MINISTRY FOR
INNOVATION AND TECHNOLOGY
TRANSPORTATION SAFETY BUREAU

FINAL REPORT

2016-071-4P
SERIOUS INCIDENT

LHBP
16/03/2016

ATR 72-200
YR-ATI

The sole objective of the technical investigation is to reveal the causes and circumstances of aviation accidents and incidents, to initiate the necessary technical measures and to make recommendations in order to prevent similar cases in the future. It is not the purpose of this activity to apportion blame or liability.

NOTE: This document is the translation of the Hungarian version of the final report. Although efforts have been made to translate it as accurately as possible, discrepancies may occur. In this case, the Hungarian is the authentic, official version.

INTRODUCTION

This investigation was carried out by Transportation Safety Bureau, Hungary on the basis of

- Regulation (EU) № 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and repealing Directive 94/56/EC,
- Act XCVII of 1995 on aviation,
- Annex 13 identified in the Appendix of Act XLVI. of 2007 on the declaration of the annexes of the Convention on International Civil Aviation signed in Chicago on 7th December 1944,
- Act CLXXXIV of 2005 on the technical investigation of aviation, railway and marine accidents and incidents (hereinafter referred to as Kbvt.),
- Decree № 123/2005. (XII. 29.) of the Ministry of Economy and Transport on the rules of technical investigation of aviation accidents and incidents and other occurrences,
- Decree № 70/2015 (XII.1) of the Ministry of National Development on the technical investigation of aviation accidents and incidents, as well as on the detailed investigation for operators, and,
- In absence of other relevant regulation in the Kbvt., in accordance with Act CXL of 2004 on the general rules of administrative authority procedure and service.

The competence of the Transportation Safety Bureau of Hungary is based on Government Decree № 278/2006 (XII. 23.), and, as from 01 September 2016, on Government Decree № 230/2016. (VII.29.) 23) on assignment of a transportation safety organisation and on the dissolution of Transportation Safety Bureau with legal succession.

Under the aforementioned regulations

- The Transportation Safety Bureau of Hungary shall investigate aviation accidents and serious aviation incidents.
- The Transportation Safety Bureau of Hungary may investigate aviation incidents and irregularities which - in its judgement - would have resulted in accidents in other circumstances.
- The Transportation Safety Bureau of Hungary is independent of any person or entity which may have interests conflicting with the tasks of the investigating organisation.
- In addition to the aforementioned laws, the ICAO Doc 9756 and the ICAO DOC 6920 Manual of Aircraft Accident Investigation are also applicable.
- This Final Report shall not be binding, nor shall an appeal be lodged against it.

Incompatibility did not stand against the members of the IC. The persons participating in the technical investigation did not act as experts in other procedures concerning the same case and shall not do so in the future.

The IC shall safe keep the data having come to their knowledge in the course of the technical investigation. Furthermore, the IC shall not be obliged to make the data – regarding which the owner of the data could have refused its disclosure pursuant to the relevant act – available for other authorities.

This Final Report

was based on the draft report prepared by the IC and sent to all affected parties (as specified by the relevant regulation) for comments. All relevant parties accepted the draft report; the comments relating to the draft report have been integrated by TSB in this Final Report.

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DEFINITIONS AND ABBREVIATIONS

ADC	Aerodrome Controller
AGL	Above Ground Level
ATC	Air Traffic Control
ATC Clearance	Preliminary authorisation issued by the ATC prior to the start of an aircraft relevant to the route and procedure to follow during the flight
ATPL	Airline Transport Pilot Licence
ATS	Air Traffic Service
BEA	Bureau d'enquêtes et d'analyses pour la sécurité de l'aviation civile The technical investigation body of France for aviation occurrences
CAA	Civil Aviation Authority (Hungary)
CIAS	Civil Aviation Safety Investigation and Analysis Center The technical investigation body of Romania for aviation occurrences
CPL	Commercial Pilot Licence
CVR	Cockpit Voice Recorder
DRR	Digital Radio System (for communication within the airport)
FCL	Flight Crew Licencing
FDR	Flight Data Recorder
foot	unit of length (1 ft = 30.48 cm)
GKM	Ministry of Economy and Transport
GRC	Ground Controller
HQ	Headquarters
IC	Investigating Committee
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
ITT	Inter Turbine Temperature The gas temperature measured between the low-pressure turbine and the power turbines
Kbvt.	Act CLXXXIV of 2005 on the technical investigation of aviation, railway and marine accidents and incidents
LHBP	ICAO Code of Budapest Liszt Ferenc International Airport

LROP	ICAO Code of Bucharest Henri Coandă International Airport
LT	Local Time
MAYDAY	Emergency message code word
mbar	millibar: unit of pressure (1 mbar = 100 N/m²)
MIT	Ministry for Innovation and Technology
NFM	Ministry of National Development (also responsible for transport)
№2	Number 2 turbine (right hand side)
PT	power turbine (it rotates the propeller through a reduction gearbox module)
PWC	Pratt & Whitney Canada (an engine manufacturing company
QRH	Quick Reference Handbook
RHTP	Airport Fire Service
ROT236	Code name of the Budapest – Bucharest flight of TAROM Airline
RWY	Runway
RWY 13L	Left hand side runway, with the orientation of 125-135 degrees
RWY 13R	Right hand side runway, with the orientation of 125-135 degrees
RWY 31L	Left hand side runway, with the orientation of 305-315 degrees
RWY 31R	Right hand side runway, with the orientation of 305-315 degrees
TSB	Transportation Safety Bureau of Hungary
UTC	Universal Time Coordinated (always used in this Report unless indicated otherwise)
VAF	Vector Aerospace France (an engine maintenance company)

BRIEF DESCRIPTION OF THE OCCURENCE

Occurrence category		Serious incident
Aircraft	**Class**	Fixed wing aircraft
	Manufacturer	AVIONS DE TRANSPORT RÉGIONAL G.I.E.
	Type	ATR 72-200
	Registration	YR-ATI
	Operator	TAROM Romanian Air Transport
Occurrence	**Date and Time (Local Time)**	16 March 2016, 14:12
	Location	LHBP

The №2 (right hand side) engine of the aircraft and its nacelle were significantly damaged in the occurrence.

Reports and Notifications (local time)

The occurrence was reported to the dispatcher of TSB at 14:18 on 16 March 2016 by the duty service of HungaroControl Zrt.

The TSB dispatcher

– notified the duty service of CAA Hungary at 14:20 on 16 March 2016.
– informed the duty service of NFM at 14:28 on 16 March 2016.
– notified the investigating body of the operator's country at 11:05 on 17 March 2016.
– notified the investigating body of the manufacturer's country at 13:10 on 17 March 2016.
– notified the investigating body of the engine manufacturer's country at 08:01 on 17 March 2016.

Investigating Committee

The Director General of TSB assigned the following Investigating Committee (hereinafter referred to as IC) for the investigation of the serious incident on 16 March 2016:

Investigator-in-Charge (IIC)	György Háy	Investigator
IC Member	Gábor Erdősi	Investigator
IC Member	Péter Illés	Field Technician

Figure 1: *The affected aircraft at Stand № 220 after the passengers disembarked*

Participants in the investigation process

Operator	Tarom
Engine manufacturer	P&W Canada
Operator's country	CIAS (Romania)
Manufacturer's country	BEA (France)
Engine manufacturer's country	TSB Canada

Overview of the investigation process

The IC visited the scene of the occurrence, interviewed the crew of the aircraft, inspected the aircraft, copied the documentation available, and took photos. The IC received from HungaroControl Zrt. the voice records related to the occurrence and the management thereof, as well as the information recorded of the various radar systems during the given period of time. The IC received from the Airport Fire Service the reports related to the management of the occurrence. The IC received from Budapest Airport Zrt. the DRR communication voice record related to the management of the occurrence, as well as the report of the organization which was involved in the management of the occurrence. After the Operator's experts arrived, the IC took part in the inspection of the aircraft, and then supervised the dismounting of the engine. The IC seized the faulty engine as well as the voice and data recording devices, and had them transported to Paris by road, using the vehicle provided by the Operator. Under supervision of the IC, and in the presence of representatives from other organisations affected, the engine was disassembled and inspected at the Paris Plant of Vector Aerospace. Under joint supervision of the French (BEA) and Canadian (TSB) technical investigation bodies, the damaged parts were transferred to the laboratory of Pratt & Whitney Canada, the manufacturer of the engine, for a more detailed material testing and analysis, and were inspected there. Records from the CVR voice recording system and FDR data recording system were downloaded at the Paris site of BEA, and were subject to preliminary analysis with the participation of representatives of competent organisations. Data was transferred to the Budapest office of the IC for more detailed analysis.

A short summary of the occurrence

During takeoff in Budapest, following the retraction of the landing gears, the fire alarm system of the engine № 2 was activated. The pilots reported emergency, interrupted climb at an altitude of 3000 ft. above sea level, and turned back to land at LHBP. After the fire alarm, they reduced the power of the engine № 2, and then, after about one more minute, they completely shut it off, and started to operate both bottles of the engine fire extinguishing system one after the other. After landing, escorted by the fire service vehicles, they taxied to the stand where the passengers were disembarked. Disassembly and inspection of the engine showed that a 1st stage PT rotor blade fractured at its root, which then caused fracture of several other blades, strong vibration of the gas turbine, internal oil fire, and, in conclusion, severe internal damages to the engine. According to the test performed in the engine manufacturer's lab, fracture of the first blade was caused by a fatigue crack starting out of the trailing edge of the turbine blade. Neither the geometric inspection nor the material testing performed in the manufacturer's lab could identify exactly the cause of the crack. The IC recommended TSB Hungary to issue a safety recommendation to the Airline, and recommends the air traffic service to consider performing an earlier safety recommendation in order to manage similar cases more safely.

1. FACTUAL INFORMATION

1.1 History of the flight

On 16 Mach 2016, the aircraft type ATR 72-200 of Tarom (Romanian) airline, with registration number YR-ATI, started to perform the Budapest – Bucharest flight № ROT236. At 13:06, after receiving ground service in Budapest, the crew received the ATC clearance and the authorisation to start the engines from the GRC. At 01:08, following the engine start, the GRC authorised taxiing on taxiway P1 to holding point K of Runway 13L. When the aircraft arrived at the holding point, the GRC referred the aircraft to the ADC to the 118.1 MHz frequency. The aircraft established radio contact with the ADC who authorised them to enter Runway L13 and take-off from there.

During take-off, simultaneously with starting the retraction of the landing gears, the crew detected fluctuation in the torque of the №2 (right hand side) engine, and then the fire alarm of the engine was activated. At 13:12:28, on the 118.1 MHz (ADC) frequency, the pilots reported emergency (by using the standard 'MAYDAY' expression three times) and then engine problem. Although the flight crew reported no fire or smoke, the ADC directly (visually) detected smoke emission from the engine, and ordered 'Anticipated air traffic occurrence' alarm.

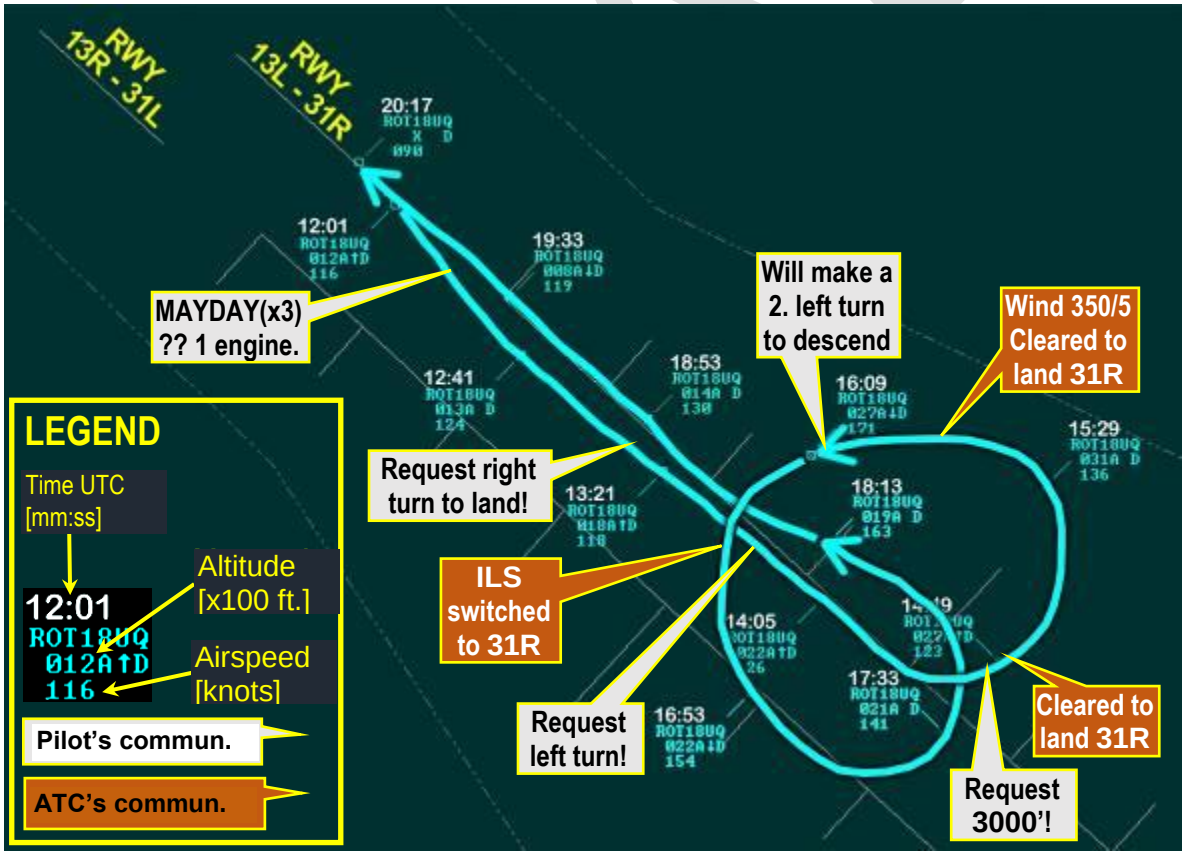


Figure 2: *The route, parameters and communication of the flight ("??": incomprehensible utterance)*

At 13:13:10 the First Officer communicated on the radio that they intended to return to the airport by a right turn. Then the Captain assumed radio communication and said that, opposite earlier communication, they intended to return to LHBP by a left turn. After receiving authorisation from the ADC, they started to turn back with a left turn, but also continued climbing, and at 13:14:49,

still climbing at an altitude of 2700 ft., they requested authorisation for 3000 ft., which they were given.

During the turn, the ADC gave authorisation for landing at Runway 31R. However, the flight crew found during the turn that their altitude was too high for landing from a straight-line flight towards the runway, so they requested and received authorisation to perform a descending left turn. During the second turn, the ADC informed the flight crew that the ILS (Instrument Landing System) had been switched over to Runway 31R. The alarmed units of the Airport Fire Service were deployed, and they were on hold in two groups: the one at the crossing of the Taxiways A8 and X, and the other at the crossing of the Taxiways N and B4.

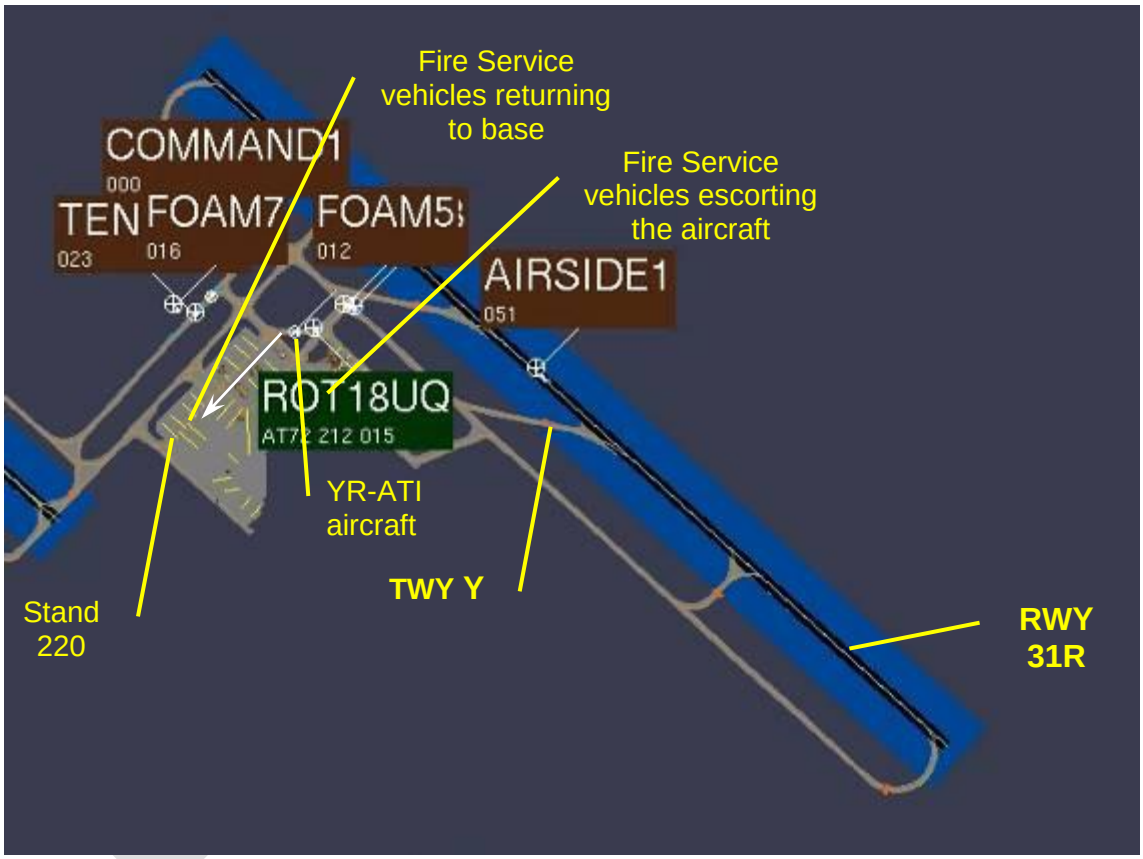


Figure 3: *After landing, the aircraft taxied to Stand 220, escorted by the Fire Service*

The aircraft landed at Runway 31R with no further difficulty at 13:20:12, and left it through the speed exit taxiway Y. As soon as the landing aircraft passed the holding point X, the fire vehicles waiting at the crossing of the Taxiways A8 and X entered the runway, and started to follow the landing aircraft at high speed. At 13:20:29, the ADC asked the flight crew whether they were able to taxi on their own. As the answer was positive, the ADC redirected them to the frequency (121.9 MHz) of the GRC. The GRC ordered the aircraft to taxi to Stand № 220 through Taxiway L. The fire vehicles arriving from the runway through Taxiway A7 closed up behind the continuously moving aircraft. Some of the fire vehicles on standby began to return to their central base, while others escorted the aircraft as far as its stand. The aircraft, the escorting fire vehicles and other vehicles arrived at Stand № 220 at 13:25, where, after shutdown of the working engine № 1, the passengers disembarked in the usual way.

1.2 Injuries

Injuries	Crew		Passengers	Other
	Flight Crew	Cabin Crew		
Fatal	-	-	-	-
Serious	-	-	-	-
Minor	-	-	-	-
None	2	2	19	

1.3 Damage to the Aircraft

The power turbine stage of the right hand side (№2) engine (Figure 4) and the tail pipe were badly damaged, and the fire caused significant damage to the engine nacelle (Figure 5). Engine failure was contained and no damages have been found outside of the engine nacelle.

Figure 4: *engine №2 from the direction of the tail pipe, after landing*

Figure 5: *Visible signs of the high temperature in the nacelle of the engine №2*

1.4 Other damage

The IC has no information on other damage.

1.5 Information on personnel

1.5.1 Captain

Age, Nationality, Gender		28, Romanian, Male
License data	**Type**	RO.FCL / ATPL
	Professional validity until	31/07/2016
	Medical validity until	25/05/2016
	Ratings	ATR 42/72
	Certificates	IR, MET
Flying experience in hours	**Total**	3 083 hours
	In previous 28 days	84:50 hours
	In previous 7 days	21:25 hours
	on the involved aircraft type, total	AT72: 816 hours AT42: 2 123 hours
Aircraft types flown		ATR 45/72
During the occurrence: flew the aircraft / performed assistance		Flew the aircraft
Rest time in the previous 48 hours		34:15 hours
Date of last training		06/05/2015 / 26/11/2015
Date and result of simulator test		27/11/2015 „Excellent”

1.5.2 First Officer

Age, Nationality, Gender		48, Romanian, Male
License data	**Type**	RO.FCL / CPL
	Professional validity until	31/08/2016
	Medical validity until	01/07/2016
	Ratings	ATR 42/72
	Certificates	IR, MET
Flying experience in hours	**Total**	4 482 hours
	In previous 28 days	34:10 hours
	In previous 7 days	14:45 hours
	on the involved aircraft type, total	AT72: 890 hours AT45: 3 592 hours
Aircraft types flown		AT 45/72
During the occurrence: flew the aircraft / performed assistance		Performed assistance
Rest time in the previous 48 hours		34:20 hours
Date of last training		16/07/2015 / 18/02/2016
Date and result of simulator test		18/02/2016 „Pass”

1.6 Aircraft data

1.6.1. General

Aircraft class	Engine-powered land plane
Manufacturer	AERO INTERNATIONAL
Type / subtype (number)	ATR 72-212A
Date of manufacturing	29/04/2009
Serial number	867
Registration	YR-ATI
State of Registry	Romania
Owner	TAROM S.A.
Operator	TAROM S.A.
Call sign during the affected flight	TAROM S.A.
Date of manufacturing	ROT18UQ

1.6.2. Airworthiness

Airworthiness Certificate	**Serial**	244
	Date of issue	05/06/2009
	Valid until	04/06/2016
	Last review	27/05/2015
	Restrictions	N/A

1.6.3. Engine data

Class	Turboprop	
Type	PW127M	
Manufacturer	Pratt & Whitney Canada	
Position on aircraft	Engine №1	Engine №2
Serial number	Not relevant	AM0088
Date of installation	Not relevant	12 Nov 2014
	hours/ cycles flown	
Since manufacture (Jan 1998)	Not relevant	28 952 h / 25 708
Since last overhaul	Not relevant	10 981 h / 10 755
Since last periodical maintenance	Not relevant	2 491 h / 2 415

Maintenance history of the affected engine

Contents of maintenance	**Date**	**Hours (*cycles*) flown**	**Maintenance organisation**
Overhaul	28/09/2009	17 971 *14 953*	Vector Aerospace France
Hot section inspection + repair	01/02/2012	21 677 *18 589*	Fiat Avio
Hot section inspection + life limited parts replacement	21/10/2014	26 461 *23 293*	Vector Aerospace France

1.6.4. Propeller data

Sort	Six-blade, variable pitch
Type	Hamilton Sundstrand 568F-1

1.6.5 Aircraft loading data

The loading data of the aircraft had no effect on the course of events, so it needs no detailed analysis.

1.6.6 Faulty system and equipment information

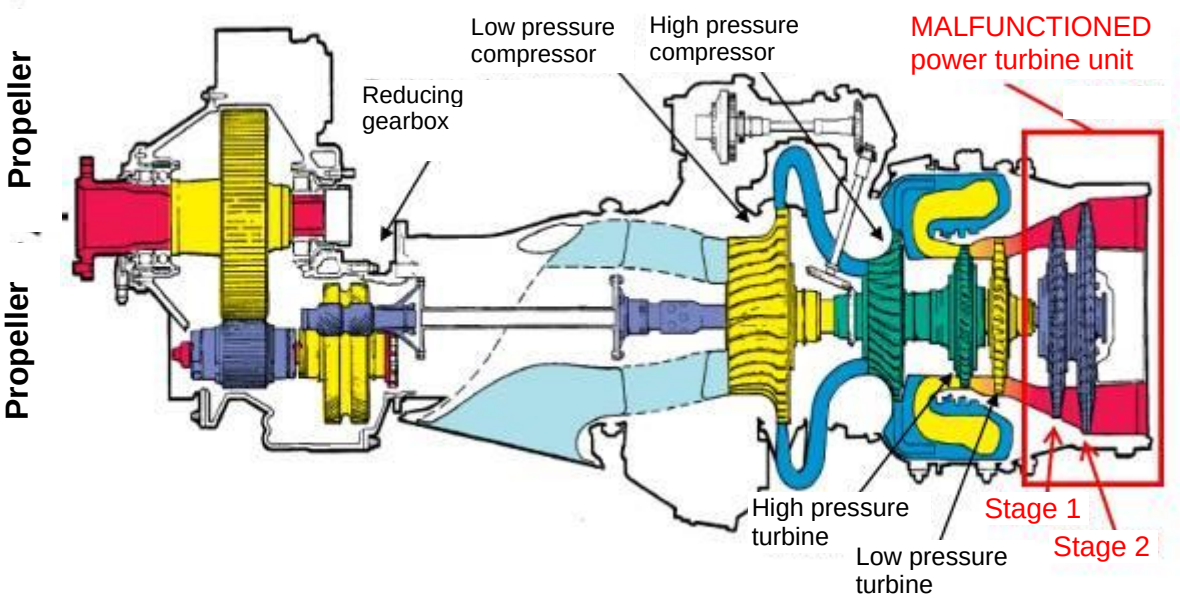


Figure 6: *Principal layout of the Pratt & Whitney PW 127M turboprop engine*

The engine has three rotor assemblies with two-stage centrifugal compressors. Each compressor is powered by a single-stage axial flow turbine. The propeller is rotated by a two-stage power turbine through a reduction gearbox module.

During the flight under investigation, a blade of the rotor assembly of 1st stage Power Turbine fractured in the course of the take-off run. The fractured blade badly damaged the blades of both the stator and the 2nd stage rotor assembly. The outblown debris damaged the tail pipe. The vibration caused by the imbalanced rotor assembly damaged the № 6 & /7 bearing housing and the connected lube oil pipes, and, consequently, also the low- and high-pressure rotor assemblies and shafts. The long-acting high temperature caused further severe damages to the low- and high-pressure turbines and their shafts.

The item number of the turbine blade which initiated the malfunction is 3078563-01, and its serial number is HWMM6651. It was installed in the engine during repair at the plant of Vector Aerospace France on 21 Oct 2014. Then it performed 2 491 hours (2 415 cycles) until the malfunction under investigation.

1.6.7 On-board warning systems

The aircraft was equipped with a transponder and TCAS, as well as with GPWS. The systems worked in compliance with the requirements; the IC made no comment relevant to their operation, nor was any irregularity reported to the IC.

1.7 Meteorological data

The occurrence took place at daytime, with good visibility and no weather phenomena worth mentioning.

METAR: LHBP 161300Z 05005KT 360V120 9999 FEW031 SCT065 09/00Q1030 NOSIG
(Wind: 5 knots from 50 degrees, variability: between 360 and 120 degrees. Visibility: over 10 km. Few clouds at 3100 feet, scattered clouds at 6500 feet. Temperature: 9ºC, Dew point: 0ºC. Pressure corrected to sea level (QNH): 1030 mbar. No significant change expected.)

The weather circumstances had no effect on the course of events, so no detailed analysis is needed.

1.8 Navigation aids

The navigation aids had no effect on the course of events, so no detailed analysis is needed.

1.9 Communication

The communication equipment worked correctly, had no effect on the course of events, so need not be analysed in detail.

1.10 Airport information

The aircraft took off from Runway 13L at LHBP airport on 16 March at 13:11. The scheduled destination airport was LROP. Actual landing took place at Runway 31R at LHBP airport on 16 March at 13:20. The Runway 13L-31R has concrete finish, and its dimensions are 3707m x 45m.

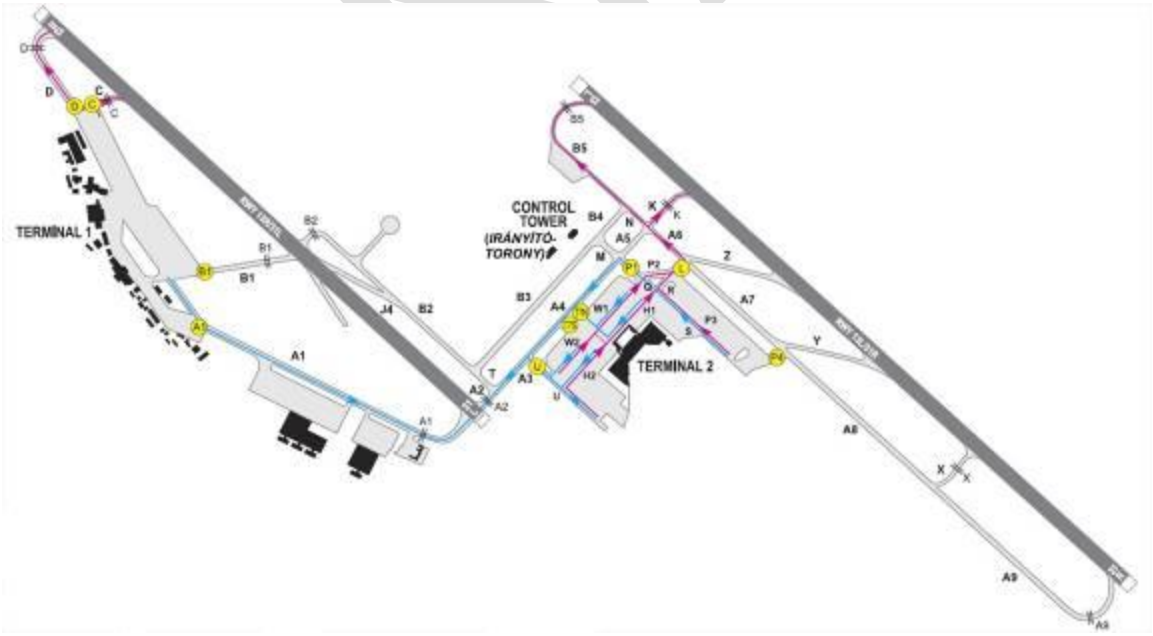


Figure 7: *Layout of Budapest Liszt Ferenc International Airport*

1.11 Flight recorders

As regards the ATC equipment and the aircraft, the required data recording systems were operated. The IC secured the voice recorder and the flight data recorder of the aircraft on the day of the occurrence, and had them sent to Paris, and then to the laboratory of BEA. Experts from BEA read out and primarily evaluated the recordings. They made certain data of the flight ending in an incident and the report including a preliminary evaluation available, in electronic format, to the IC. After successful readout, the IC released the seizure of the recorders, and the devices were returned to the aircraft operator.

1.11.1 CVR (Cockpit Voice Recorder)

Onboard voice recorder	**Manufacturer**	L3 Communications
	Type	FA2100
	Serial number	596517
	Place of readout	BEA HQ Paris

The audio recorder recorded the voices and noises in the cockpit on the following four channels for 2 hours, 4 minutes and 14 seconds:

- the voice of the passenger information system,
- the microphone in the First Officer's headset,
- the microphone in the Captain's headset,
- audio record of the general noise in the cockpit

The CVR recordings and the FDR recordings were synchronised on the basis of the noise of shut-off of the autopilot.

Auditory signals identified in the audio records (hh:mm:ss):

13:11:32 ..... single chime
13:11:44 – 13:11:54 .... continuously repetitive chime
13:12:04 – 13:12:05 .... continuously repetitive chime
13:12:08 – 13:12:09 .... continuously repetitive chime
13:12:15 ..... single chime
13:12:17 ..... single chime
13:12:21 ..... single chime

1.11.2 FDR (Flight Data Recorder)

Onboard data recorder	**Manufacturer**	L3 Communications
	Type	FA2100
	Serial number	590638
	Place of readout	BEA HQ Paris

Following the readout, the raw data file recorded of a total period of 305 hours was decoded using the description (dataframe: V2b conf1) received from the aircraft manufacturer. The charts created on the basis of the most important data of the flight ending in an incident are shown in Figures 8 and 9.

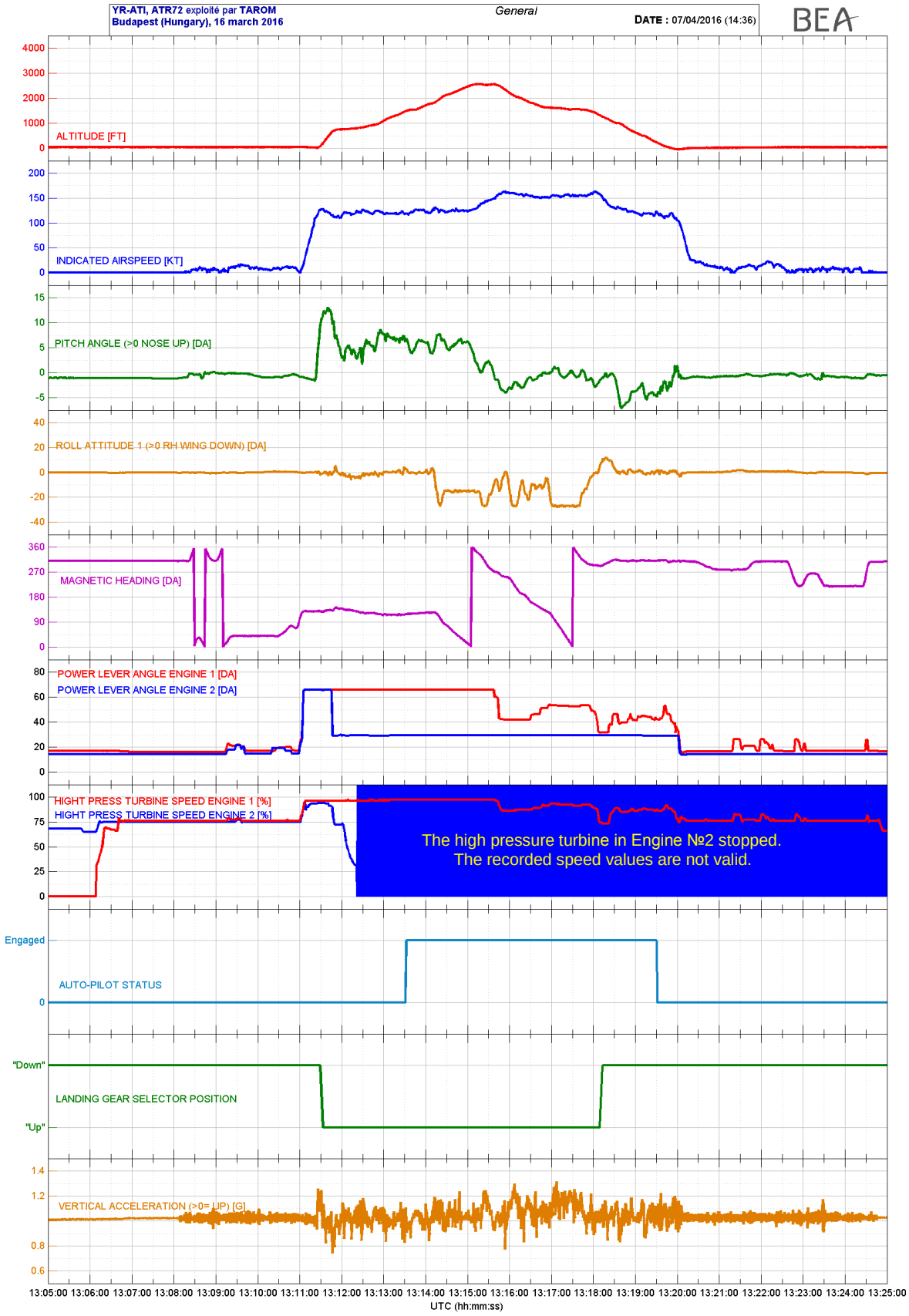


Figure 8: *Major flight data from the entire period of the last flight, as read out from the FDR.*

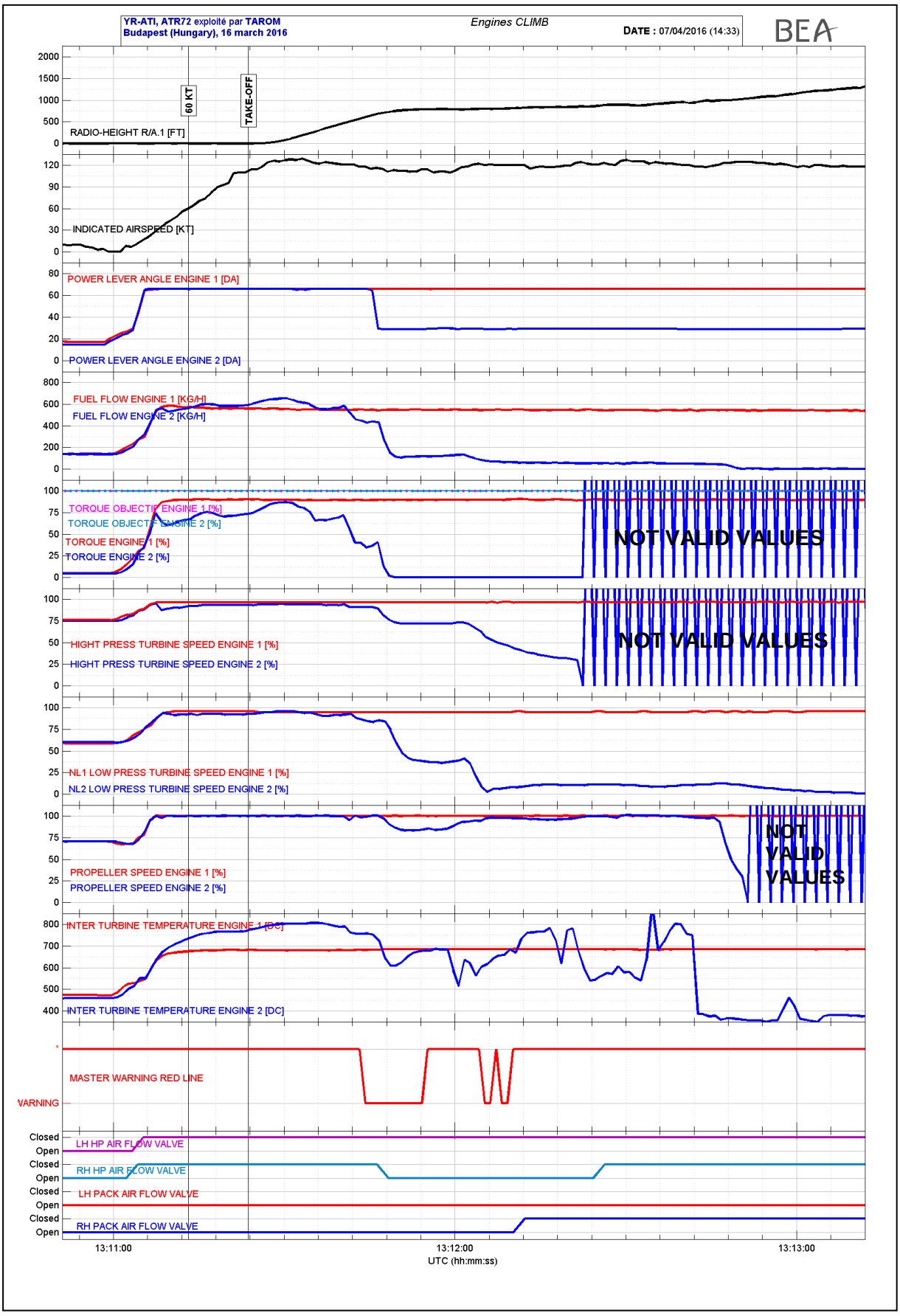


Figure 9: *Major flight data from the entire period of the climb, as read out from the FDR.*

1.12 Wreckage and impact information

There was no wreckage.

1.13 Medical and pathological information

There was no evidence that physiological factors, or other impediments have affected the legal capacity of the personnel concerned.

1.14 Fire

During the incident, the fire alarm system of the engine №2 of the aircraft was activated, smoke flowed into the passenger cabin, and the smoke emitted from the engine №2 was perceived visually in the control tower of the airport. The pilots reduced the power of the malfunctioned engine, but it was only a minute after that they shut it off and started both bottles of the fire extinguishing system of the engine. The fire alarm worked for ten seconds, then it stopped. Damages caused by severe burn were observed both in the engine and its nacelle during the inspection. The burns did not reach beyond the nacelle.

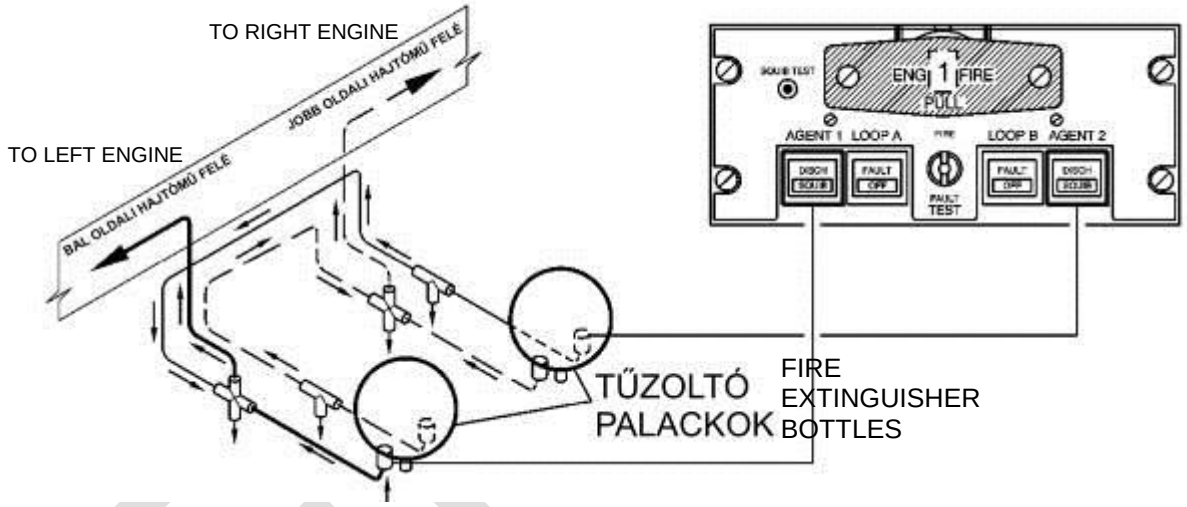


Figure 10: *Layout of the engine fire extinguishing system.*

1.15 Survival aspects

No injury occurred during the incident.

At 13:12:18, the Captain of the aircraft reported emergency to the ADC by using the ‘MAYDAY’ expression. As regards the nature of the problem, his communication only included that they were flying with one engine. He said nothing more, even when asked by the ADC. The ADC who detected the smoke emitted from the engine directly (visually) ordered ‘Anticipated air traffic occurrence’ alarm. The Airport Fire Service received the alarm at 13:13. As not informed on the number of passengers, the Commander of the Service took the capacity of the aircraft into consideration, and ordered high priority alarm (№ 4). The alarmed units of the Airport Fire Service started to deploy at 13:16, and were on hold in two groups: the one at the crossing of the Taxiways A8 and X, and the other at the crossing of the Taxiways N and B4.

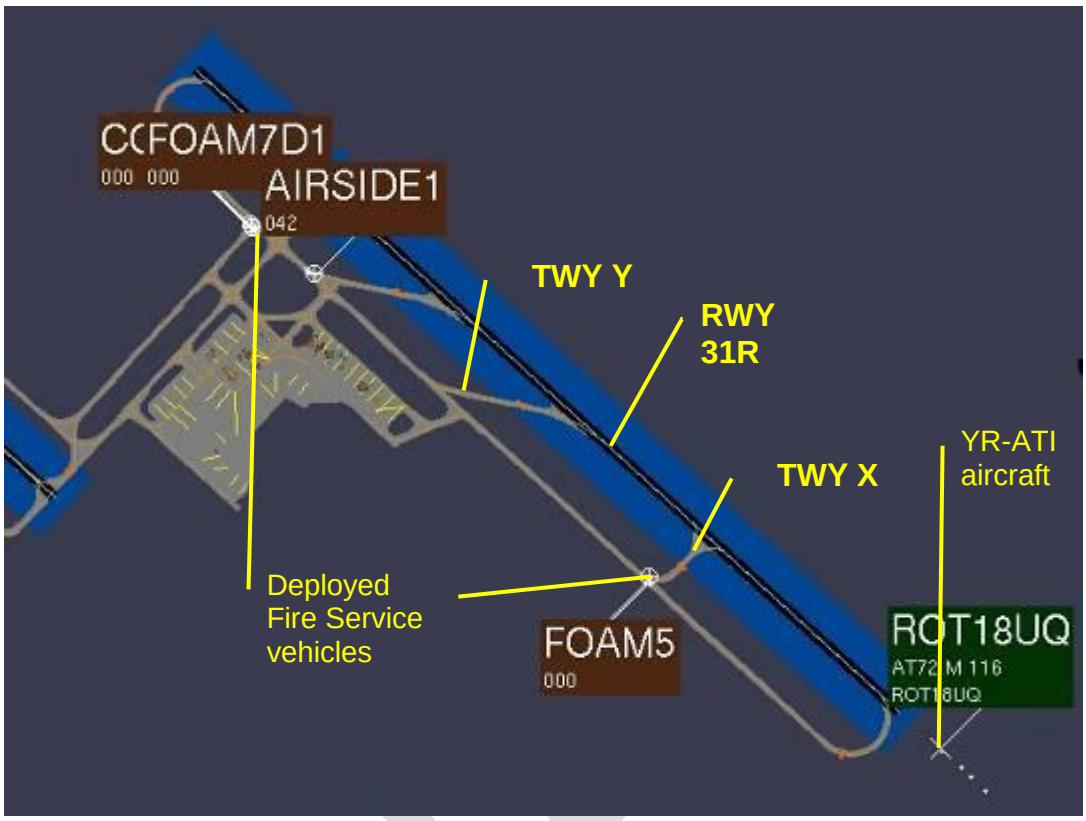


Figure 11: *Deployment of the Fire Service units prior to the landing of the aircraft*

During remote inspection of the landing aircraft, the leader of the fire brigade detected no sign of fire or smoke. As soon as the landing aircraft passed the holding point X, the fire vehicles waiting at the crossing of the Taxiways A8 and X entered the runway, and started to follow the landing aircraft at high speed. At 13:20:29, the ADC asked the flight crew whether they were able to taxi on their own. As the answer was positive, the ADC redirected them to the frequency of the GRC, who ordered the aircraft to taxi to Stand № 220 through Taxiway L. The fire vehicles arriving from the runway through Taxiway A7 closed up behind the continuously moving aircraft. Some of the fire vehicles on standby began to return to their central base, while others (Command-1, Command-2, Foam-5, and Foam-8) escorted the aircraft as far as its stand. At 13:23, the leader of the fire brigade took action to turn back the firefighting units alarmed in the city. The aircraft and the escorting fire vehicles arrived at Stand № 220 at 13:25, where, after shutdown of the working engine № 1, the passengers disembarked in the usual way. The fire brigade members (Fire-24 and Aircraft-20) inspecting the aircraft inside smelt smoke which they eliminated by ventilating the fuselage. The Fire Service handed over the scene to the arriving investigators of TSB Hungary at 13:48.

1.16 Test and investigation methods

Under supervision of the IC, and in the presence of representatives from competent organisations, the engine was disassembled and inspected at the Paris Plant of Vector Aerospace. The parts which seemed to require more detailed testing were transported to the laboratory of Pratt & Whitney Canada, the manufacturer of the engine. The lab informed the IC on the findings of that inspection in the form of a written report.

1.16.1 Disassembly of the engine

Figure 12: *Disassembly of the engine at the Paris plant of Vector Aerospace France*

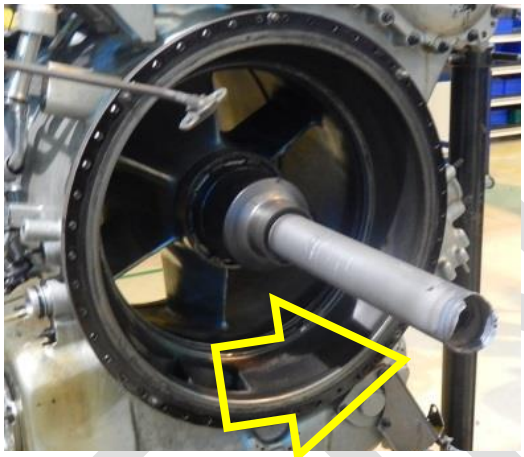
The engine dismounted from the aircraft was inspected and disassembled at the Paris plant of Vector Aerospace France (VAF), the contracted maintenance company on 5 and 6 April 2016, in the presence of the representatives of the Hungarian, French and Romanian safety investigation bodies, the operator, the manufacturer, and the affected insurance company.

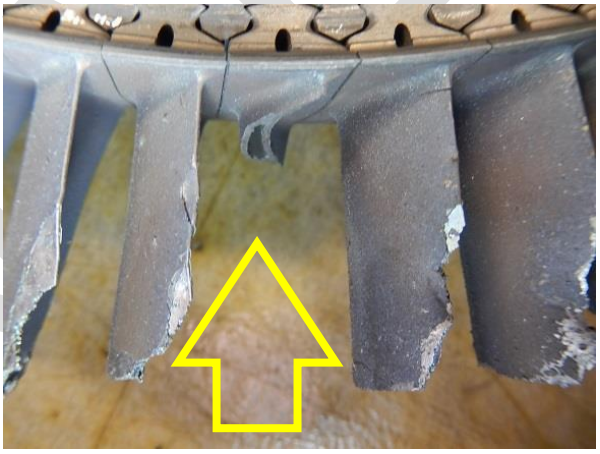
Figures 13 & 14: *Boroscope photos of the low pressure turbine and the power turbine (VAF)*

It was found during the boroscope inspection and disassembly that

- The blades of the discs of both stages of the power turbine were badly damaged
- The low-pressure compressor showed no sign of damage caused by ingested foreign object.
- The outside of the engine showed the signs of effects of high temperatures.
- Significant quantity of metal debris was found in the oil system
- Both discs of the power turbine were badly damaged.

- 19 blades of 2nd stage PT were fractured and the rest of the blades were damaged.
- The tail pipe was damaged by partly molten metal debris flowing out.
- Each blade of the 2nd stage PT stator was damaged.
- Each blade of the 1st stage PT rotor assembly fractured. A blade of the rotor assembly broke off near its root, which may have been the point where the engine started to become inoperable.
- Several blades of the 1st stage PT stator were melted.
- The № 6 & 7 bearing housing disintegrated due to high temperature.
- The shafts of the low-pressure turbines and power turbines melted and fractured.
- Each blade of the rotor assembly of the low-pressure and high-pressure turbines fractured.
- The surface of the stator of the low-pressure turbine melted at the high temperature.
- The blades of the low- and high-pressure compressors were damaged when they reached inside the housing due to the failed turbines, bearings and shafts.





Figures 15 & 16: *The fractured shaft of the power turbine, and the stump of the fractured blade which started the process leading to engine failure (Vector Aerospace France)*

The information acquired during disassembly of the engine show that the process leading to the failure of the engine may have been started by the fracture of a blade in the 1st Stage PT. The rotor assembly became unbalanced, and the vibration evoked by it probably broke the three oil pipes holding the № 6 & 7 bearing housing. The unsupported bearing housing could not keep the shafts in place, and the spilt oil caught fire. As a consequence of the above events, both the low-pressure and the power turbine rotor assemblies were displaced, and were finally damaged, and the shafts fractured. The damages of the compressors are the consequence of the severe damages of the turbine section.

1.16.2 Inspection of the faulty parts of the engine at the factory

Following the disassembly of the engine in Paris, the following parts were sent to the lab of Pratt & Whitney Canada (PWC) for a more detailed examination:

- stator and rotor assembly of the power turbine
- power turbine shaft
- The common housing of the № 6 & № 7 bearings with the three oil pipes to it
- rotor assemblies of the low- and high-pressure turbines
- shaft of the low-pressure turbine

Figure 17: *Parts sent to PWC (VAF)*

Figures 18 & 19: *the rotor assembly and the fractured, molten shaft of power turbine, 2nd stage (PWC)*

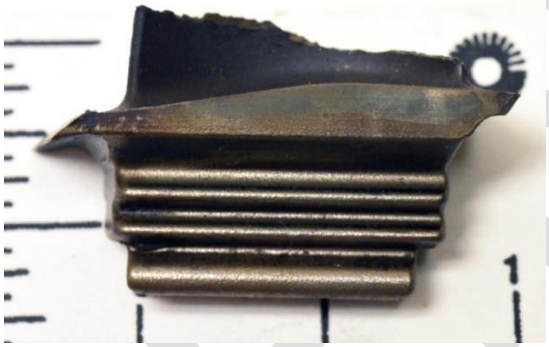
The examination of the parts was finished on 26 July 2016. The submitted parts were subject to material testing by optical and electron microscopy and spectroscope. Major findings of the examination:

- The ends of the blades of the rotor assembly of the HP turbine fractured, and there are signs of overheating at the top of the trailing edge.
- A blade of the rotor assembly of the HP turbine broke in halves due to a single impact.
- The rotor assembly of the LP turbine shows signs of mechanical damages and burn.
- The sealing of the № 6 bearing burnt.
- The 1st stage PT stator shows impact damage and molten material debris.
- The 1st stage PT rotor assembly shows damage caused by impact and friction.

- The 2nd stage PT stator shows impact damage.
- Several blades of the 2nd stage PT rotor assembly fractured at different heights due to single impact.
- The bearing housing № 6&7 was overheated, deformed, its fastening screws fractured; the oil pipes to it also broke and show burn marks as well.
- The PT shaft melted and fractured at the № 5 bearing area.
- The shaft of the LP turbine also fractured at the № 5 bearing area as an effect of friction with the fractured shaft of the power turbine.

Figure 20: *The molten and fractured shaft of the power turbine (Pratt & Whitney Canada)*

1.16.3 Material testing of the blade which started the engine failure



Figures 21 & 22: *Root of the fractured PT blade and the fractured surface (Pratt & Whitney Canada)*

The remaining part of the fractured blade of the 1st stage PT rotor assembly was sent to the material testing lab of Pratt & Whitney Canada for more detailed testing. Major findings of the lab test:

- A fatigue crack started out from the trailing edge of the blade and spread towards the leading edge (Figures 21 & 22, white arrow), as far as half of the chord length. The remaining part fractured due to overloading.
- The composition of the alloy of the blade meets the relevant requirements.
- The geometrical layout of the trailing edge of the blade shows no anomaly.
- The remainders of other blades of the power turbine showed no fatigue cracks.

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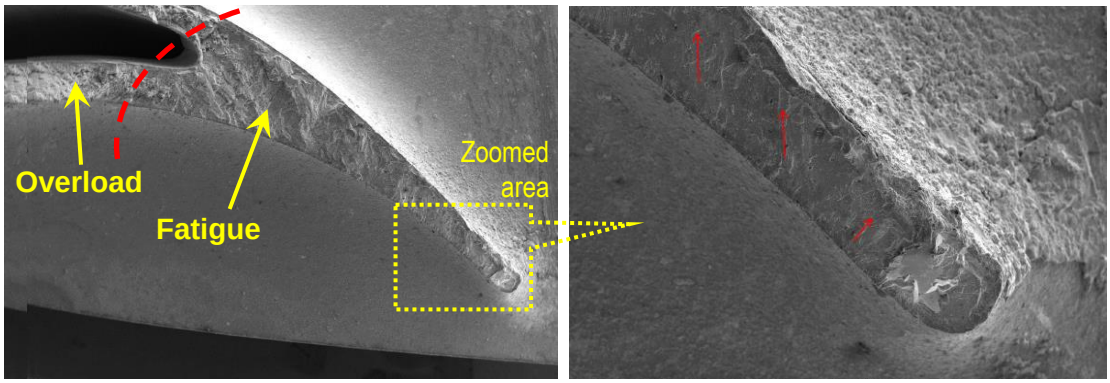

Figure 23: *Electron microscopy image of the fractured surface at the trailing edge of the blade (PWC)*

The 1st stage PT rotor assembly included both new blades and used ones. The fractured blade was fitted as a new one between two old ones. It cannot be stated that the fatigue crack which led to fracture of the blade would have been due to the vibration generated by loose fastening.

On the basis of information from the lab test, the experts of the manufacturer said that the cause of the formation of the fatigue crack which caused fracture of the blade cannot be established in absence of the structural and dimensional differences.

It may be established on the basis of information from the lab test that a fatigue crack started out from the trailing edge of the trailing edge of a blade of the PT1 and its spreading finally led to fracture of the blade. No defect of material or mechanical damage was found around the area where the crack started out. The damage to other stator vanes and rotor blades of the power turbine was a consequence of the first blade fracture. The power turbine became unbalanced, and its intensive vibration caused fractures of the of the oil pipes and screws which fixed bearing housing № 6 & 7, as a result of which the low- and high-pressure power turbine shafts may have contacted and fractured. The fire fuelled by spilt oil led to thermal damage to or deformation of the 1st stage PT stator, the low-pressure turbine, the bearing housing № 6&7, and the oil pipes. The damage to the blades of the high-pressure turbine was due to overheating.

1.17 Organizational and management information

1.17.1 Requirements for the flight crew's activity

A QRH manual is placed in the flight cabin of the aircraft, at a location where it is readily available to the pilots at work. This contains, among others, the procedures developed to assist the managing of various extraordinary and emergency situations.

PL: Power Lever
FI: Flight Idle
CL: Condition Lever (*Propeller control lever*)
FTR: FeaTheR
SO: Shut Off
PULL
AGENT (*fire extinguishing media*)
DISCHarge
ASAP: As Soon As Possible

Figure 24: *Emergency checklist related to in-flight engine fire or serious engine malfunction*

1.17.2 Requirements for the activities of the airport services

Annex 4 to the ATS Manual which regulates the work of the air traffic controllers of HungaroControl includes a general procedure to apply in cases of emergency. Section 1.6 discusses the case of on-board fire or smoke. That section includes no reference to aircraft moving on the ground.

Part 1 ICAO Doc 9137 of discusses rescue and firefighting activities. Section 12.3.23 of this deals with aircraft fire warning indicators and says that “it is advisable to bring the aircraft to a stop and allow the rescue and firefighting personnel to inspect the area involved, prior to parking at the apron where fire would endanger other aircraft or buildings”. The aircraft should continue taxiing to the apron depending on the result of such inspection.

1.18 Additional information

Earlier similar occurrence 1 (TSB Hungary ref.: 2010-185-4P)

On 21 July 2010, the smoke detector of the rear luggage compartment of the aircraft type Embraer ERJ-170 (flying as Flight LOT531 of the Warsaw – Budapest line) indicated smoke prior to landing in Budapest. The crew activated the fire extinguishing system of the luggage compartment, reported MAYDAY, and performed priority landing at Runway 31R, under control of the ‘Traffic Director’ service. The fire service was alarmed and deployed, and they were on standby. The smoke indicator remained active after landing too, but, as no signs of actual fire was detected visually neither from the passenger cabin nor from the control tower, the aircraft taxied, without stopping, to the terminal apron under escort of the fire service, and then it finally stopped at the № 70 stand. Simultaneously with the disembarking of passengers, the luggage compartments were opened and inspected. No fire or signs of earlier fire were found. According to the IC, the handling of the aircraft after landing took several risks which could have been significantly reduced by appropriate actions. The IC issued safety recommendations for the sake of safer management of similar situations. One of these recommendations related to the movement of aircraft on the ground, as follows:

BA2010-185-4-4 *The IC recommends HungaroControl Zrt. to regulate, in its ATS manual or in other appropriate manner, the procedure to be followed relating to the managing of aircraft which report smoke or fire*

warning, with special regard to communication and the movement of such aircraft on the ground.

Earlier similar occurrence 2 (TSB Hungary ref.: 2011-120-4P)

The ATR42-500 aircraft (registration YR-ATG, operated by TAROM) took off from runway 31L of Budapest Liszt Ferenc International Airport for Bucharest (as flight ROT234) at 17:21 UTC on 17 June 2011. The RH engine failed and caught fire 11 seconds after take-off. The flight crew acted in accordance with the emergency checklist and declared MAYDAY while making a turn with the intention to land. Some of the passengers panicked when they noticed the smoke in the cabin and the flaming engine through the window. The pilots received clearance from the tower and landed on runway 13L, 3 minutes after takeoff, and left for the taxiway. The engine fire was put off in-flight using the built-in fire extinguishing system of the engine. The captain ordered emergency evacuation of the aircraft on the taxiway, which was successfully performed. After inspection, the aircraft was towed to the technical apron, escorted by the fire service.

The engine was dismounted and tested at the manufacturer's laboratory, and the results proved that the failure was caused by fracture of a turbine blade. The blade fracture was a fatigue fracture as a consequence of latent material defect (microshrinkage porosity). Other damages to the engine were direct or indirect consequences of the fracture of the turbine blade.

During the investigation, the IC became aware of two similar occurrences involving the same aircraft type and engine type: one in 2011, and another in 2013. The three investigating bodies (Italian, Danish, Hungarian) involved in the investigation of the occurrences of 2011 issued five interim safety recommendations with mutually agreed wording, primarily in the subject of inspection of turbine blades during manufacturing, and the requirements relating to the handling of similar in-flight emergency situations.

1.19 Useful or effective investigation techniques

The investigation did not require techniques differing from the conventional approach.

2. ANALYSIS

2.1 Course of the flight in detail

UTC time (hh:mm:ss)	Altitude AGL (ft)	Airspeed (kt)	Event description
ON GROUND (AT TAKE-OFF)			
13:10:59	-	0	Power levers started to move forward
13:11:05	-	16	Power levers were set to 65°
13:11:07	-	27	Torque engine #1 reached 79% and continued to increase. Torque engine #2 reached 74% and started to decrease. The first sign of irregular operation of the engine #2.
13:11:11	-	49	Torque engine #1 stabilized to 89.5%. Torque engine #2 was 64.2%. Propellers' speed was about 100% for both engines. ITT was about 640°C for both engines.
13:11:13	-	60	ITT engine #2 increased more than ITT engine #1 (ITT engine #1 = 677°C ; ITT engine #2 = 740°C)
IN FLIGHT (AFTER TAKE-OFF)			
13:11:24	1	114	The aircraft was in flight.
13:11:29	53	125	Fuel flow for engine #1 was 554 KG/H Fuel flow for engine #2 was 650 KG/H Torque engine #2 reached a maximum value of 86.7% and started to decrease.
13:11:30	100	127	ITT engine #2 reached 802 °C. *(It may explain the single scheme recorded on the CVR two seconds later.)*
13:11:33	199	129	The landing gear was retracted.
13:11:35	260	123	ITT engine #2 reached 806°C and started to decrease. (ITT engine #1 was stabilized on 680°C.)
13:11:44	588	118	Master Warning light ('FIRE') activated during about 10 seconds. *(A continuous repetitive chime was recorded in the CVR at this time.)*
13:11:46	653	116	Power lever engine #2 was set to 29°. Fuel flow for engine #2 decreased rapidly from 432 Kg/h to 116 Kg/h.
13:11:48	691	111	RH HP air flow valve passed from Closed to Open. (The aircraft manufacturer indicated that the opening of this valve is the consequence of Power lever engine #2 set to 29°. Smoke begins to flow into the fuselage from the damaged engine #2 through the air conditioning system.
13:11:49	705	113	Torque engine #2 reached 0%. The engine starts autorotation at ITT internal temperatures fluctuating between 500°C and 851°C.

13:12:12	777	120	RH Pack air flow valve passed from Open to Closed. *(The aircraft manufacturer indicated that this valve got close because of lack of muscle pressure into the valve actuator.)* The smoke stops flowing into the fuselage.
13:12:20	792	119	The pilot reports engine-related emergency (MAYDAY).
13:12:22	799	124	HIGH Press Turbine speed engine #2 reached 0% *and became invalid until the end of flight*. *Torque engine #2 became invalid until the end of the flight.*
13:12:25	813	121	RH HP bleed valve passed from Open to Closed. *(The aircraft manufacturer indicated that the valve closed because of lack of muscle pressure into its actuator.)*
13:12:40	901	120	The cockpit noise record on the CVR included a noise similar to the operation of the Fire Handle.
13:12:42	910	118	ITT engine #2 decreased abruptly to 384°C and stayed low until the end of the flight.
13:12:45	923	119	Engine #2 propeller speed started to decrease from 98% to 0% *and then became invalid.* End of the autorotation. Feathering of the propeller of the engine #2 took place.
13:13:32	1485	118	Auto-pilot was engaged.
13:13:54	1640	125	The captain takes over radio communication from the first officer and reports that the aircraft would turns back with a left turn.
IN FLIGHT TURN BACK			
13:14:20	1967	123	The aircraft starts to turn back, but it continues to climb.
13:15:19	2565	140	The aircraft reached a maximum standard altitude of 2565 ft.
13:15:38	2556	148	The aircraft started to descend.
13:16:09	2063	158	The pilot reported they would take an orbit to descend. *(A straight-path glide angle would have been too steep: 5.4°.)*
13:20:07	-	-	The aircraft landed.

2.2 Engine malfunction:

According to information from voice recordings and form the findings of the inspection of the engine, the engine failure took place as follows: A fatigue crack started out in the trailing edge of a PT1 blade, the spreading of which finally led fracture of the blade. The damage to other stator vanes and rotor blades of the power turbine was the consequence of the first blade fracture. The power turbine became unbalanced, and its intensive vibration caused fractures of the oil pipes and screws which fixed bearing housing № 6&7. The unsupported bearing housing could not keep the shafts in place, and the spilt oil caught fire. The low- and high-pressure power turbine shafts may have contacted with each other and fractured. The fire fuelled by spilt oil led to thermal damage to or deformation of the 1st stage

PT stator, the low-pressure turbine, the bearing housing № 6&7, and the oil pipes. The HP turbine blades were damaged by overheating.

2.3 Flight crew activity:

(Altitude: AGL, Time: UTC)

Two seconds after the appearing of the audio and light signals warning of fire in the engine №2 (13:11:44), the flight crew set the power lever of the malfunctioned engine to idle, according to the requirements included in the emergency checklist. Feathering of the propeller and dropping of the fuel supply to the engine №2 to zero took place after a minute only (at 13:12:45). These facts show that subsequent steps of the emergency procedure (operation of the Condition Lever and the Fire Handle) were taken only at that time. From the moment of catching fire till the moment of propeller feathering the engine №2 autorotated at high temperatures (ITTmax=851ºC), which could have contributed to the serious internal damage to the engine. A non-feathered propeller creates a non-symmetrical drag which affects the handling quality of the aircraft. Propeller was feathered one-minute after the engine failure.

In the case of engine fire, the emergency checklist requires landing with no delay: “LAND ASAP” (As Soon As Possible). When the fire warning appeared and the power lever of the malfunctioned (№2) engine was pulled the altitude of the aircraft was 604 - 676 ft (184 - 206 metres). Subsequently, the aircraft continued to climb for over 3 minutes (till 13:15:19), and reached a maximum altitude of 2565 ft (782 m). Consequently, when it turned back in the direction of the airport, it was too high to land “in a straight line”. The crew had to perform a descending, 360º left turn in order to take appropriate positon for a successful landing. All in all, the duration of the flight in the period between the appearance of the fire warning and actual landing was 8 minutes and 23 seconds, i.e. more than twice the time spent in the air by the type ATR (ATR42) aircraft involved in the fairly similar occurrence (our ref.: 2011-120-4P) mentioned in Section 1.18 above.

2.4 Activities of airport services:

After the landing, the ADC asked the flight crew of the aircraft (reg: YR-ATI, Flight №: ROT236) whether they were able to taxi on their own. As the answer was positive, the ADC transferred the aircraft to the frequency of the GRC, who ordered the aircraft to taxi to the stand 220. Finally, upon order from the airport control service, the aircraft taxied to the stand 220 located at the apron of Terminal 2, in such manner that no one checked the state of the faulty engine or whether the engine fire – which had started during take-off and was detected even visually by the ATC – had been put off or was still burning.

Should the fire have still been burning onboard the aircraft, the fact of taxiing to the stand would largely have increased the risk of a more serious outcome of the occurrence, through the major causes as follows:

- The time spent on taxiing delays the start of fire extinguishing and evacuation.
- Other aircraft, vehicles and other objects staying at the apron may significantly hinder the movement of the people performing fire extinguishing or evacuation.
- The risk of spreading of the fire is much higher at the apron than on the runway or on the taxiways.

According to the procedure (1.17) recommended in Section 12.3.23 Part 1 of ICAO Doc 9137, an aircraft arriving with fire or smoke warning indication should only be

allowed to taxi to the apron after it was checked whether the indicated fire hazard was real.

The Safety Recommendation **BA2010-185-4-4** issued by TSB Hungary as a result of the investigation of the occurrence № 2010-185-4P mentioned in Section 1.17 recommends HungaroControl Zrt. to regulate the procedure relating to the managing of aircraft landing with fire or smoke warning indication in the ATS manual. According to information available to the IC, the recommended change has not been made to the ATS manual since the safety recommendation was issued. Experience gained from the managing of the occurrence under investigation shows that the practice of managing aircraft landing after fire warning indication has not changed substantially either.

3. CONCLUSIONS

3.1 Factual findings

The flight crew had sufficient authorization, qualifications and experience during the incident.

The aircraft was airworthy prior to the engine failure. It had a valid certificate of airworthiness. According to its documents, it was equipped and maintained in compliance with the regulations in effect and with accepted procedures. The aircraft was supplied with fuel of sufficient quality and quantity for the flight.

A fatigue crack had been formed in one of the blades of 1st stage PT of the engine №2 during prior operation. The blade performed 2 491 hours (2 415 cycles) until the malfunction under investigation.

The cracked blade of the power turbine fractured during the take-off subject to investigation.

The broken off part of the blade badly damaged both stages of the power turbine.

The turbine became unbalanced due to the blade fracture, and its vibration combined with the oil fire caused serious internal damage to the engine.

The crew reduced the power of the failed engine immediately, but the engine was completely shut down only after one more minute.

The aircraft turned back to LHBP airport.

The aircraft continued to climb for over 3 minutes after the fire warning indication, so it climbed so high (2565 feet AGL) that it was able to land only after a 360° descending turn, i.e. after flying for 8 minutes in total.

After landing, the aircraft taxied to the stand #220 without stopping, in accordance with the order from the tower, and the passengers and the crew disembarked according to the normal procedure.

In connection with another investigation (2010-185-4P) performed six years before this investigated incident, TSB recommended to HungaroControl Zrt. to regulate the ground movement of aircraft landing with fire or smoke warning indication.

3.2 Cause of the event

During the safety investigation, the IC concluded that the cause of the incident was that

– a blade of 1st stage PT of the engine №2 fractured as a consequence of a fatigue crack

Factors increasing the risk of a more serious outcome of the incident:

– The flight crew shut off the failed engine with delay.
– The flight lasted longer than the required minimum time.
– The aircraft taxied to the apron without being inspected after landing.

4. SAFETY RECOMMENDATION

4.1 Actions taken by the Operator/Authorities/etc. during the technical investigation

The IC is not aware of any measure taken in connection with the incident during the investigation.

4.2 Recommendations issued during the technical investigation

In connection with another investigation (2010-185-4P) performed six years before this investigated incident, TSB recommended to HungaroControl Zrt. to regulate the ground movement of aircraft landing with fire or smoke warning indication. The IC wold find it justified if HungaroControl Zrt. would consider again the implementation of the safety recommendation issued under № **BA2010-185-4P-4**.

4.3 Recommendations issued after the technical investigation

BA2016-071-4P-1 *In the course of the safety investigation, the Investigating Committee of TSB Hungary found that, during the occurrence, the flight crew of the aircraft did not properly follow the contents of the emergency checklist relating to the occurrence.*

> **Transportation Safety Bureau recommends TAROM Romanian Air Transport airline company to pay special attention during pilot training to the procedures to be followed in the case of engine fire or serious damage to the engine.**

The Investigating Committee considers that in the case of accepting and implementing the above recommendation, the managing of similar cases may represent less risk for the passengers and crew of the aircraft.

Budapest, „ 09 „ October 2018

György Háy
Investigator-in-Charge

Gábor Erdősi
IC Member

Péter Illés
IC Member

This document is the translation of the Hungarian version of the Draft Report. Although efforts have been made to translate it as accurately as possible, discrepancies may occur. In this case, the Hungarian is the authentic, official version.