DUTCH
SAFETY BOARD

Engine failure during initial climb, Boeing 747-412BCF, Meerssen

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The Hague, April 2023

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Photograph cover: Maastricht Aachen Airport

The Dutch Safety Board

When accidents or disasters happen, the Dutch Safety Board investigates how it was possible for these to occur, with the aim of learning lessons for the future and, ultimately, improving safety in the Netherlands. The Safety Board is independent and is free to decide which incidents to investigate. In particular, it focuses on situations in which people's personal safety is dependent on third parties, such as the government or companies. In certain cases the Board is under an obligation to carry out an investigation. Its investigations do not address issues of blame or liability.

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N.B: This report has been published in the Dutch and English language. If there are differences in interpretation the English report prevails.

CONTENTS

SUMMARY

On Saturday 20 February 2021, a Boeing 747-400 encountered a contained engine failure during the initial climb out from Runway 21 at Maastricht Aachen Airport in the Netherlands. The engine failure caused parts of the engine to exit the tail pipe of the engine and to come down in the village of Meerssen, which is located approximately 2 kilometres south of the end of Runway 21. The engine parts injured two people and damaged property such as houses and cars. After the flight crew had shut down the engine, they diverted to Liege Airport in Belgium, where a safe landing was made.

The Dutch Safety Board conducted an investigation into the cause of this serious incident. This investigation answers the following two questions: (1) What was the cause of the engine failure? (2) In what way is the risk for people on the ground, in relation to departing engine parts, managed?

The reason to investigate the risk for people on the ground is that the Dutch Safety Board had received e-mail messages and letters from residents, expressing safety concerns related to the airport. These letters also addressed that injuries to residents and damage to property had occurred as a result of this occurrence. Furthermore, these residents depend on the government for the way their safety in relation to Maastricht Aachen Airport was managed. The residents experienced the location of the airport as unsafe, because of its positioning between several residential areas and its use by commercial air transport, including heavy freighter aeroplanes. The present serious incident reinforced this feeling of unsafety.

The investigation into this serious incident revealed that the turbine of engine number one of the aeroplane had failed. This engine failure was caused by high gas temperatures that existed for an extended period of time in the high pressure turbine of the engine causing wear and deformation of outer transition duct panels. This resulted in one outer transition duct panel coming loose and one being fractured, which subsequently caused severe damage to the turbine. Consequently, engine debris -turbine parts- exited the tail pipe of the engine and came down in the village of Meerssen.

To prevent the failure of the outer transition ducts and turbine section, several service bulletins have been issued by the manufacturer of the engine since 1993. Also airworthiness directives were issued to ensure the safe working of the engine. These improvements concerned among others additional cooling features for the high pressure turbine and the installation of new outer transition duct panels. The investigation revealed that the engine was equipped with those new panels; however, the engine was not modified with the additional cooling features. Not installing the additional cooling features was the cause of the abovementioned high gas temperature. The installation of these cooling features, as adviced by Service Bulletin 72-462, was not mandatory.

The operator, who had been using the aeroplane in its fleet for three months at the time of the incident, was not able to present the documented reasoning regarding the non-incorporation of Service Bulletin 72-462. The aircraft (engine) was in use by a different operator at the time this service bulletin was published. Therefore, the initial decision whether to (not) embody Service Bulletin 72-462 would have been taken (and should have been recorded) by that operator.

Having an adequate record keeping of maintenance documentation enables the operator and its maintenance organisation to make sound risk management decisions about the continuing airworthiness of their aeroplanes. This is crucial for the safe operation throughout the operating life of, in this case, the engine.

With the convergence of air traffic over areas surrounding airports, there is an increased risk of occurrences in these areas. In this case, the area of convergence runs over the villages of Meerssen, Geverik and Beek. This means that their residents are involuntarily exposed to a risk of departing engine debris, that is likely higher than in other residential areas surrounding the airport. Within aviation, the magnitude of the risk of departing engine debris has not been determined and translated into regulations. The engine failure showed that the hazard of departing engine parts is real, resulting in injured people and damaged property. The present case contributed to the feelings of unsafety of the residents.

Residents around airports are at least exposed to two types of risks: first, parts departing the aircraft and second an accident with an aircraft. Until now, an assessment for residential areas around Maastricht Aachen Airport of the risks of parts departing the aircraft, such as departing engine debris, has not routinely been done. According to the Dutch Safety Board, based on the results of such an assessment an informed decision about the acceptability of these local risks should be made.

RECOMMENDATIONS

The Dutch Safety Board issues the following recommendations:

To Longtail Aviation:

1. Make and keep the record keeping of the (non-)implementation of service bulletins for leased engines of your fleet of commercial air transport aeroplanes complete and accessible.

To United States Federal Aviation Administration:

2. Reconsider whether Service Bulletin 72-462, in light of third party risk, should be made mandatory through an Airworthiness Directive.

To the Minister of Infrastructure and Water Management:

3. Perform and publish an assessment for residential areas around Maastricht Aachen Airport of the risks of parts departing the aircraft, such as departing engine debris.

S. Zouridis
Vice Chairperson Dutch Safety Board

C.A.J.F. Verheij
Secretary Director

ABBREVIATIONS

AAIB	Air Accidents Investigation Branch
AD	Airworthiness directive
AMSL	Above mean sea level
APU	Auxiliary power unit
ATIS	Automatic Terminal Information Service
BCF	Boeing converted freighter
BOAS	Blade outer air seal
°C	Degree Celsius
CVR	Cockpit voice recorder
DAAD	Deviation Acceptance and Action Document
EASA	European Union Aviation Safety Agency
EGT	Exhaust gas temperature
°F	Degree Fahrenheit
FDR	Flight data recorder
FL	Flight level
HPC	High pressure compressor
HPT	High pressure turbine
ICAO	International Civil Aviation Organization
kg	Kilogram
kt	Knots
Lbf	Pound-force
LIDO	Lufthansa Integrated Dispatch Operation
LPC	Low pressure compressor
LPT	Low pressure turbine
MEL	Minimum equipment list
NTSB	National Transportation Safety Board

OPT	Onboard performance tool
OTD	Outer transition duct
PDA	Parts departing aircraft
QNH	Mean sea level pressure
SB	Service bulletin
SID	Standard instrument departure
TCO	Third country operator
UTC	Coordinated Universal Time

GENERAL OVERVIEW

Identification number:	2021007
Classification:	Serious incident
Date, time of occurrence:	20 February 2021, 16.12 hours[1]
Location of occurrence:	Meerssen, the Netherlands
Operator:	Longtail Aviation
Aircraft registration:	VQ-BWT
Aircraft type:	Boeing 747-412 BCF
Aircraft category:	Fixed wing aircraft - freighter
Type of flight:	Scheduled cargo
Phase of flight:	Initial climb
Damage to aircraft:	Internal damage to engine 1
Number of flight crew:	Two (captain and first officer)
Other crew:	One (loadmaster)
Passengers:	None
Injuries:	Two persons on the ground suffered injuries
Other damage:	Damage to cars and houses
Light conditions:	Daylight

1 All times in this report are local times (UTC + 1 hour), unless otherwise specified.

1 INTRODUCTION

On 20 February 2021, a Boeing 747-400 took off from Runway 21 at Maastricht Aachen Airport in the Netherlands. During the initial climb an engine failure occurred. Engine debris came down in the village of Meerssen, causing damage to houses and cars. Two persons on the ground suffered injuries. The flight crew shut down the engine and diverted to Liege Airport in Belgium, where the aeroplane landed safely.

The Dutch Safety Board classified the occurrence as a serious incident, because of the potential for an accident, as the departing engine debris that came down in a village could have seriously injured people, besides the injuries that had taken place. In accordance with the Dutch Safety Board Act and EU regulation No 996/2010[2], the Dutch Safety Board conducted the safety investigation of this serious incident.

This investigation into the engine failure answers the following questions:

(1) What was the cause of the engine failure?
(2) In what way is the risk for people on the ground, in relation to departing engine parts, managed?

The reason to investigate the risk for people on the ground is that the Dutch Safety Board received e-mail messages and letters from residents who expressed their safety concerns and that injuries to residents and damage to property had occurred as a result of this occurrence. Furthermore, these residents depend on the government for the way their safety in relation to Maastricht Aachen Airport is managed. The residents experienced the location of the airport between several residential areas and its use by commercial air transport[3] including heavy freighter aeroplanes, as unsafe. The present serious incident reinforced this feeling of unsafety.

In accordance with ICAO Annex 13[4], the following organisations were involved in the investigation. The Dutch Safety Board represented the state of occurrence. The National Transportation Safety Board (NTSB) represented the state of design and the state of manufacture of the Boeing 747 and the affected Pratt & Whitney PW4056 engine. Further, the NTSB appointed an accredited representative and advisors from Boeing Commercial Airplanes, Pratt & Whitney and the United States Federal Aviation Administration. The Air Accidents Investigation Branch (AAIB) represented the state of the operator and the

2 European Union, *REGULATION (EU) No 996/2010 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the investigation and prevention of accidents and incidents in civil aviation and repealing Directive 94/56/EC*, October 2010.
3 Commercial air transport entails aircraft operation to transport passengers, cargo or mail for commercial purposes.
4 ICAO, *Annex 13 to the Convention on International Civil Aviation: Aircraft Accident and Incident Investigation*, July 2020.

state of registry.[5] The AAIB appointed an accredited representative and advisors from the operator Longtail Aviation.

Chapter 2 of this report provides the factual information gathered and considered relevant. In Chapter 3, the accident is analysed. The findings and conclusions from the previous chapter are combined and listed in Chapter 4.

5 The operator is based in Bermuda and the aeroplane has a Bermuda registration. Bermuda is a sovereign state of the United Kingdom and therefore this state is the responsibility of the AAIB.

2 FACTUAL INFORMATION

2.1 History of the flight

On 20 February 2021, the Boeing 747-400 with registration VQ-BWT was scheduled to operate a cargo flight from Maastricht Aachen Airport in the Netherlands to John F. Kennedy Airport, New York in the United States of America. The flight crew consisted of a captain and a first officer.

2.1.1 Flight preparation

When the flight crew reported for duty, loading of the aeroplane had already finished. They stated that they prepared the flight in accordance with company procedures. The aeroplane was refueled with 82,100 kg of fuel, making the total amount of fuel on board the aeroplane at departure 101,300 kg. The aeroplane was loaded with 76,485 kg of cargo.

The aircraft technical log[6] mentioned that the auxiliary power unit (APU)[7] was unserviceable due to its inlet door being stuck in a partially open position. The partially open door is taken into consideration when calculating the take-off performance, because of the extra drag it creates.[8] According to the minimum equipment list[9] (MEL) of the airline, the aeroplane may be dispatched in this condition. When performing the takeoff performance calculation, using the Boeing Onboard Performance Tool program, the flight crew took the APU door penalties as mandated by the MEL into account. The takeoff weight of the aeroplane was 342,411 kg, which was below the takeoff performance limited weight of 343,000 kg.

2.1.2 Start up, taxi out and takeoff

For this flight the first officer was pilot flying, while the captain performed the task of pilot monitoring. Air traffic control cleared the flight to its destination via standard instrument departure OLNO 2B to FL060.[10] The flight crew started the engines; the start up times were within limits and all engine indications were normal. Thereafter, the

6 A document specific to every aircraft which details the maintenance status of that aircraft.
7 The APU is a small jet engine which is normally located in the tail cone of the aeroplane. It allows an aeroplane to operate autonomously without reliance on ground support equipment, such as a ground power unit, an external air-conditioning unit or a high pressure air start cart.
8 The door must be fully open for the APU to work. Now the door was partially open; this creates extra drag during flight.
9 A list which provides for the operation of aircraft, subject to specified conditions, with particular equipment inoperative, prepared by an operator in conformity with, or more restrictive than, the master MEL established for the aircraft type by the manufacturer.
10 A standard instrument departure route (SID) is a standard route identified in an instrument departure procedure, by which aircraft should proceed from the takeoff phase to the en-route phase.

aeroplane taxied to the beginning of Runway 21 via entry E1. This taxi route provided sufficient time for the engines to comply with the minimum warm-up time, as recommended by the engine manufacturer.

At 16.11 hours, the runway controller issued the takeoff clearance for Runway 21. The flight crew had selected flaps 20 and engaged the autothrottle, applied full thrust and the aeroplane started its takeoff roll. The aeroplane became airborne uneventfully.

2.1.3 The engine failure

At an altitude of 1,150 feet AMSL (800 feet above ground), the flight crew heard a banging sound and noticed that the aircraft rolled and yawed slightly to the left. The exhaust gas temperature indication for engine 1 showed an exceedance of the maximum temperature. The flight crew identified the situation as an engine surge. Shortly hereafter engine 1 failed and lost thrust.

The first officer, as pilot flying, corrected the aeroplane for the asymmetric thrust condition by applying right aileron and right rudder inputs. He performed the first memory item for the 'engine limit or surge or stall' procedure by retarding the thrust lever of engine 1 to flight idle. Almost simultaneously, the runway controller informed the flight crew that flames were observed from the number 1 engine (see Figure 1). The captain declared an emergency situation and informed air traffic control they were shutting down the engine. Furthermore, he requested radar vectors for navigation. Although there was no engine fire indication in the cockpit, the crew decided to treat the event as an engine fire and performed the memory items for the 'engine fire' procedure. They switched the number 1 fuel control switch to cutoff, pulled the engine 1 fire switch and rotated it to its stop to exert a fire suppressing agent into the engine. These actions isolated the engine from the hydraulic system and shut off fuel to the engine. Meanwhile, the runway controller informed the flight crew, at their request, that he did not observe flames coming from engine 1 any longer.

Figure 1: Observed flames after the engine number 1 failure. (Source: Maastricht Aachen Airport)

2.1.4 Diversion to Liege Airport

The flight crew decided not to continue to the planned destination and discussed the best course of action: either return to Maastricht Aachen Airport or to divert to an alternate airport. They decided to divert to Liege Airport in Belgium because of a longer runway available than at Maastricht Aachen Airport.

The weight of the aeroplane was above its maximum landing weight of 295,742 kg. Therefore, the crew coordinated with air traffic control to continue climbing to FL100 to maintain sufficient altitude to allow for the fuel jettison procedure.[11] The flight crew jettisoned fuel to reduce the aeroplane weight to below the maximum landing weight. Thereafter, the captain became pilot flying as the flight crew considered the landing with an engine failure as an abnormal situation which the captain should handle.

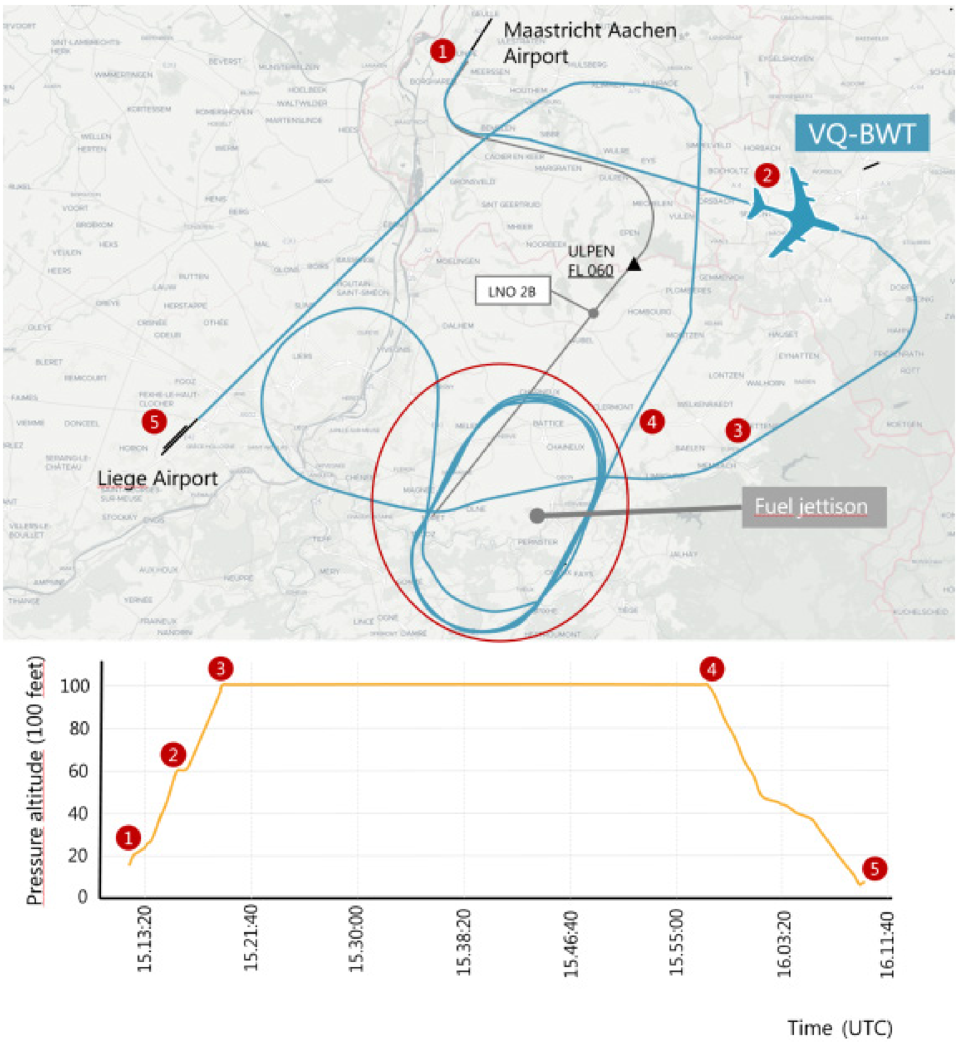

Figure 2: Top view of flown route and graphical representation of pressure altitude against time (in UTC). (Source: Air Traffic Control the Netherlands, modified by Dutch Safety Board)

11 FL100 (10,000 feet) is high enough for the fuel to atomize completely, so that it doesn't hit the ground as liquid (droplets).

While performing the fuel jettison[12], the flight crew was informed by air traffic control that metal parts had been found on the ground at approximately the same position as where the flight crew experienced the engine failure. Therefore, the flight crew took into consideration that possible damage to the wing or flaps might have happened. They also considered the consequences of a possible second engine failure.

In accordance with air traffic control procedures, the flight was transferred to Liege Approach. A long final approach was flown to allow time to stabilise the aeroplane for landing and to counter possible emerging control difficulties. At 17.09 hours, the aeroplane landed uneventfully on Runway 22L at Liege Airport. After landing, the fire brigade escorted the aeroplane to the parking position. The fire brigade reported to the flight crew that there were no signs of fire from engine number 1, nor that there was external damage visible. The aeroplane was subsequently towed to a parking spot. The landing weight was 292,000 kg, which is below the maximum allowable landing weight. After engine shutdown, significant damage was visible to the aft stages of the low pressure turbine when looking forward into the tail pipe (see Figure 3).

Figure 3: Damage visible to low pressure turbine, looking forward into the tailpipe. (Source: Dutch Safety Board)

12 The total amount of fuel jettisoned was 40,000 kg.

2.2 Injuries to persons

Two persons on the ground suffered injuries. One person was struck by a falling piece of debris and fell. This person has been treated in a hospital and has required medical care for a long time. The other person received minor burns while picking up a piece that was still hot.

2.3 Damage to aircraft

The number 1 engine encountered a contained failure and sustained internal damage of among others the high pressure turbine and low pressure turbine. For a further description of the damage, see Section 2.10.1. There was no damage to other parts of the aeroplane.

Figure 4: Engine number 1 after the diversion to Liege Airport. (Source: Dutch Safety Board)

2.4 Other damage

The aeroplane lost metal parts over residential areas of the village of Meerssen (see Figure 5), causing damage to cars (see Figure 6) and houses. Parts were collected and identified as turbine fragments of the number 1 engine (see Figure 7).[13] Examination of

13 Low pressure turbine vanes and blades of the fifth and sixth stage.

these parts revealed that some were of considerable size[14] and weight and thus posed a hazard to people on the ground and their property.

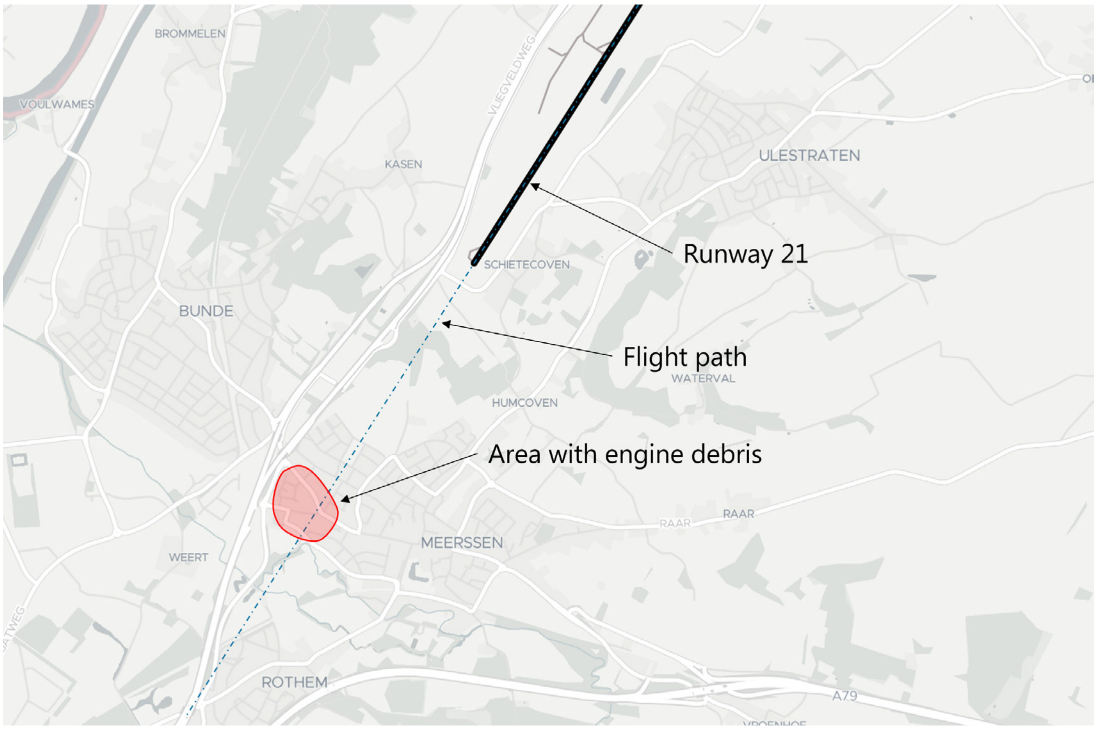

Figure 5: Map showing the area in which most damage occurred. (Source: OpenStreetMap, modified by Dutch Safety Board)

Figure 6: Turbine fragment in car roof. (Source: Algemeen Nederlands Persbureau)

14 The largest part collected by the Dutch aviation police and handed over to the Dutch Safety Board measured 23 by 4 cm.

Figure 7: Collected turbine fragments. (Source: Dutch Safety Board)

2.5 Personnel information

The flight crew consisted of a captain and a first officer. Both were qualified to fly the Boeing 747-412BCF. A loadmaster was sitting on the jump seat behind both pilots on the flight deck, he had no duties related to the execution of the flight.[15]

Table 1: Flight experience of the flight crew

	Total time (hours)	Time on Boeing 747-400 (hours)
Captain	16,769	9,920 (of which 1,233 as pilot in command)
First officer	10,721	7,044

15 A loadmaster is an aircrew member tasked with the loading, transport and unloading of aerial cargoes. The loadmaster performs the calculations and plans cargo and passenger placement to keep the aircraft within permissible center of gravity limits throughout the flight. He is also responsible for the tiedown of the cargo.

2.6 Aircraft information

2.6.1 General

Manufacturer	Boeing Commercial Airplanes
Model	747-412BCF
Date of manufacture	21 February 1991
Serial number	24975
Registration	VQ-BWT
Maximum takeoff weight	394,625 kg
Maximum zero fuel weight	276,691 kg
Maximum landing weight	295,742 kg
Wingspan	64 metres
Total flight hours	84,025
Total landings	14,279

The Boeing 747-412BCF had a valid certificate of airworthiness and maintenance was carried out according to the maintenance programme.

The technical logbook included entries about the exhaust gas temperatures (EGT)[16] and the oil and fuel consumption of the four engines of the aeroplane. These entries did not provide any reason for the crew to doubt the technical state of the aeroplane.

Airframe
The aeroplane was delivered on 21 February 1991 as a passenger aeroplane. On February 2007, the aeroplane was converted to a full freighter aeroplane. During the 30 years of operation, the aeroplane was temporarily taken out of operational service several times. It changed owner seven times and operator twelve times.

2.6.2 Weight and balance

The loadmaster provided the flight crew with a manual weight and balance calculation in the form of a loadsheet. The aircraft was equipped with an on board weight and balance calculating device, which gives an indication of the weight and centre of gravity, when the aircraft is on the ground. With information from this device, the loadsheet and data from the flight data recorder, it was determined that the gross weight and centre of gravity of the aeroplane during takeoff were within the limits as prescribed in the aeroplane flight manual.

16 In a turbine engine, exhaust gas temperature (EGT) is the temperature of the turbine exhaust gases as they leave the turbine unit. The gas temperature is measured by a number of thermocouples mounted in the exhaust stream and is presented on a flight deck gauge.

2.6.3 Engine number 1

General

Manufacturer	Pratt & Whitney
Model	PW4056
Date of service entry	January 1993
Serial number	P727305
Total time	73,995 hours
Total cycles	9,964
Time since overhaul (2010)	11,516 hours
Cycles since overhaul (2010)	1,998

Engine description

The PW4056 is a version of the PW4000-94" model, part of the PW4000 family of engines (see Figure 8). The PW4000-94" engine is a high bypass ratio axial flow turbofan engine with a certified thrust of 56,000 lbf. The basic engine includes a 94-inch diameter fan with 38 shrouded fan blades coupled to a four stage low pressure compressor (LPC). Both the fan and LPC are driven by a four stage low pressure turbine (LPT).[17] The core of the engine includes an eleven stage high pressure compressor (HPC) driven by a two stage high pressure turbine (HPT).[18]

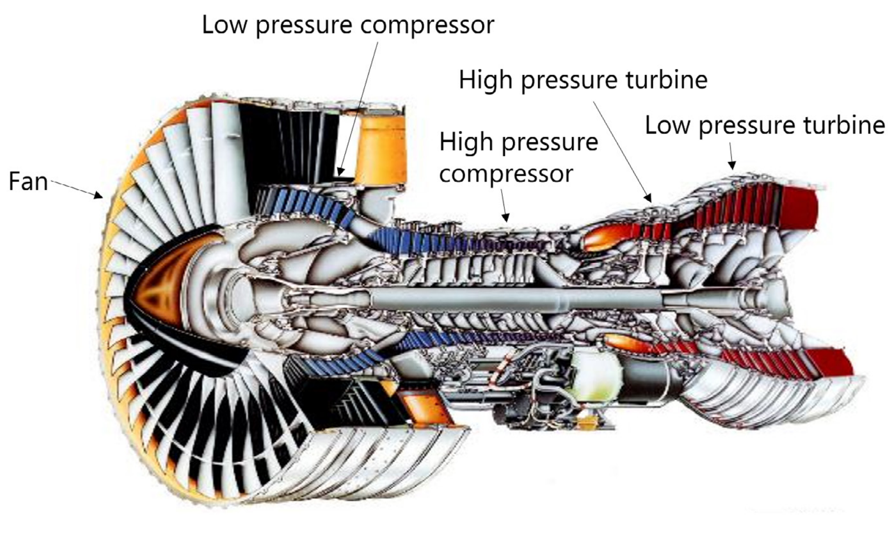

Figure 8: PW4000-94" fan engine. (Source: Pratt & Whitney)

17 Collectively the fan, LPC, and LPT are called the low, or N1, rotor.
18 Collectively, the HPC and HPT are called the high, or N2, rotor.

2.7 Meteorological information

At Maastricht Aachen Airport, the visibility was more than 10 kilometres and skies were clear. A south to south-westerly wind brought in continental tropical air. The airmass was unstable up to 2,000 feet.

The automatic terminal information service (ATIS)[19] of Maastricht Aachen Airport, valid at 16.11 hours, mentioned that the wind came from direction 170 degrees with 12 knots and was variable between 140 and 200 degrees, with a strength between 8 and 18 knots.

2.8 Aerodrome information

2.8.1 General

Maastricht Aachen Airport has one runway with a length of 2,750 metres[20] and a width of 45 metres. It allows for operations with large commercial aeroplanes, like the Boeing 747-400. Runway 21 is used as an active runway in 75 to 80% of the takeoffs and landings.

The airport had a valid aerodrome certificate.[21,22] The Deviation Acceptance and Action Document (DAAD)[23] attached to this certificate contained two deviations concerning the runway turn pad at the end of Runway 21. These deviations are unrelated to the present incident.

2.8.2 Birds

In view of the small number of flight movements, runway inspections are regularly carried out. Birds are actively expelled. Geese are increasingly common at the airport. Smaller birds mainly live in a nature reserve on the west side of the airport. Several crane birds were flying in the vicinity of the airport at the moment the aeroplane was departing.

During a runway inspection after the occurrence, no foreign object debris[24] was found that could have influenced the occurrence. No bird remains were found during the engine inspection.

19 ATIS is a continuous broadcast of recorded aeronautical information in busier terminal areas, i.e. airports and their immediate surroundings.

20 The takeoff distance available and takeoff run available for Runway 21, which has a displaced runway threshold of 250 metres, are both 2,500 metres.

21 This gave the airport authorisation to operate in accordance with the provisions of Regulation (EC) No 2018/1139 and its implementing rules, the aerodrome certification basis, the aerodrome manual, the terms of the certificate and the Deviation Acceptance and Action Document (DAAD) attached to the aerodrome certificate.

22 Human Environment and Transport Inspectorate, *Certificate reference NL-ADR-003, revision number 6*, January 2017.

23 Human Environment and Transport Inspectorate, Ministry of Infrastructure and Water Management, *Overzicht van afwijkingen die zijn aangemerkt als items voor het Deviation Acceptance and Action Document (DAAD), NL-ADR-003, revision number 6*, February 2021.

24 This relates to various obects (fallen from aircraft or vehicles, broken ground equipment, birds, etc.) that are present on a runway that may adversely affect fast-moving aircraft (during takeoff and landing).

2.9 Flight recorders

The aeroplane was equipped with a solid-state memory Flight Data Recorder (FDR), manufactured by AlliedSignal and a solid-state Cockpit Voice Recorder (CVR), manufactured by L3 Communications.

Both the FDR and CVR recorded the entire duration of the flight. They were read out successfully and were used for the analysis of the occurrence. The values of some relevant parameters that were recorded by the FDR are shown graphically in Appendix C.

2.10 Test and research

2.10.1 Borescope inspection of engine 1

The affected engine was removed from the aeroplane at Liege Airport. On 26 and 28 February 2021, borescope inspections took place under the supervision of the Dutch Safety Board. The Board was assisted by Pratt & Whitney and a licensed engineer, who was hired under the authority of the Board. The other three engines of the aeroplane have not been examined.

During visual inspections of the engine and the borescope inspections, no damage was observed on the nacelle, engine cases, fan, high pressure compressor and combustor.

The boroscope inspections revealed various damages within the high pressure turbine (HPT) and low pressure turbine (LPT) (see Figure 9). The HPT showed damage to the trailing edge of second stage blades. Two outer transition ducts (see Figure 10) had come loose and displaced in the flow path of the LPT (see Figure 11). Multiple third stage vanes (first stage of the LPT) were missing and damaged. The last two stages of the LPT were missing turbine blades and vanes. Pratt & Whitney stated that the damage was consistent with other outer transition ducts that had separated in the past (see Section 2.12.2).

During the borescope inspection, it was not possible to identify the configuration of the outer transition duct segments.[25] In order to determine the configuration, maintenance data were requested from the organisations that had serviced the affected engine. However, these organisations were not able to provide the Dutch Safety Board with the required information. Therefore, during this phase of the investigation, it was not possible to determine the configuration of the outer transition duct segments.

25 With configuration is meant, the type of the separate segments. This configuration was among others dependent on the relevant service bulletins that had been incorporated.

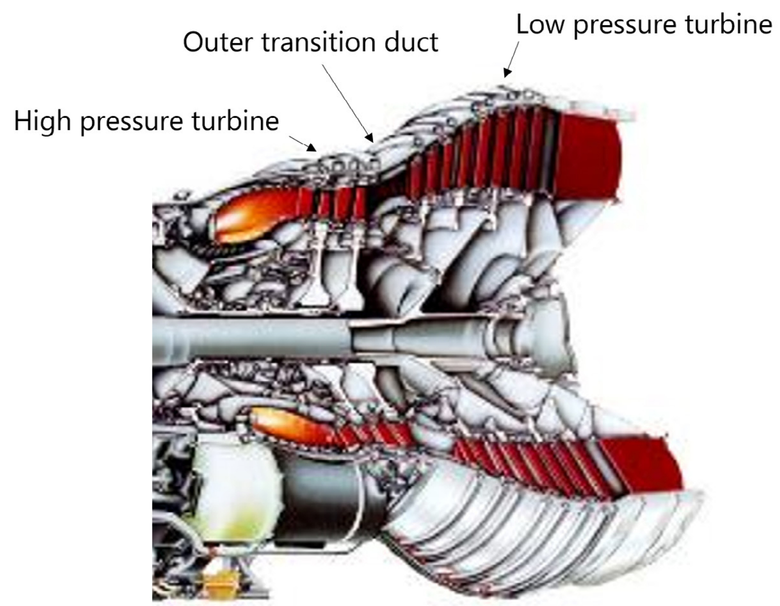

Figure 9: The aft part of the engine with an outer transition duct indicated. (Source: Pratt & Whitney)

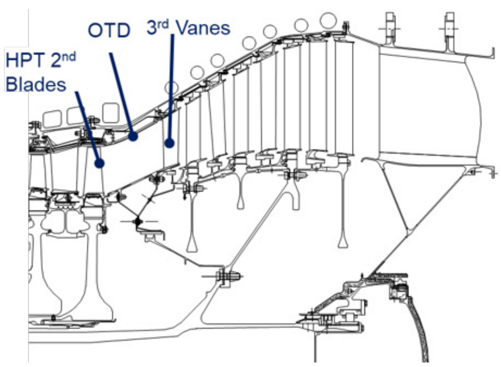

Figure 10: Cross-section view of HPT/LPT transition area. (Source: Pratt & Whitney)

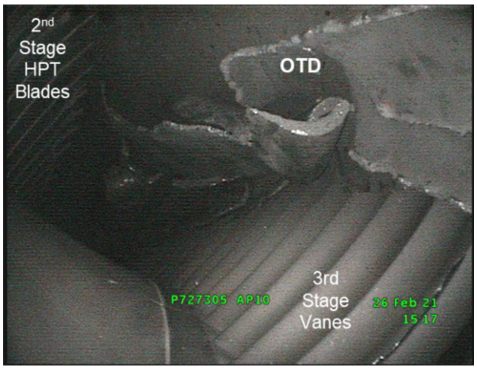

Figure 11: Picture of damaged outer transition duct, taken during borescope inspection. (Source: Pratt & Whitney)

2.10.2 Engine teardown

In April 2021, the engine was shipped to MD Turbines in Hialeah, Florida, USA, for teardown and examination. The teardown was completed in June 2021. Delegates from the Dutch Safety Board, the National Transportation Safety Board, Pratt & Whitney and the operator were present.

During the teardown two significant observations were made. First, the engine did not have a modification of the high pressure turbine (HPT). This modification had been advised by the engine manufacturer since March 1993 through a service bulletin. The modification consisted of among others additional cooling features in the aft seal of the HPT.[26] This modification improves the durability of the ceramic coating of the second stage HPT duct segments by providing additional air required to cool these segments.

The second observation was that all outer transition duct segments were of a redesigned type.[27] This redesign among others reduced the leakage of hot gasses at the aft side of the outer transition duct segments, which prevented deformation.

2.10.3 Metallurgical analysis of engine components

In the first week of July 2021, various parts of the HPT and LPT were shipped to the Pratt & Whitney maintenance facility in East Hartford, Connecticut, USA for further examination.

The metallurgic analysis found that the HPT stage 2 blade outer air seals, the outer transition ducts and the LPT case were exposed to high temperatures (see Figure 12). These temperatures resulted in among others, fractures, wear, warping and degradation of coatings. Further details of this analysis are presented in Appendix D.

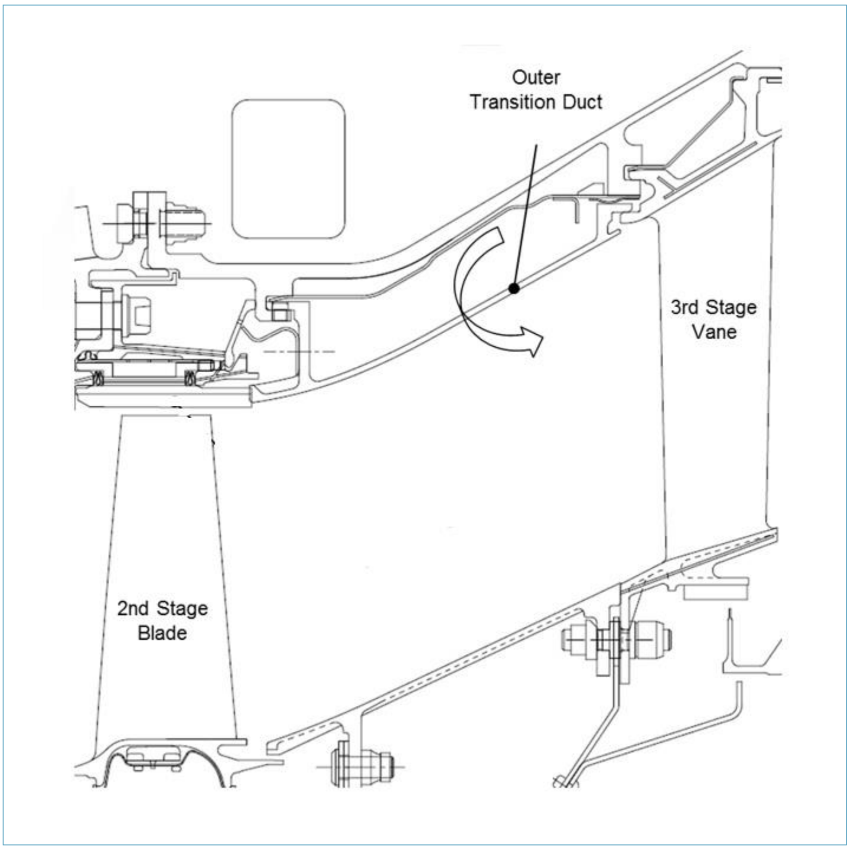

Figure 12: Cross-section view of HPT/LPT transition area. The arrow indicates the direction of movement of a detached outer transition duct. (Source: Pratt & Whitney)

26 Prescribed by SB 72-462 on 18 March 1993, see Appendix F.
27 The redesigned type of the outer transition duct segments was advised by SB 72-488 on 31 August 2009; see Appendix F.

2.11 Organizational and management information

2.11.1 The operator

Longtail Aviation is a charter airline based in St. George's, Bermuda and was established in August 1999. The operator provides air cargo and chartered passenger transport. Longtail Aviation has outsourced aircraft maintenance and airworthiness management.

Longtail Aviation had leased the Boeing 747-412BCF with registration VQ-BWT and put it into service on 20 November 2020. The operator had therefore been using the aeroplane no longer than three months on the day the occurrence took place.

2.11.2 Operator's safety authorisation

The European Union (EU) has centralised the process to authorise third-country (non-EU) operators performing commercial air transport operations into the EU, thereby replacing various schemes of the EASA member states previously in place. Instead, a single safety authorisation is issued centrally by the European Union Aviation Safety Agency (EASA).[28]

According to EU regulation[29], third country operators involved in commercial air transport operations of aircraft have to comply with the relevant standards of the International Civil Aviation Organisation (ICAO).

On 12 April 2018, EASA issued a safety authorisation to Longtail Aviation, indicating that the operator complied with international (ICAO) safety standards and applicable airspace user requirements in EU airspace.[30]

Since the initial authorisation, continued compliance with the applicable requirements has regularly been assessed by EASA. The operator had been assessed in Q2 of 2018 and Q3 of 2020, all following a desktop review where documentation and information provided by the operator were scrutinized. In this period, a total of two "Level 2" findings[31] had been raised since the initial authorisation of Longtail Aviation. However, both findings were immediately closed following the provision of additional supporting documentation by the operator that was initially not given.

2.11.3 Airworthiness Directives and Service Bulletins

Continuing airworthiness is the set of processes by which an aircraft, engine, propeller or part complies with the applicable airworthiness requirements and remains in a condition for safe operation throughout its operating life. Both airworthiness directives (AD) and service bulletins (SB) are tools used to notify aircraft owners or operators as part of the

28 EASA website; Domains, Air Operations, Third Country Operators (TCO) (consulted on 1 June 2022).
29 Regulation (EC) No 216/2008 and Regulation (EU) No 452/2014. In particular ICAO Annexes 1 (Personnel licensing), 2 (Rules of the Air), 6 (Operation of Aircraft, Part I (International Commercial Air Transport – Aeroplanes) or Part III (International Operations-Helicopters), as applicable, 8 (Airworthiness of Aircraft), 18 (Dangerous Goods), and 19 (Safety Management).
30 Compliance with the requirements of Part-TCO as layed down in Commission regulation (EU) No 452/2014.
31 A "Level 2 finding" is any non-compliance with EASA Regulations. It may indicate that safety standards and organisational procedures have been compromised.

process of ensuring continuing airworthiness.[32] Airworthiness directives and service bulletins differ in the way operators are to incorporate the requirements.

Airworthiness directives are legally enforceable regulations by the national aviation authorities to correct safety deficiencies in a product (aircraft, engine, component).[33,34] To ensure the airworthiness of aeroplanes, operators must comply with the requirements as put forth by airworthiness directives or must accomplish an approved alternate means of compliance with the airworthiness directives.

Manufacturers issue service bulletins to inform owners and operators about critical and useful information on aircraft safety, maintenance, or product improvement. A service bulletin is advisory, and compliance is not mandatory unless it is included in an airworthiness directive.[35] Manufacturers usually recommend operators to adhere to the proposed modifications as stated in service bulletins. The operator of an aeroplane over 5,700 kg maximum certificated takeoff mass shall obtain and assess continuing airworthiness information and recommendations available from the organization responsible for the type design and shall implement resulting actions considered necessary in accordance with a procedure acceptable to the state of registry.[36]

The service bulletins and airworthiness directives relevant to the occurrence with the engine involved and Pratt & Whitney's service bulletin category codes are depicted in the table below and described in Appendix F.

Table 2: Status of relevant service bulletins and airworthiness directives.

SB/AD number	Original issue date	Subject	Status for engine 1
SB 72-462	18 March 1993	Additional HPT cooling features.	Not incorporated.
SB 72-488	29 October 1993	Redesigned outer transition duct segements.	Incorporated.
AD 2012-14-09	7 November 2012	Inspections LPT vanes, disassembly and reassembly of HPT and LPT rotors.	Not incorporated. In 2009, the last shop visit occurred, which was prior to the release of this AD.
AD 2012-22-16	19 December 2012	Replacement of certain third stage LPT duct segments.	Not applicable, because SB 72-488 had been incorporated at the 1999 shop visit.

32 ICAO, *Airworthiness of aircraft, Annex 8 to the Convention on International Civil Aviation, twelfth edition*, July 2018.
33 https://www.easa.europa.eu/domains/aircraft-products/airworthiness-directives-ad (consulted on 4 April 2022).
34 https://www.faa.gov/regulations_policies/airworthiness_directives/ (consulted on 4 April 2022).
35 https://www.faa.gov/newsroom/safety-briefing/service-bulletins-and-aircraft-owner (consulted on 4 April 2022).
36 ICAO, *Annex 6 to the Convention on International Civil Aviation, Operation on Aircraft, Part I – International Commercial Air Transport – Aeroplanes, Twelfth Edition*, July 2022.

In relation to SB 72-462, the United States Federal Aviation Administration (FAA) stated that "*this service bulletin was introduced in 1993 to address the ceramic deterioration on the HPT second stage duct segment by adding cooling airflow and enhanced sealing to the HPT. The FAA did not issue an airworthiness directive for this issue, because the ceramic deterioration of the HPT second stage duct segment was not seen as a safety concern.*"

2.12 Additional information

2.12.1 Takeoff and climbout performance calculations

The analysis of the calculated and actual takeoff performance in case of an engine occurrence during takeoff or initial climb is a standard part of an investigation. These calculations are described below and more extensively in Appendix E.
To verify the calculated takeoff parameters and the actual takeoff performance, data from the loadsheet, the flight data recorder and the cockpit voice recorder were used. The various takeoff parameters were calculated with two different takeoff performance software tools.[37] The calculated parameters were compared to the actual flown parameters as derived from the flight data recorder and cockpit voice recorder.

Maximum takeoff weight and takeoff parameters
The loadsheet did not reveal any discrepancies with the used takeoff weight for the calculations performed by the flight crew. The result of the calculation indicated that the actual takeoff weight was below the maximum allowable takeoff weight for Runway 21 and the actual environmental conditions. The different takeoff speeds were correctly calculated prior the flight and correctly applied during the actual takeoff and climbout (the results of the calculations are listed in Appendix E).

Determining the actual takeoff distance and point of liftoff
Runway 21 at Maastricht Aachen Airport, which has a takeoff run available of 2,500 metres from where the aeroplane started its takeoff roll, can be considered as a relatively short runway for operations with large freighters, such as a Boeing 747. A short runway for these operations means that normally these aeroplanes can not takeoff with their maximum allowable takeoff weight; this is known as the aeroplane being "runway limited." Consequently, in most cases, large freighters will use all available runway length to maximize their payload. Following the incident, some residents who lived in the vicinity of Maastricht Aachen Airport had expessed concerns about the fact that large freighter aeroplanes become airborne close to the departure end of the runway; implying an unsafe situation.

The takeoff distance as calculated by the flight crew was analysed in relation to the available runway length. The takeoff distance as calculated by the two software tools were 1,930 and 2,004 metres. Despite not being equal, these calculated distances are

37 For this, use was made of LIDO and the Boeing OPT, for Runway 21, Intersection E1, at Maastricht Aachen Airport for the same type of aeroplane with identical engines, including the applicable MEL item.

well below the takeoff distance available of Runway 21[38] and show that the aeroplane was able to perform its takeoff within operational and aerodrome limits.

In addition, the Dutch Safety Board was provided with a video recording of the departing aeroplane, made by an aeroplane spotter standing outside the gate of the airport. Interpretation of the video images resulted in an estimated actual lift off point of 2,000 metres from the beginning of Runway 21. The images from the video recording show that the actual take off distance was practically equal to the calculated take off distance. The aeroplane performed as expected and within the calculated operational and aerodrome limits.

Climb out performance
When aeroplanes are limited in their maximum takeoff weight because of a limited available runway length, the climb out performance is normally more than sufficient. For the takeoff performance calculation of the present incident, the aeroplane was, as mentioned above, runway limited. This meant that the maximum allowable weight for the aircraft was limited by the available runway length. As this weight of 343,000 kg was well below the maximum takeoff weight of 394,625 kg, the climb performance was above the minimum required climb performance by the departure procedure. Because the engine failure took place at 800 feet above the ground, the aircraft was already established in the climb and therefore the climb performance degradation was less critical.[39]

For the takeoff performance calculation of every aeroplane type, regardless of the number of engines available, an engine out situation is taken into account. For a two-engine aircraft this means the loss of one engine and therefore loss of 50% of engine thrust in case of an engine failure. For a four-engine aircraft the loss of one engine only means a loss of 25% of thrust. For the situation with an engine failure, the required height over the end of the runway remains the same, resulting in the lift-off point to be comparable for both two and four-engine aircraft. In case a normal takeoff is made without an engine failure, the two-engine aircraft has twice the minimum amount of thrust available to continue the takeoff after the decision speed V_1[40], whereas for a four-engine aircraft this results in 33% of extra thrust. The actual runway length used under normal conditions will therefore be significantly shorter for a two-engine aircraft compared to a four-engine aircraft.

38 The takeoff distance available is 2,500 metres.
39 Instead of just after the decision speed V_1 during the takeoff roll, which is the most critical point for an engine failure to happen during takeoff.
40 V_1 is the maximum speed in the takeoff at which point a pilot must take the first action (e.g., apply brakes, reduce thrust, deploy speed brakes) to stop the aeroplane within the accelerate-stop distance. V_1 also means the minimum speed in the takeoff, following a failure of the critical engine at the engine failure speed V_{EF}, at which the pilot can continue the takeoff and achieve the required height above the takeoff surface within the take-off distance. (https://skybrary.aero/articles/v1, consulted on 20 July 2022).

2.12.2 Previous events PW4000-94" fleet

According to data provided by Pratt & Whitney, 22 outer transition duct (OTD) liberation events have occurred in the PW4000-94" fleet since 1987. No injuries to third parties or damage to property occurred during any of those prior events, though one event was categorised as nacelle uncontained.[41] The OTDs were redesigned; the redesign was introduced by means of a service bulletin in 1993 (SB 72-488). In 2012, an airworthiness directive (AD 2012-22-16) was issued, which required removing and replacing the original OTD segments. Of the engines involved in the OTD liberation events, 19 out of 22 had a full set of the earlier version of the OTD segments. One engine had a partial set of this earlier version OTD segments and the configuration of two engines is unknown. As mentioned before, the event engine was equipped with the latest type of OTD segments.

2.12.3 Engine in-flight shutdown

Modern day turbine engines can be in service for many years because of their design requirements and maintenance programs. These turbine engines are known to have a high level of reliability; however, engine malfunctions occasionally occur. These malfunctions may lead to an engine to be shut down in flight. These shut downs normally do not constitute a serious safety risk because aircraft are designed and certified to fly with one engine inoperative.

2.12.4 Risks for residents around airports

External safety

'Airports are centres for air traffic in the air transportation system. Consequently, their presence causes a convergence of air traffic over the area surrounding the airport. For those people living in the vicinity of an airport, this implies involuntary exposure to the risk of aircraft accidents'.[42] In the event of a serious incident, such as this occurrence, there are also risks for local residents.

The Dutch government has established requirements to ensure the safety for residents around airports is case of an accident with an aeroplane. These safety criteria are represented in so-called location-specific risk contours, which extend from the runway ends in line with the runway (see Figure 13). The contours are used to indicate the risk of death as a result of an accident -a crash- with an aeroplane in the immediate vicinity of a runway. In these contours, the probability of separation of engine parts is not included to determine the external risk.[43] In Figure 13, the dark blue color indicates where this location-specific risk is 10^{-5} per year. The light blue color indicates a location-specific risk of 10^{-6} per year.

41 See Section 2.12.4, for a description of contained and uncontained engine failures.
42 ICAO, *Airport Planning Manual, Part 2 Land Use and Environmental Control, Fourth Edition*, 2018.
43 Compendium voor de Leefomgeving, *Externe veiligheid rond regionale luchthavens, 2010-2018*, augustus 2021 (https://www.clo.nl/indicatoren/nl2029-externe-veiligheid-regionale-luchthavens).

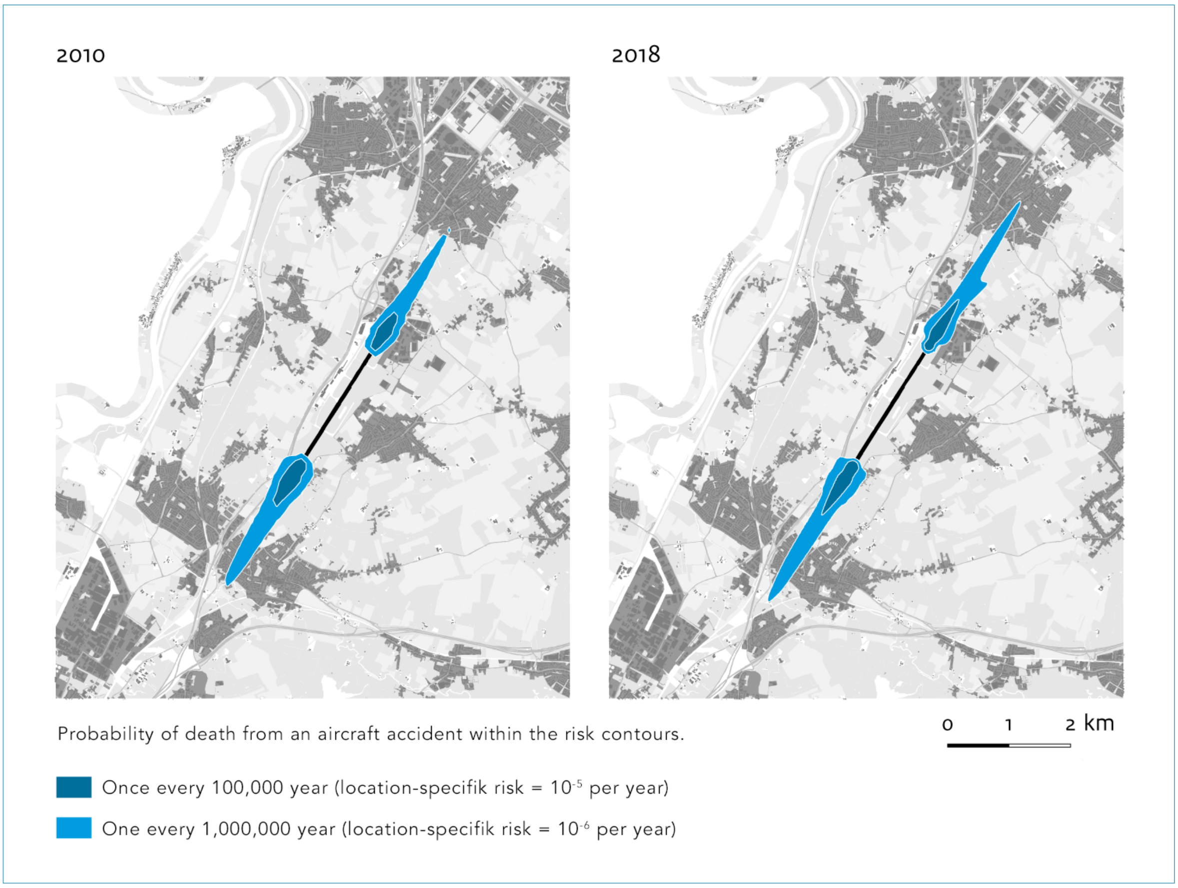

Figure 13: Location-specific risk contours around Maastricht Aachen Airport. (Source: Compendium voor de Leefomgeving)

EASA's certification memorandum

In 2018, EASA issued a certification memorandum about parts detached from aeroplanes.[44,45] It is concluded in this document that in this type of events, given the current observed rates of loss of parts per flight hour, the risk of injuries to persons on the ground or damage to other aeroplanes does not constitute an unsafe condition.[46] However, this certification memorandum does not apply to engine debris, considered as high energy rotating parts.

ANSV investigation

The Italian Agenzia Nazionale per la Sicurezza del Volo (ANSV) published a report[47] on their investigation into the serious incident involving a Boeing 787-8 that occurred during the initial climb after takeoff from Rome Fiumicino International Airport in Italy on 10 August 2019. At 1,028 feet radio altitude over the city of Fiumicino, the flight crew felt

44 EASA, *Certification Memorandum, PARTS DETACHED FROM AEROPLANES, CM–21.A-A-001 Issue 01*, November 2018.

45 The purpose of this Certification Memorandum (CM) is to provide specific guidelines, limited to large aeroplanes, for evaluating whether an unsafe condition exists in events where parts departed from aeroplanes. The conclusions in the CM apply to engine parts as well.

46 As per AMC 21.A.3B(b), Unsafe condition.

47 ANSV, *FINAL REPORT, SERIOUS INCIDENT, Aircraft B787-8 registration marks LN-LND, Rome Fiumicino International Airport, Italy,10th of August 2019*, January 2022.

strong vibrations followed by malfunction messages relating to the left engine.[48] The flight crew shut down this engine and returned to the airport where an overweight landing was made. All occupants were unharmed. Debris, mainly fragments of turbine blades, were recovered from the streets of Fiumicino where several cars and buildings had been damaged. No one on the ground was injured.

As part of the investigation, the ANSV reviewed the certification memorandum mentioned above. The ANSV issued, among others, the following recommendation to EASA: It is recommended to evaluate the opportunity of revising the risk assessment related to people on ground being hit by PDA, considering in the most conservative way the different specific scenarios for each phase of flight for the improvement of safety. Special attention should be given to people living nearby the airports. The results should be taken into account for the next certification requirements.[49]

EASA's response to this recommendation was: […] The EASA therefore considers CM-21.A-A-001 Issue 01 is already conservative enough to cover the risk related to people on ground being hit by PDA, for all phases of flight.

Contained and uncontained engine failures
Engine failures involving separation of engine parts can be categorised as either contained or uncontained. The engine has a containment structure which is designed to withstand the consequences of the release of a single fan or turbine blade, and which is often adequate to contain additional released blades and static parts.[50] Almost all gas turbine engine failures are contained, which means that although the components might disintegrate or separate inside the engine, they either remain within the engine case or are ejected from the engine intake or exhaust. With respect to aeroplane safety, the engine debris in the present event can be seen as parts that became detached from the aeroplane with no or low initial relative speed to the aeroplane (and also not as high energy rotating parts).

Uncontained failures of high energy rotating parts potentially pose serious hazards to the aeroplane occupants, the aeroplane structure, the adjacent engine(s) and the integrity of multiple systems such as the fuel supply system and the flight control system. EASA's certification specifications[51] require large aeroplane design precautions to be taken to minimise the hazard from such failures.

Beside engine parts, other parts may also separate from aeroplanes. Therefore, initial airworthiness requirements address different scenarios in which parts, such as doors and panels, are assumed to fail and depart from the aeroplane. These scenarios are focussed on the consequences of a failure to the aeroplane, assuming that a failure will not present

48 Rolls-Royce Trent 1000 engine.
49 Recommendation ANSV-10/1147-19/4/I/21.
50 EASA, *Easy Access Rules for Engines (CS-E) (Amendment 5),* February 2020.
51 EASA, *Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes (CS-25),* November 2011. and EASA, *Easy Access Rules for Engines (CS-E), (Amendment 5),* February 2020.

an immediate safety risk to the aeroplane itself and its occupants. However, pieces of departed debris may present a hazard to persons on the ground.

2.12.5 Actions taken by Pratt & Whitney

Following the present occurrence and the findings of the investigation, Pratt & Whitney discussed the importance of incorporating the improved HPT cooling configuration at both the January and April 2022 Customer Council Calls. The subject was also discussed at the November 2022 PW4000 World Operators Conference.

3 ANALYSIS

In this chapter, the cause of the engine failure is analysed. The risk for people on the ground, in relation to departing engine parts, is also analysed.

The actions performed by the flight crew in relation to the engine failure were also analysed. It was found that the flight crew's preparation of the flight, the handling of the engine failure and the diversion were in accordance with procedures that are standard in commercial air transport.

3.1 The engine failure

The cause of the engine failure
The investigation revealed that the second stage blade outer air seal of the high pressure turbine (HPT), as well as the HPT itself had deteriorated. This exposed the outer transition ducts to elevated temperatures. These two factors contributed to the slow deformation of the outer transition ducts. The outer transition duct panels distorted, the attachment hooks deformed and backed away from the case, which led to liberation of one panel and one being fractured. These panels then damaged the turbine blades, resulting in fragments of the turbine leaving the engine via the exhaust pipe. The investigation ruled out that runway foreign object debris or a bird strike or drone strike had led to the engine failure. The meteorological conditions played no part in this failure either.

Implementation of service bulletins
The failure mode as described above was known to Pratt & Whitney. This manufacturer proposed solutions to prevent reoccurrence since the beginning of the nineties. These solutions have been introduced via service bulletins (SB) and airworthiness directives (AD) (see Appendix F). At the publication date of this report, engines equipped with the additional cooling features and redesigned outer transition ducts, as prescribed by the SBs and ADs, have not exhibited this failure mode. Therefore, the measures appeared to be effective to prevent this failure mode. However, information provided by Pratt & Whitney during the investigation indicated that (given certain conditions) it is still possible to liberate an outer transition duct with both SB 72-488 and SB 72-462 incorporated, but these upgrades add significant margin and greatly minimize the probability of these events.

The event engine was not modified according to SB 72-462, which advises additional cooling features in the HPT. This service bulletin aims to reduce the elevated temperatures in the HPT, which prevent the failure of the outer transition ducts and subsequently parts of the HPT and LPT. According to Pratt & Whitney's analytical modelling, the outer transition ducts failure would not have occurred if SB 72-462 had been incorporated.

This claim seems credible, as the investigation did not find similar failure modes with engines that had been modified with the additional cooling features.

As mentioned above, the engine was not modified with the additional cooling features, as prescribed by SB 72-462. However, it was modified with outer transition ducts of the redesigned type, as prescribed in SB 72-488. Despite the fact that the engine was equipped with the redesigned outer transition ducts, the temperature could rise to a level that it caused damage over a long period of time, which led to liberation of outer transition duct panels and finally failure of the engine, whereas the lacking additional cooling features were supposed to prevent this from happening. It should be noted that according to Pratt & Whitney, the present failure was the first known time that outer transition ducts failed that were of the redesigned type in the PW4000-94" engine family.

The configuration standard in which the engine was found was permissible, as SB 72-462 was not mandatory to be incorporated. Normally, operators weigh on factors such as financial, operational and safety aspects to incorporate a service bulletin. This incorporation can be done either during a scheduled shop visit or during a separate maintenance action.

More specifically, the service bulletin had a compliance category code 5[52], which indicates that incorporation can be accomplished when the engine is disassembled sufficiently during scheduled maintenance and therefore considered not time critical. Scheduled maintenance was accomplished in 1999 and 2009 during which the engine was disassembled (see the timeline in Appendix F). During this time, the aeroplane and engine were used by another operator. The incorporation of a service bulletin is an operator's decision. Therefore, the initial decision whether (not) to embody SB 72-462 would have been taken (and should have been recorded) by that operator. Despite not being responsible for the decision not to embody SB 72-462 at the shop visits in 1999 and 2009, the operator at the time of the occurrence was not able to present the documented reasoning regarding the non-incorporation of SB 72-46. The content of the service bulletin was not considered an urgent safety issue.

> The engine failed because of liberation of one outer transition duct panel and one being fractured, that initiated subsequent damage to the high pressure turbine and low pressure turbine, which was caused by elevated gas temperatures that prolonged for an extended time. This failure mode is similar to occurrences that took place in the past. The engine was not modified according to Service Bulletin 72-462, which entails among others a change of the high pressure turbine with additional cooling features.
> Despite not being responsible for decisions not to embody SB 72-462 at the shop visits in 1999 and 2009, the operator was not able to present the documented reasoning regarding the non-incorporation of Service Bulletin 72-462.

52 See Table 3 in Appendix F for an explanation of these codes, which have been defined by Pratt & Whitney.

Inspections
During normal hot section inspections, as part of the prescribed maintenance services, no special attention is paid to any damage to the outer transition ducts in the LPT as a leading indicator of a liberation of those ducts. Further, normal wear and distress are not telltale signs of an imminent liberation either. According to Pratt & Whitney, it is therefore unlikely that a prior hot section borescope inspection would have been able to detect indications of the pending duct liberation in the event engine.

Since this incident, Pratt & Whitney developed an inspection, in part due to the present engine failure, that looks for known aggravating factors such as HPT stage 2 blade outer air seals coating spallation as a contributor to thermal distress of the outer transition duct hook.

3.2 The present engine failure and external safety

This section is about the risk for people on the ground as a consequence of departing engine parts. The Dutch Safety Board has received letters from residents living in the vicinity of Maastricht Aachen Airport about feelings of unsafety for several years. These safety concerns are about various subjects, such as fallen roof tiles from houses located in close vicinity of the airport as a result of wake turbulence;[53] the risk caused by unusual –emergency- situations when aeroplanes fly close to the industrial park of Chemelot; adverse health consequences for local residents as a result of environmental impact, such as noise nuisance and air pollution; and the risk associated with overflights of heavy freighters at a relative low altitude over several villages, including the villages of Meerssen, Geverik and Beek. The present case falls under this last subject and confirms that the hazard of departing engine parts actually exists; it therefore contributed to the existing feelings of unsafety.

Commercial air transport in general strives for a high level of safety. From an aviation perspective, this incident may be viewed as being one with relavitely low risks with regard to the operation of the aeroplane itself. The engine failure did not lead to consequential damage to the aeroplane and the four-engine aeroplane was designed to fly with one engine inoperative. In addition, the flight crew was licensed and trained and handled the engine failure according to established procedures. However, in the present case the high level of safety was adversely affected, which resulted in two people on the ground sustaining injuries and property such as houses and cars being damaged.

Both the aeroplane and the engine were designed and tested to meet a given set of certification specifications. A wide range of possible system failures and subsequent consequences are identified as part of this process. These certification requirements are maintained during the use of an aeroplane and engine by a process that seeks to ensure continuing airworthiness. Nevertheless, these certification and continuing airworthiness requirements can not guarantee failure free flight operations.

53 Wake turbulence is defined as turbulence which is generated by the passage of an aeroplane in flight.

This specific incident shows that there was a hazard for people on the ground because turbine parts had exited the tailpipe and dispersed over the village of Meerssen. With the convergence of air traffic over areas surrounding airports, there is an increased risk of occurrences in these areas.. In this case, the area of convergence runs over the villages of Meerssen, Geverik and Beek. This means that their residents are involuntarily exposed to a risk of departing engine debris that is likely higher than in other residential areas surrounding the airport.

Within aviation, the magnitude of the risk of departing engine debris for people on the ground has not been determined and translated into regulations. What is determined, is the risk of death as a result of an accident -a crash- with an aeroplane in the immediate vicinity of a runway. This risk is managed by location-specific risk contours. These risk contours are not applicable to the loss of engine parts; however, these contours can be seen as an indication of areas with convergence of air traffic near airports. Noted, an indicating of the risk of departing engine debris for people on the ground is provided in Certification Memorandum CM–21.A-A-001. This memorandum contains non-binding information and does not constitute certification requirements or any legal obligation. It can be seen as a starting point to further develop the risk assessment of departing engine debris for people on the ground into regulations. This necessity to revise the assessment is underscored by the Italian ANSV investigation report concering the incident that occurred over the city of Fiumicino in 2019.

Given the degree of feelings of unsafety and the area of convergence of air traffic being situated over the village of Meerssen, the Dutch Safety Board is of the opinion that the risk of departing engine debris should be determined. In general, residents around airports are at least exposed to two types of risks: first, parts departing the aircraft, and second an accident with an aircraft. Until now, an assessment for residential areas around Maastricht Aachen Airport of the risks of parts departing the aircraft, such as departing engine debris, has not routinely been done. According to the Dutch Safety Board, based on the results of such an assessment an informed decision about the acceptability of these local risks should be made.

The engine failure caused no serious risk to the aeroplane. However, the engine turbine fragments that had exited via the tailpipe caused a hazard to persons and property on the ground.

The engine failure showed that the hazard of departing engine parts is real, resulting in injured people and damaged property. The present case contributed to the feelings of unsafety of the residents. In general, residents around airports are at least exposed to two types of risks: first, parts departing the aircraft, and second an accident with an aircraft. Until now, an assessment for residential areas around Maastricht Aachen Airport of the risks of parts departing the aircraft, such as departing engine debris, has not routinely been done. Based on the results of such an assessment, an informed decision about the acceptability of these local risks should be made.

4 CONCLUSIONS

The investigation into this contained engine failure with the departing engine debris, revealed that the turbine of the number one engine of the aeroplane had failed. This engine –turbine- failure was caused by elevated gas temperatures that existed for an extended period of time in the turbine of the engine causing wear and deformation of outer transition duct panels. This resulted in one outer transition duct panel coming loose and one being fractured, which subsequently caused severe damage to the turbine. Consequently, engine debris -turbine parts- exited the tail pipe of the engine and came down in the village of Meerssen.

The manufacturer of the engine was aware of the problem with the outer transition ducts coming loose since the nineteen-eighties. To prevent the failure of the outer transition ducts and turbine section, several service bulletins were issued since 1993. Also airworthiness directives were issued to improve the reliability of the outer transition ducts and the safe working of the engine. These improvements concerned among others additional cooling features for the high pressure turbine and the installation of new outer transition duct panels. The investigation revealed that the engine was equipped with those new panels; however, the engine was not modified with the additional cooling features. The lacking additional cooling features were supposed to prevent a too high level of gas temperature. The installation of these cooling features, as adviced by a service bulletin, was not mandatory.

The operator, who had been using the aeroplane in its fleet for three months at the time of the incident, was not responsible for decisions not to embody Service Bulletin 72-462 at the shop visits in 1999 and 2009. Despite this, the operator was not able to present the documented reasoning regarding the non-incorporation of this service bulletin.

Having an adequate record keeping of maintenance documentation enables the operator and its maintenance organisation to make sound risk management decisions about the continuing airworthiness of their aeroplanes. This is crucial for the safe operation throughout the operating life of, in this case, the engine.

With the convergence of air traffic over areas surrounding airports, there is an increased risk of occurrences in these areas. In this case, the area of convergence runs over the villages of Meerssen, Geverik and Beek. This means that their residents are involuntarily exposed to a risk of departing engine debris that is likely higher than in other residential areas surrounding the airport. The engine failure showed that the hazard of departing engine parts is real, resulting in injured people and damaged property. The present case contributed to the feelings of unsafety by the residents.

Residents around airports are at least exposed to two types of risks: first, parts departing the aircraft, and second an accident with an aircraft. Until now, an assessment for residential areas around Maastricht Aachen Airport of the risks of parts departing the aircraft, such as departing engine debris, has not routinely been done. According to the Dutch Safety Board, based on the results of such an assessment an informed decision about the acceptability of these local risks should be made.

5 RECOMMENDATIONS

The Dutch Safety Board issues the following recommendations:

To Longtail Aviation:

1. Make and keep the record keeping of the (non-)implementation of service bulletins for leased engines of your fleet of commercial air transport aeroplanes complete and accessible.

To United States Federal Aviation Administration:

2. Reconsider whether Service Bulletin 72-462, in light of third party risk, should be made mandatory through an Airworthiness Directive.

To the Minister of Infrastructure and Water Management:

3. Perform and publish an assessment for residential areas around Maastricht Aachen Airport of the risks of parts departing the aircraft, such as departing engine debris.

APPENDIX A

RESPONSES TO THE DRAFT REPORT

In accordance with the Dutch Safety Board Act, a draft version of this report was submitted to the parties involved for review. The following parties have been requested to check the report for any factual inaccuracies and ambiguities:

- Air Accidents Investigation Branch
- Air Traffic Control the Netherlands
- Belgian Air Accident Investigation Unit
- Bureau of Enquiry and Analysis for Civil Aviation Safety
- European Union Aviation Safety Agency
- Federal Aviation Administration
- Flight crew members
- Longtail Aviation
- Maastricht Aachen Airport
- Ministry of Infrastructure and Water Management
- National Transportation Safety Board
- Pratt & Whitney
- The Boeing Company

The responses received, as well as the way in which they were processed, are set out in a table that can be found on the Dutch Safety Board's website (www.safetyboard.nl).

The responses received can be divided into the following categories:
- Corrections and factual inaccuracies, additional details and editorial comments that were adopted by the Dutch Safety Board (insofar as correct and relevant). The relevant passages were amended in the final report.
- Not adopted responses; the reason for this decision is explained in the table.

Longtail Aviation did not wish to comment on the draft report.

TURBINE PARTS FOUND IN MEERSSEN

Figure 14: Turbine part. (Source: Dutch Safety Board)

Figure 15: Turbine parts. (Source: Dutch Safety Board)

FLIGHT DATA RECORDER PARAMETERS

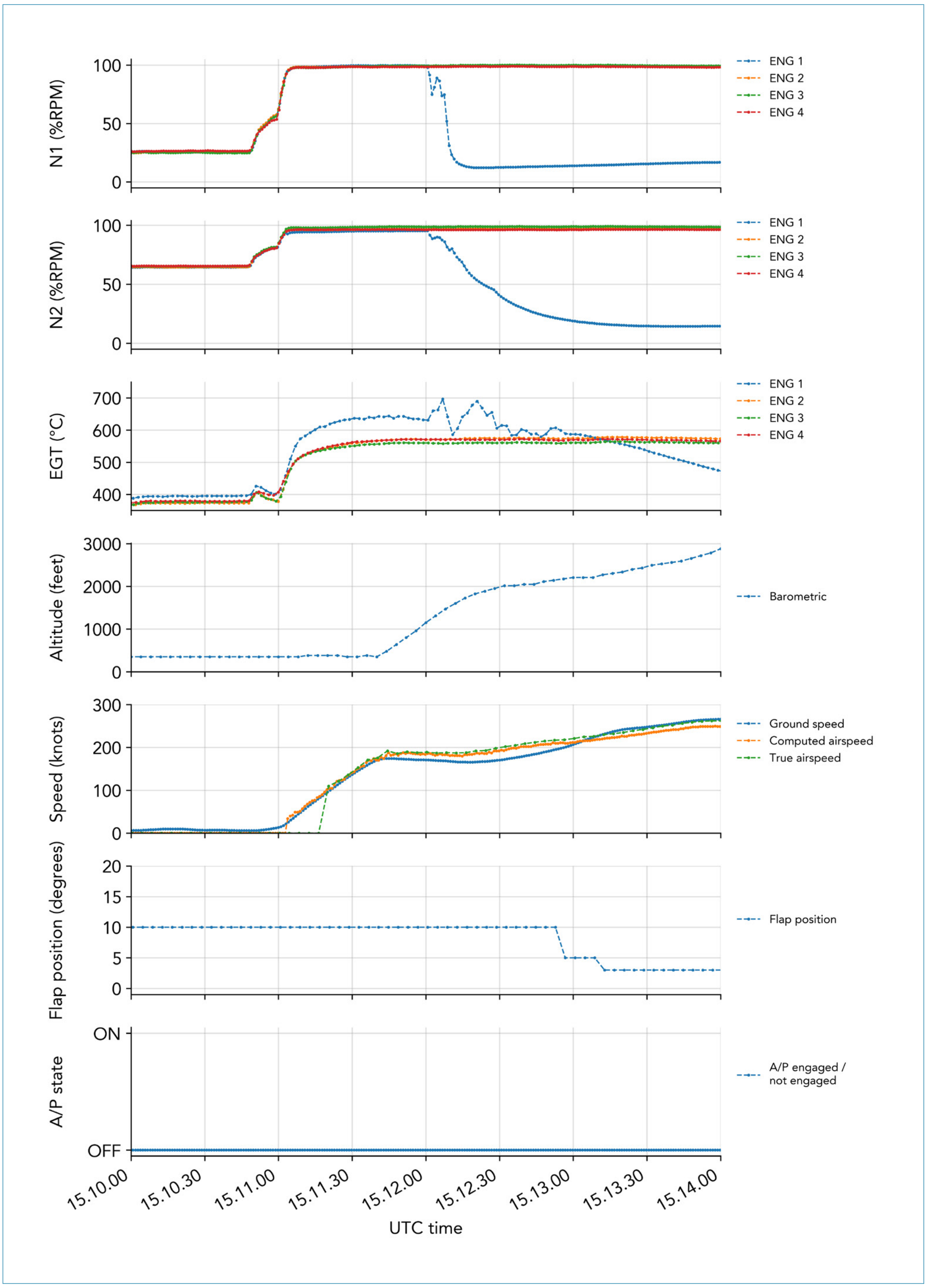

Figure 16: Flight parameters. (Source: FDR data)

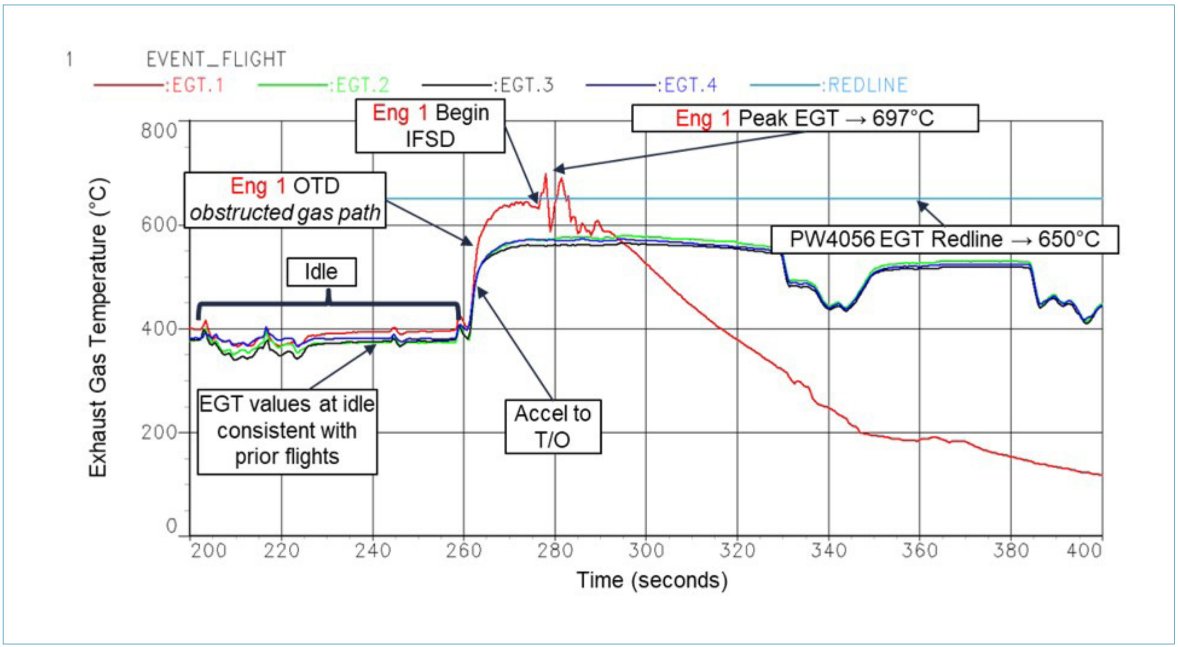

Figure 17: Exhaust gas temperature. (Source: Pratt & Whitney)

The graph is based on data recorded by the flight data recorder. As can be seen, during the period that the engines were set to idle before takeoff, all exhaust gas temperatures (EGT) were around 400 °C. After adding more power to the engines for takeoff, the EGT of engine 1 began to differ by rising to a temperature around 650 °C. The in-flight shut down started with two peaks of almost 700 °C, before the EGT temperature consistently decreased.

APPENDIX D

METALLURGICAL ANALYSIS

The following parts were further examined in the Pratt & Whitney maintenance facility in East Hartford, Connecticut, USA:

- LPT case, LPT third stage vanes, OTD, inner transition ducts, and remaining seals (assembled).
- HPT second BOAS and BOAS supports (assembled).
- LPT third stage vane and OTD fragments found in transition area at disassembly.

The final disassembly of the hardware and review of it was conducted in July 2021. The analysis of the effect of the original HPT configuration on the outer transition ducts was conducted in September 2021.

Pratt & Whitney performed a metallurgical investigation of the HPT second stage blade outer air seals (BOAS) and duct supports and made a report of the findings.[54] The main findings are listed below.

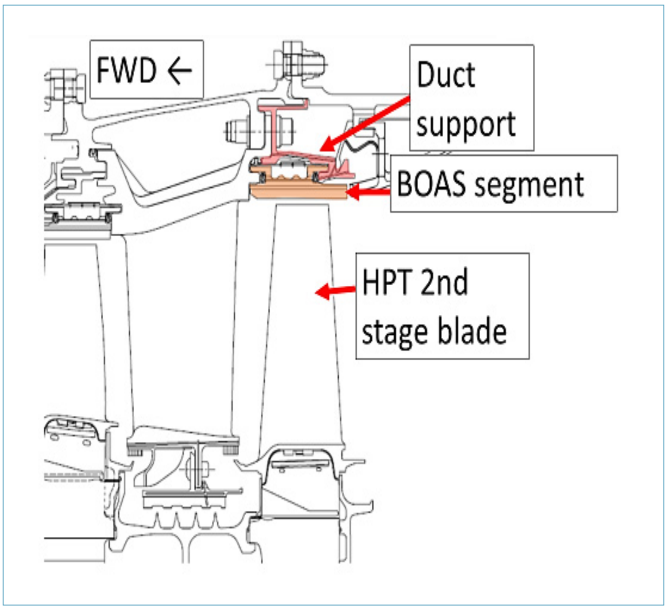

Figure 18: BOAS segment and HPT second stage blade. (Source: Pratt & Whitney)

54 Pratt & Whitney Materials & Processes Engineering, *Metallurgical Investigation Final Report*, December 2021.

Metallurgical investigation findings

Stage 2 blade outer air seals
Confirmed HPT stage 2 blade outer air seals (BOAS) reached temperatures > 2,000 °F

Visual observations:
- Multiples BOAS experienced significant coating spallation
- 19 of 21 BOAS experienced coating spallation preferential to the aft edge

Metallurgical section observations:
- Metal temperatures reached range of 2,000-2,500 °F on cracked/spalled BOAS
- Exposed to gas path temperatures during normal operation
- Hardness consistent with typical material requirements

Outer transition ducts
Confirmed outer transition ducts (OTD) reached temperatures > 2,000 °F

Visual observations:
- OTDs revealed fractures, wear and warping
- Keyenece white-light interferometry measurements show a maximum of 0.009" wear

Metallurgical section observations:
- Microstructure of liberated OTD suggested high temperature exposure
- Intact OTDs show metal temperatures in the range of 2,000-2,050 °F
- Temperature model estimates typical range of 1,550-1,785 °F

Low pressure turbine case
Confirmed low pressure turbine (LTP) case reached temperatures > 1,600 °F

Visual observations:
- LPT case revealed a bulge/warped area near the OTD area
- Bulging spans from #2 to the #13 OTD liner positions

Metallurgical section observations:
- Bulk microstructure show solutioning of intergranular phase, indicating high temperature exposure
- Hardness degradation of the LPT case indicates exposure of at least 1,650 °F

Structural creep disengagement results

HPT (dog bone) seal has significant influence on OTD disengagement life.
Configuration with down change HPT (dog bone) seal (green) predicted to disengage approximately three times faster.

TAKEOFF PERFORMANCE CALCULATION

The flight crew entered the following parameters in the electronic flight bag for the takeoff performance calculation:

Temperature	16 °C
QNH	1011 hPa
Runway/Intersection	21/E1
Use of Anti-ice	off
Runway condition	Dry
Selected level of derated thrust	Full thrust, no assumed temperature
Packs on or off	On
Takeoff run available	2,500 metres
Takeoff distance available	2,500 metres
Accelerated stop distance available	2,500 metres

The takeoff performance calculation resulted in the following values:

Takeoff flaps: 20

V_1	142 kt
V_r	156 kt
V_2	169 kt

	LIDO	OPT
TOGW[55]	342,400 kg	342,411 kg
PLTOW[56]	343,600 kg	343,395 kg
V_1	141 kt	142 kt
V_r	156 kt	156 kt
V_2	169 kt	169 kt

Full takeoff thrust, Takeoff flaps 20

55 Take Off Gross Weight.
56 Performance Limited Takeoff Weight.

SERVICE BULLETINS AND AIRWORTHINESS DIRECTIVES

Service Bulletins

SB 72-462

SB 72-462 was introduced on 18 March 1993 because the second stage HPT duct segments have had the ceramic coating deteriorate in high time service engines. To improve the durability of these segments, additional air is required to cool the segments. Modifications to the HPT case, duct supports, and second stage HPT 'dog bone' seal provide the additional air required to cool the second stage duct segments.

SB 72-462 was a category 6 bulletin prior to the revision in 2000 to category 5.[57] It was updated to expedite the incorporation of the SB.

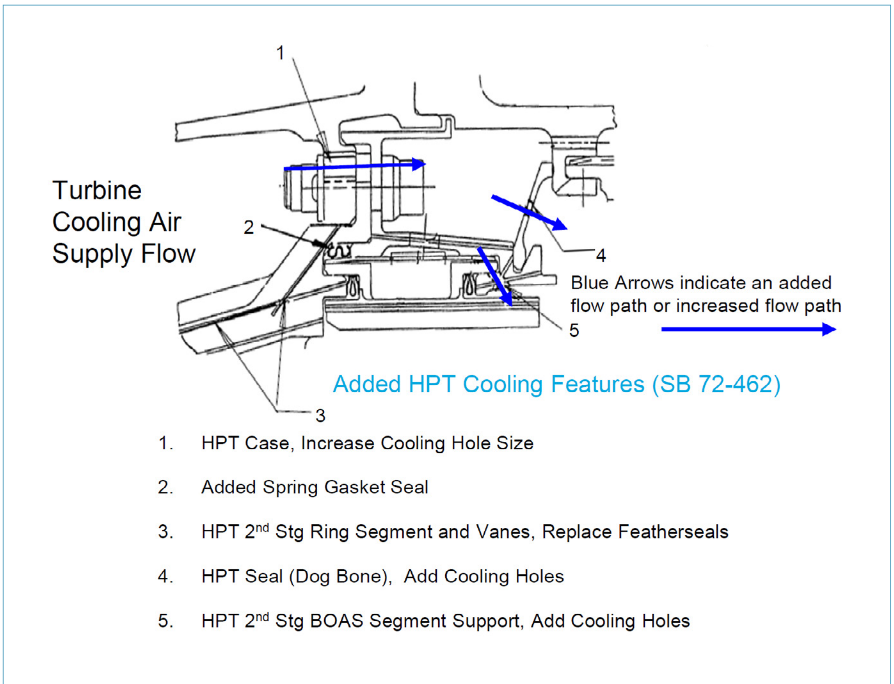

Figure 19: Added HPT cooling features (SB 72-462). (Source: Pratt & Whitney)

57 The different categories are described later in this appendix.

SB 72-488
Pratt & Whitney identified that the riveted seal plates on the outer transition duct segments, also known as the third stage low pressure turbine duct segments, may become loose and could be liberated into the low pressure turbine duct due to normal engine vibrations.

On 31 August 2009, SB 72-488, which was originally issued on 29 October 1993, was updated from category 8 to category 6. It required incorporation of redesigned outer transition duct segments at a next shop visit with access to the area. The segments must then be replaced in full sets.

Airworthiness Directives

AD 2012-14-09
This AD has been effective since 7 November 2012 and requires dimensional inspections of LPT 3rd stage vanes and the rear turbine case, inspection of LPT 4th stage vanes at the next LPT overhaul and removal of vanes with non-conforming airfoil fillet radii and vanes with more than one strip and recoat repair. This AD also requires disassembly and reassembly of the 2nd stage high-pressure turbine (HPT) rotor and 3rd stage LPT rotor at the next HPT and LPT overhauls.

This AD was issued to prevent 3rd and 4th stage vane fractures in the LPT, damage to the LPT rotor, uncontained engine failure, and damage to the airplane.

In 2009, the last shop visit of the affected engine occurred, which was prior to the release of this AD. Therefore the AD had not been complied with.

AD 2012-22-16
Since 19 December 2012, AD 2012-22-16 has been effective to prevent failure of the third stage LPT duct segments, which could lead to LPT rotor damage, uncontained engine failure, and damage to the airplane. This AD requires removing and replacing certain third stage LPT duct segments.[58]

58 Also called outer transition duct segments.

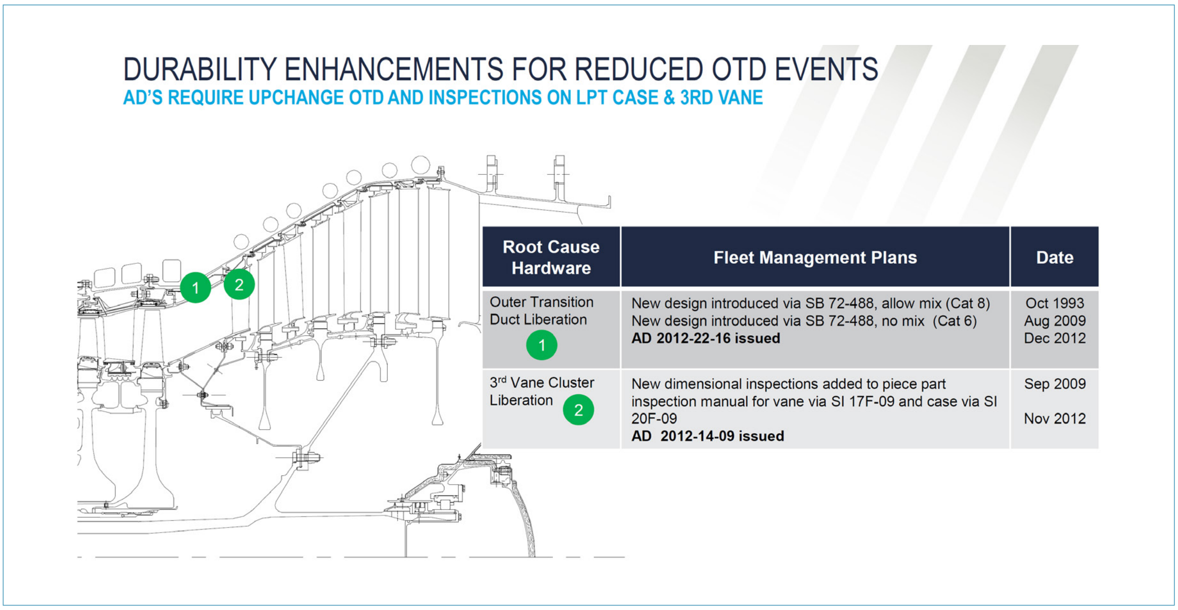

Figure 20: Durability enhancements for reduced OTD events. (Source: Pratt & Whiney)

Table 3: Pratt & Whiney service bulletin compliance category codes

Compliance category codes (service bulletin)	
Code	**Description**
1	Do before subsequent flight.
2	Do at the first time when the aircraft can stay at a line station or maintenance base which can do these procedures.
3	Do in "xxx" hours (or "xxx" cycles).
4	Do when the engine of module first goes to a maintenance base which can do these procedures regardless of the scheduled maintenance action or the reason for engine removal.
5	Do when the engine is disassembled sufficiently to give access to the changed subassembly (i.e. module, accessories, components, build groups) and to all changed spare subassemblies.
6	Do when the subassembly (i.e. modules, accessories, components, build groups) is disassembled sufficiently to give access to the changed part and to all changed spare parts.
7	Do when the supply of superseded parts is fully used.
8	Do when the operator thinks that the change is necessary because of experience with the parts being replaced.

Time line PW4000-94'' engine with serial numer 727305

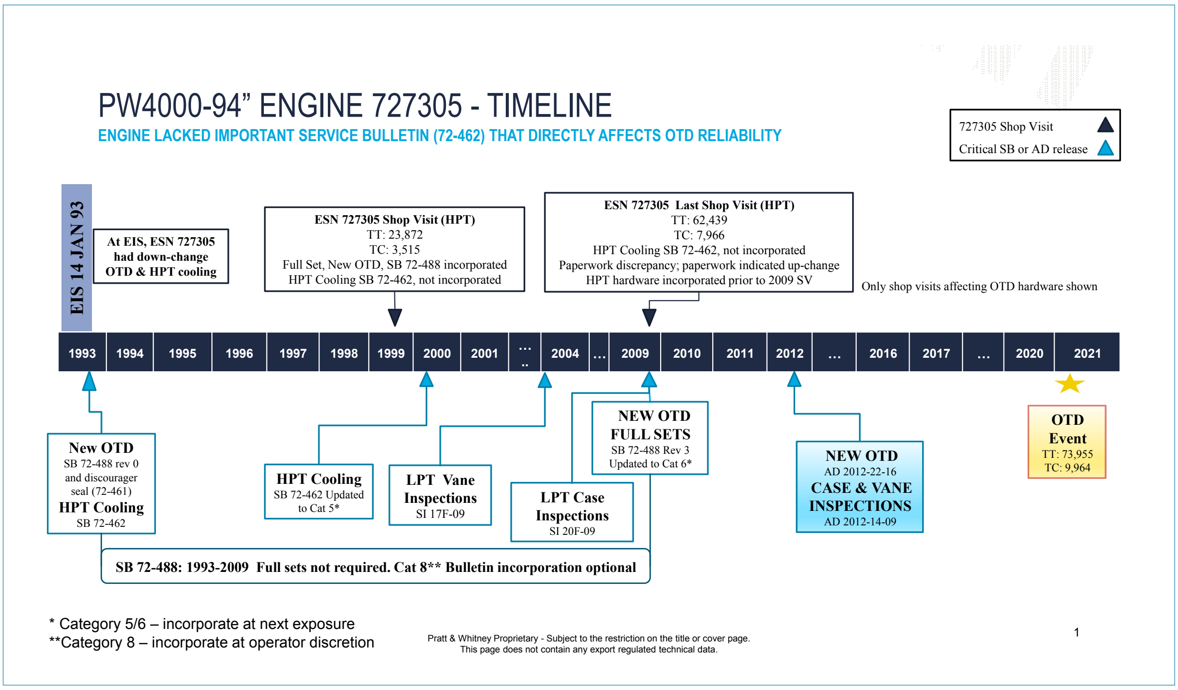

Figure 21: Time line PW4000-94'' engine with serial numer 727305. (Source: Pratt & Whitney)

In Figure 21, the box of the last shop visit mentions that there was paperwork discrepancy, indicating that ESN 727305 already had up-change components. The discrepancy referred to the part number for the dog bone seal of the HPT. The Dutch Safety Board did not investigate if and to which degree this discrepancy may have influenced decision-making by previous owners/operators about whether or not to embody SB 72-462 (as replacement of the dog bone seal is part of this service bulletin).

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