank coating. The diffused platinum coating on the current standard of blade is being replaced with a pack aluminised coating to offer enhanced protection against oxidation and sulphidation. This design change will be introduced under Service Bulletin SB 72-K414. RR advised that the SB would be introduced later in 2021. This is one of the effective means of managing the risk.

2.5.2. Maintenance Actions

2.5.2.1. New Inspection Technique

(1) As an additional risk mitigation activity, RR has initiated a review of available inspection techniques to establish if there is a viable technique for on-wing HPTB inspection.

(2) Phased Array UT inspection techniques have been successfully developed for use on other RR engine types and components. The application of this technique on the Trent 700 HPTB has therefore been explored. However, after a number of unsuccessful trials the development of a phased array inspection technique for the HPT blade root shank has been stopped. It is because the material and geometry of the blade make this type of inspection almost impossible with the current phased array technology.

2.5.2.2. Enhancement of Inspection Procedures

To improve awareness for inspectors, Aircraft Maintenance Manual (AMM) task reference 72-00-200-814-A has been improved to specifically identify the location on the blade where cracking can be seen. Notice To Operators (NTO) 276 has also been issued to increase operators' awareness of this issue and to provide a visual example of a cracked blade. This is one of the effective means of managing the risk.

2.5.3. CFL Model for Prediction of High Risk Engines

(1) RR constructed an operator specific Corrosion Fatigue Lifing (CFL) model using specific operational data including selected engine parameters, likely contaminant exposure (city pairs and exposure during assumed flight path), and time at take-off condition. The CFL model was an additional risk mitigation measure being used to predict expected levels of corrosion damage. The aim was to identify specific engines at risk of corrosion for removal and blade change to improve general fleet reliability.

(2) However, during the continual development of the CFL model, the validation activities did not give a result which would permit the use for additional risk reduction to help predict expected levels of corrosion damage and as such its development is no longer being progressed.

2.5.4. Revised HPT Blade Life

(1) Before the incident, the HPT blades would be replaced before accumulating 6,000FC or every engine refurbishment shop visit. According to RR's investigation, at least 380 engines completed 5,500 to 6,000FC without HPTB failure, and there was only one failure in this life range.

(2) After RR issued alert NMSB RB.211−72−AK165, which was mandated by EASA AD 2018-0291, the schedule for HPT blades replacement has been reduced to 5,800 FC based on RR's data analysis. This is one of the effective means of managing the risk.

(3) The design change mentioned in 2.5.1 will be the terminating action for the life limitations on Group 2 blades of this NMSB.

2.5.4.1. Effectiveness of Risk Mitigation Measures

At the time of this report, the shortening of HPT blade life is considered to be an effective means of risk mitigation before the modified standard of HPTB is available for the affected engine groups.

2.5.5. Operation Limitation

(1) At the time this incident occurred, the IFSD rate of the RR A330 fleet was 0.011 and below the EDTO limit. Even though this inflight shutdown happened, the IFSD rate was lower than the target rate published by CAD for 180 min EDTO operation.

(2) In addition, according to RR's analysis, the CPA A330 fleet was still appropriate for the 180 min EDTO operation. Therefore, no additional operation limitation was imposed.

2.6. Follow-up under CAD MOR Scheme

2.6.1. Reporting by CPA

CPA submitted an MOR to CAD on this engine failure incident in accordance with CAD 382 on 2 February 2018. After that, there were a series of meetings among CPA, CAD, and EASA about the update of the investigation by RR, the mitigation of risks and the permanent solutions to the technical issues. CAD also disseminated safety information to all other operators of A330 with Rolls Royce engines in Hong Kong and invited them to join the meetings with EASA.

2.6.2. CAD Communication with EASA

(1) After the incident, CAD, together with RR and Hong Kong A330/Trent 700 operators, had four tele-conferences with EASA to follow up the investigation and the technical issues. In one of the tele-conferences, RR updated the progress of the corrective actions including HPT blade Modification (originally planned by Q4 2018), Inspection Technique Improvement (originally planned by mid-2019) and the use of the CFL model to identify high-risk engines from services. As a safety measure,

RR suggested HK Operators to remove some "high-risk" Trent 700 engines identified during RR's investigation.

(2) On regulatory actions, EASA advised that they continued their work with RR on the sulphidation issue and expected to come up with an action plan by end of August 2018.

2.6.3. The MOR Process

The MOR process was gone through as per Article 86 of Cap. 448C and CAD 382 guidance materials. After accepting the mitigation by RR and CPA, CAD closed the MOR on 24 December 2018.

2.7. EDTO Permission for CPA

(1) The CPA A330 fleet has an EDTO Permission granted by CAD. At the time of this event, the IFSD rate of the fleet was zero.

(2) Hong Kong operators provide CAD with IFSD rate regularly for monitoring. CAD attends operators' Monthly Reliability Meeting which includes agenda items on the reliability, including IFSD rate, of all fleets.

(3) This event was not related to the IFSD rate or oversight by the CAD.

3. Conclusions

3.1. Findings

(1) The aircraft was certified, equipped and maintained in accordance with the existing regulations. (1.6.4, 1.6.5, and 2.3.1)

(2) The A330/Trent 700 aeroplane/engine combination was capable for ETOPS. (1.6.3)

(3) The operator held EDTO Permission for 180 min diversion time granted by CAD. At the time of the incident, the IFSD rate of CPA's A330 fleet was within the approval limits. [1.18.8 (4) and 2.5.5]

(4) The flight crew were licensed and qualified for the flight in accordance with the existing regulations. [1.5 (2)]

(5) The weather conditions were within the limits for the flight. (1.7)

(6) One HPT blade fractured due to Type 1 sulphidation corrosion and high cycle fatigue. [1.12.1, 2.3.2 (2), and 2.3.2 (3)]

(7) After the incident, RR issued an NMSB RB.211−72−AK165 (Trent 700 Management of High-pressure Turbine Blades) to reduce the life limits of the HPT blade. [1.18.4 (1), 1.18.4 (2), and 2.5.4 (2)]

(8) EASA issued an AD 2018-0291 to mandate the NMSB. (1.18.5)

(9) The operator reported the occurrence to CAD as an MOR which was processed by CAD in accordance with CAD 382. [1.18.6 (3)]

(10) Individual operators may have IFSD rate significantly different from that of the worldwide fleet due to specific operations, etc. [1.18.11.1 (4)]

(11) RR advised that SB 72-K414 for introduction of a revised blade shank coating would be introduced later in 2021. (2.5.1)

(12) The material and geometry of the blade make the Phased Array UT technique for the inspection almost impossible with the current phased array technology. [2.5.2.1 (2)]

(13) The CFL model validation activities did not give a result which would permit the use for additional risk reduction to help predict expected levels of corrosion damage and as such its development is no longer being progressed. [2.5.3 (2)]

(14) The pending root shank coating change, the enhanced inspection procedures on the aerofoil and the existing HPT blade life limitations set out in NMSB 72-AK165 are the effective means of managing the risk of blade failure. The root shank coating change will be the terminating action for the life limitations on Group 2 blades of NMSB RB.211−72−AK165. [2.5.1, 2.5.2.2, 2.5.4 (2), and 2.5.4 (3)]

(15) RR uses IFSD rate as a precursor to establish whether they need to assess the DIFSD and hazard rate to determine if an unsafe condition is present and mandatory occurrence reporting is required. [1.18.9.3 and 1.18.11.2 (2)]

(16) The failure mode of the HPT blade fracture was corrosion cracks in the aerofoil exterior which transited into High Cycle Fatigue and incidental release of the blade. [2.3.2 (2)]

3.2. Cause

The IFSD was due to HPT blade fracture caused by sulphidation corrosion and High Cycle Fatigue. [3.1 (6)]

4. Additional Safety Issues

(1) Whether or not the AAIA identifies safety issues in the course of an investigation, relevant organisations may initiate safety action in order to reduce their risks.

(2) The AAIA has been advised of the following safety action in response to this occurrence.

4.1. Actions Taken by Rolls-Royce

(1) RR advised that NMSB RB.211−72−AK165 (Trent 700 Management of High-pressure Turbine Blades) was issued on 31 October 2018 to identify specific engines which required early removal and to reduce the life of the HPT blade. This included all engines operated by affected Hong Kong based operators.

(2) Aircraft Maintenance Manual (AMM) task reference 72-00-200-814-A has been improved to specifically identify the location on the blade where cracking can be seen. Notice To Operators (NTO) 276 has also been issued to increase operators' awareness of this issue and to provide a visual example of a cracked blade.

(3) RR has developed a modified HPT blade by introducing a revised blade shank coating. This design change will be introduced under Service Bulletin SB 72-K414 later in 2021.

4.2. Actions Taken by EASA

EASA issued an airworthiness directive (AD) 2018-0291 to make NMSB RB.211−72−AK165 mandatory for worldwide operators of specific Trent 700 engines. The AD was issued on 21 December 2018 and became effective on 4 January 2019.

4.3. Actions Taken by CAD

(1) CAD advised that on receipt of the MOR submitted by the operator, they followed up and coordinated with all other operators of A330 with RR engines in Hong Kong. CAD also had a series of meetings with RR and/or EASA.

(2) The outcome of the discussion made from the meetings enabled Hong Kong A330 operators to remove some "high-risk" engines as identified by RR. With the productive discussion amongst the relevant parties, EASA subsequently issued an AD (Ref. 2018-0291) on 21 December 2018.

5. Safety Recommendations

In consideration of the actions already taken by EASA, Rolls-Royce, and CAD, no further safety recommendation is proposed.

6. General Details

6.1. Occurrence Details

Date and time:	1 February 2018, 2100 hours (local time)
Occurrence category:	Incident
Primary occurrence type:	SYSTEM/COMPONENT FAILURE OR MALFUNCTION (POWERPLANT)
Location:	Hong Kong International Airport

6.2. Pilot Information

6.2.1. Pilot in Command

Age:	55 years
Licence:	Airline Transport Pilot's Licence (Aeroplanes)
Aircraft ratings:	A330
Date of first issue of aircraft rating on type:	2 November 2017
Instrument rating:	Yes
Medical certificate:	Class 1, valid till 30 June 2018
Date of last proficiency check on type:	2 November 2017
Date of last line check on type:	17 January 2018
Date of last emergency drills check:	August 2017
ICAO Language Proficiency:	Perpetual
Limitation:	Corrective lenses are required
Flying Experience:	
Total all types:	17 197 hours
Total on type (A330) :	184 hours
Total in last 90 days:	98 hours
Total in last 30 days :	118 hours 44 minutes
Total in last 7 days:	30 hours 56 minutes

Total in last 24 hours:	0 hours
Duty Time:	
Day up to the incident flight (Hours:Mins) :	0 hours
Day prior to incident (Hours:Mins) :	0 hours

6.2.2. First Officer

Age:	50 years
Licence:	Airline Transport Pilot's Licence (Aeroplanes)
Aircraft ratings:	A330, A350
Date of first issue of aircraft rating on type:	A330 30 Sep 2007 P2X, 11 Aug 2011 P1 A350 7 Sep 2016
Instrument rating:	Yes
Medical certificate:	Class 1, valid till 28 February 2018
Date of last proficiency check on type:	30 Oct 2017
Date of last line check on type:	24 Dec 2017
Date of last emergency drills check:	8 Feb 2017
ICAO Language Proficiency:	Level 6
Limitation:	Nil
Flying Experience:	
Total all types:	11 621 hours
Total on type (A330) :	6 015 hours
Total in last 90 days:	251 hours (A330 & A350)
Total in last 30 days :	94 hours 49 minutes
Total in last 7 days:	20 hours 34 minutes
Total in last 24 hours:	8 hours
Duty Time:	
Day up to the incident flight (Hours:Mins) :	0 hours
Day prior to incident (Hours:Mins) :	0 hours

6.3. Aircraft Details

Manufacturer and model:	Airbus, A330-343	
Registration:	B-HLN	
Aircraft Serial number:	389	
Year of Manufacture:	2001	
Engine:	Two (2) Rolls Royce Trent 772B-60 turbofan engines	
Propeller:	Not Applicable	
Operator:	Cathay Pacific Airways	
Type of operation:	Public Transport of Passenger	
Certificate of Airworthiness:	Issued on 10 February 2017 in the Transport Category (Passenger) and valid until 22 February 2018	
Departure:	Hong Kong International Airport	
Destination:	Hong Kong International Airport	
Maximum Approved Gross Weight:	233,000 kg	
Total Airframe Hours:	58,513 hours	
Persons on board:	Crew (flight + cabin) – 2 + 11	Passengers – 271 + 1 infant
Injuries:	Crew (flight + cabin) – 0	Passengers – Nil
Aircraft damage:	Left engine internal damage caused by release of one high-pressure turbine blade	
Left engine hours / cycles	20,066 flying hours / 4,948 flying cycles	

6.4. Aerodrome Information

Aerodrome Code	VHHH
Airport Name	Hong Kong International Airport
Airport Address	Chek Lap Kok, Lantau Island
Airport Authority	Airport Authority Hong Kong
Air Navigation Services	Approach Control, Aerodrome Control, Ground Movement Control, Zone Control, Flight Information Service, Clearance Delivery Control, Automatic Terminal Information Service
Type of Traffic Permitted	IFR/VFR
Coordinates	22° 18' 32" N, 113° 54' 53" E
Elevation	28 ft
Runway Length	3,800 m
Runway Width	60 m
Stopway	Nil
Runway End Safety Area	240 m x 150 m
Azimuth	07L / 25R, 07R/ 25L
Category for Rescue and Fire Fighting Services	CAT 10

7. Abbreviations

AAIA	Air Accident Investigation Authority
acfh	Aircraft flying hour
AEC	Aeroplane/engine combination
AMM	Aircraft Maintenance Manual
Annex 13	Annex 13 to the Convention on International Civil Aviation
AOC	Air Operator Certificate
CAA	Civil aviation authority
CAD	Civil Aviation Department, Hong Kong
CAP. 448B	Hong Kong Civil Aviation (Investigation of Accidents) Regulations
CAP. 448C	Air Navigation (Hong Kong) Order 1995
CFL	Corrosion fatigue lifing
CMP	Configuration, Maintenance and Procedures
CPA	Cathay Pacific Airways
DFDR	Digital Flight Data Recorder
DIFSD	Dual Inflight Shutdown Rate
EASA	European Aviation Safety Agency
ECAM	Electronic centralised aircraft monitors
EDTO	Extended Diversion Time Operations
EDX	Energy-dispersive X-ray spectroscopy
efh	Engine flying hour
EFIS	Electronic flight instrumentation system
ETOPS	Extended Range Operations
EWD	Engine/Warning display
FSD	Fire Services Department
HCF	High Cycle Fatigue
HKO	Hong Kong Observatory
HP	High-pressure
HPT	High-pressure turbine (HP turbine)
ICAO	International Civil Aviation Organization
IFSD	Inflight shutdown
IIC	Investigator-in-charge

IP	Intermediate-pressure
LP	Low-pressure
MOR	Mandatory occurrence reporting
NDT	Non-destructive testing
NMSB	Non-modification service bulletin
NRA	Numerical Risk Assessment
NTO	Notice To Operators
ºC	Degrees Celsius
°F	Degrees Fahrenheit
PAD	Proposed Airworthiness Directive
PF	Pilot flying
PIC	Pilot in Command
PM	Pilot monitoring
QNH	Q code for regional or airfield pressure setting
RR	Rolls-Royce
SD	System display
UT	Ultrasonic testing
VHF	Very High Frequency

8. Table of Figures, Photos, Tables