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COMISIÓN DE
INVESTIGACIÓN
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AVIACIÓN **C**IVIL

Report
IN-005/2014

Incident involving a BOEING MD-11
aircraft, registration PH-MCU, operated
by MARTINAIR CARGO,
at the Tenerife South/Reina Sofía airport
(Santa Cruz de Tenerife, Spain)
on 9 March 2014

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COMISIÓN DE INVESTIGACIÓN
DE ACCIDENTES E INCIDENTES
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Foreword

This report is a technical document that reflects the point of view of the Civil Aviation Accident and Incident Investigation Commission (CIAIAC) regarding the circumstances of the serious incident object of the investigation, and its probable causes and consequences.

In accordance with the provisions in Article 5.4.1 of Annex 13 of the International Civil Aviation Convention; and with articles 5.5 of Regulation (UE) no. 996/2010, of the European Parliament and the Council, of 20 October 2010; Article 15 of Law 21/2003 on Air Safety and articles 1., 4. and 21.2 of Regulation 389/1998, this investigation is exclusively of a technical nature, and its objective is the prevention of future civil aviation accidents and incidents by issuing, if necessary, safety recommendations to prevent from their reoccurrence. The investigation is not pointed to establish blame or liability whatsoever, and it is not prejudging the possible decision taken by the judicial authorities. Therefore, and according to above norms and regulations, the investigation was carried out using procedures not necessarily subject to the guarantees and rights usually used for the evidences in a judicial process.

Consequently, any use of this report for purposes other than that of preventing future accidents may lead to erroneous conclusions or interpretations.

This report was originally issued in Spanish. This English translation is provided for information purposes only.

Contents

Abbreviations

° ʹ ʺ	Sexagesimal degrees, minutes and seconds
ºC	Degrees centigrade
ºF	Degrees Fahrenheit
%	Percent
AD	Airworthiness directive
AGB	Angled gearbox
AGL	Above ground level
AMT	Aircraft Maintenance Technician
ATC	Air traffic control
ATPL	Air transport pilot license
BOAS	Blade out air seals
CIAIAC	Spain’s Civil Aviation Accident and Incident Investigation Commission
CIR	Clean, Inspect and Repair Manual
cm	Centimeters
CSN	Cycles since new
CSO	Cycles since overhaul
CVR	Cockpit voice recorder
DFDR	Digital flight data recorder
DME	Distance measuring equipment
EEC	Electronic engine control
EGT	Exhaust gas temperature
EP	Emergency procedures
EPR	Engine pressure ratio
ESA	Eagle Services Asia
FAA	United States Federal Aviation Administration
FADEC	Full authority digital engine control
FAR	Federal aviation regulations
FCOM	Flight Crew Operations Manual
FDR	Flight data recorder
FF	Fuel Flow
FFS	Firefighting service
FL	Flight level
ft	Feet
ft/min	Feet per minute

ft/s	Feet per second
H, hr	Hours
HF	High frequency
HPC	High-pressure compressor
HPT	High-pressure turbine
IAS	Indicated airspeed
ICAO	International Civil Aviation Organization
IDG	Integrated drive generator
ILS	Instrument landing system
In	Inches
IR(A)	Instrument flight
Kg	Kilograms
Kg/h	Kilograms per hour
Kt	Knots
lb	Pounds
LH	Left hand
LP	Low Pressure
LPC	Low-pressure compressor
LPT	Low-pressure turbine
m	Meters
MCT	Maximum continuous thrust
METAR	Aerodrome meteorological report
MHz	Megahertz
Min	Minutes
Nº	Number
N	North
N1	RPMs of the low-pressure assembly (compressor and turbine)
N2	RPMs of the high-pressure assembly (compressor and turbine)
NAV	Navigation
NTSB	United States National Transportation Safety Board
P/N	Part number
PF	Pilot flying
PM	Pilot monitoring
Psi	Pound per square inch
QAR	Quick access recorder
QRH	Quick reference handbook

RCA	Spain’s Air Traffic Regulations
S	South
s	Seconds
SAIB	Special airworthiness information bulletin
SB	Service bulletin
SBKP	ICAO code for the Viracopos Airport (Brazil)
SID	Standard instrument departure
S/N	Serial number
SEP	Single-engine piston rating
TBC	Thermal barrier coating
TEC	Turbine exhaust case
TFS	IATA code for the Tenerife South/Reina Sofía airport
TSN	Time since new
TSO	Time since overhaul
TWR	Control tower
UTC	Coordinated universal time
V1	Decision speed
VOR	Very-high frequency omnidirectional range
Vr	Rotation speed
W	West

Synopsis

Operator:	Martinair Cargo
Aircraft:	Boeing MD-11, registration PH-MCU
Date and time of incident:	9 March 2014 at 00:30[1]
Site of incident:	Tenerife South/Reina Sofía airport (Santa Cruz de Tenerife, Spain)
Persons onboard:	2 crew and 1 passenger, uninjured
Type of flight:	Air transport– Scheduled – International – Cargo
Phase of flight	Takeoff
Date of approval:	28 September 2016

Summary of the event:

An MD-11 aircraft, registration PH-MCU, was flying from the Amsterdam (Netherlands) to Viracopos (Brazil) airports, which included a stopover at the Tenerife South airport.

While taking off from Tenerife South, and as the aircraft was on its initial climb, the crew first heard a loud noise and felt the aircraft yaw to the right. At the same time the captain saw a white flash and a faint cloud in front of the aircraft. After this the crew noticed that the readings for the no. 3 engine were abnormal. This was followed immediately by the fire warning for the same engine.

The crew carried out the relevant procedure, which cleared the warning.

They continued climbing to FL070 so as to jettison fuel and lower their landing weight before returning to the Tenerife South airport.

They eventually landed normally at the airport. Once on the apron, a visual check of the aircraft revealed that the no. 3 engine had sustained an uncontained failure. There were no signs of a fuel, hydraulic fluid or oil leak.

The investigation has determined that the failure of the no. 3 engine was caused by an airfoil that detached from vane no. 22 cluster in the 4th stage of the low-pressure turbine (LPT).

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[1] Local time, coincident with UTC time.

The root cause of the fracture was probably the pressure pulses (HPT 2E excitation). generated by the 2nd stage of the high-pressure turbine (HPT), which led to high vibrations in the stator of the 4th stage of the LPT, resulting in the formation of fatigue cracks in the vanes.

1. FACTUAL INFORMATION

1.1. History of the flight

An MD-11 aircraft, registration PH-MCU, was flying from the Amsterdam (Netherlands) to Viracopos (Brazil) airports, which included a stopover at the Tenerife South airport.

During the takeoff from Tenerife South, as the airplane was on the initial climb, the crew heard a loud noise, similar to an explosion, and felt the aircraft yaw to the right. A short while later they felt vibrations and looked at the engine readings and noticed that the parameters for the no. 3 engine were not normal. N2 was at 105% and the exhaust gas temperature was at around 875° C.

They concluded that the no. 3 engine had experienced substantial damage and started to carry out the relevant procedure, during which the fire warning for the no. 3 engine was activated.

The crew continued with the initial procedure, as it is also applicable in cases of severe engine damage or fire. The fire warning was cleared after they discharged the first bottle of extinguishing agent.

They decided to return to the airport of departure. They assessed the situation and since the fire warning had cleared and the aircraft was controllable, they decided to jettison fuel to lighten their landing weight before returning to the Tenerife South airport.

They requested clearance from ATC to jettison fuel at FL070, which they received.

They climbed to FL070 and after jettisoning the necessary amount of fuel, proceeded to return to the Tenerife South airport, where they landed without further incident.

Once on the apron a visual check revealed that the no. 3 engine had experienced an uncontained failure. There were no signs of a fuel, hydraulic fluid or oil leak.

1.2. Injuries to persons

Injuries	Crew	Passengers	Total in the aircraft	Others
Fatal				N/A
Serious				N/A
Minor				N/A
None	2	1		N/A
TOTAL	**2**	**1**		

1.3. Damage to aircraft

The aircraft's no. 3 engine sustained considerable damage as the result of an uncontained fault in the low-pressure turbine (LPT) case.

There was damage to the right side of the aircraft consistent with material being ejected from the engine. This damage basically consisted of scratches and dents, as well as cracks and perforations in some composite surfaces. This damage was found in the following areas:

- Wing leading edge
- Underside of the wing
- Winglet
- Inboard and outboard flaps
- Flap rail housing (inboard, middle and outboard)
- Inboard aileron
- Horizontal stabilizer

The nacelle for the no. 3 engine had the following damage:

- The access panel for the IDG compartment on the left side was missing.
- There were two holes on the right side of the reverser cowling.

Figure 1. Photograph of the larger hole in the reverser cowling of the no. 3 engine

The larger of the two measured 78.7 x 35.5 cm. There were no burn marks or signs of melting on the fracture surfaces, the edges of which were bent outwards. In the area adjacent to the top part of the hole there were two blue-purple colored areas, consistent with heat coloring.

The other hole measured 7.6 x 5.1 cm.

- A 23-cm long section of a rib reinforcement was found fractured.
- No signs of fire were found on the cowlings.

There was significant damage to the no. 3 engine pylon, specifically to:

- The web at station 286.0 was bent and cracked.
- The web at stations 341.9 and 315.9 were cracked.
- All of the rivets between stations 286.0 and 341.9 on the right side of the upper closure web were broken or missing. The closure web in this area was bent.

1.4. Other damage

There was no other damage.

1.5. Personnel information

1.5.1. Captain

- Age: 47
- Nationality: Dutch
- License: ATPL (airplane), valid until 3/09/2015
- Ratings:
  - MD11 valid until 28/02/2015
  - IR (A) valid until 28/02/2015
  - SEP (Land) valid until 29/02/2016
- English language proficiency level 6
- Medical certificate: class 1, valid until 1/04/2015
- Total flight hours: 15787
- Flight hours on the type: 10630

- Activity:

In the previous 90 days:	129 hr
In the previous 7 days:	5:29 hr
In the previous 24 hr:	00:00 hr
Rest prior to the flight:	40:29 hr

1.5.2. First officer[2]

- Age: 40
- Nationality: Dutch
- License: ATPL (airplane), valid until 11/10/2015
- Ratings:
  - MD11 valid until 30/11/2014
  - IR (A) valid until 30/11/2014
- English language proficiency level 6
- Medical certificate: class 1, valid until 1/07/2014
- Total flight hours: 11690
- Flight hours on the type: 2237 h
- Activity:

In the previous 90 days:	78 hr
In the previous 7 days:	5:29 hr
In the previous 24 hr:	00:00 hr
Rest prior to the flight:	40:29 hr

1.6. Aircraft information

1.6.1. General

- Manufacturer: Boeing
- Model: MD-11F
- Serial number: 48757
- Year of construction: 1996

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[2] Although he is a Captain with Martinair, he acted as a dedicated first officer in this flight.

- Airworthiness review certificate: valid until 24/11/2014
- Engines, number/manufacturer and model: three (3)/Pratt & Whitney, PW4462
- Weights
    - Maximum taxi weight: 287,124 kg
    - Maximum takeoff weight: 285,990 kg
    - Maximum landing weight: 222,941 kg
- Dimensions
    - Wingspan: 51.7 m
    - Length: 61.2 m
    - Height: 17.6 m
    - Wheelbase: 10.7 m
- Hours: 81039
- Cycles: 16085
- Maintenance status:

Last inspections of the aircraft		
Inspection type	Total hours	Date
D-check	74231	20/06/2012
C-check	78510	18/07/2013
A-check	80470	20/01/2014

Engines			
Engine	No. 1	No. 2	No. 3
Model	PW4462-1E	PW4462-3	PW4462-3
Serial number	P723803	P733793	P733721
Total hours	55,096	71,647	72,424
Hours since last inspection	1,163	569	1,163
Cycles since last overhaul	3,134	2,559	2,372

1.6.2. Information on the no. 3 engine

As the table above shows, the no. 3 engine had been manufactured by Pratt & Whitney, model PW4462 and serial number 733721.

At the time of the incident, the no. 3 engine had a total of 72,424 hours and 13,511 cycles, and 12,377 hours and 2,372 cycles since its last overhaul.

The low-pressure turbine (LPT) had 25,597 hours and 5,002 cycles since its last overhaul.

The engine is part of the PW4000 family of engines, with a 94-inch diameter fan. It is a turbofan engine with a high bypass ratio.

The fan has 38 blades and is coupled to a four-stage low-pressure compressor (LPC). Both are driven by the low-pressure turbine (LPT), which also has four stages. The assembly consisting of the fan, LPC and LPT is called the low-pressure or N1 rotor.

The engine core includes an eleven-stage high-pressure compressor (HPC) that is driven by a high-pressure turbine (HPT) with two stages. The HPC and HPT assembly is called the high-pressure or N2 rotor.

As seen from behind, both the N1 and N2 assemblies turn clockwise.

The LPC and HPC are separated by an intermediate case which has the fittings for attaching the engine to the mount (forward mount).

The compressor section is separated from the turbine section by a diffuser and an annular combustion chamber.

Behind the LPT is the turbine exhaust case, which has fittings for attaching the engine (rear mount).

The engine is controlled by a full authority digital engine control (FADEC) unit, also known as electronic engine control (EEC).

The nacelle consists of an inlet cowl, fan cowl, reverser cowl and the exhaust nozzle, which provide an aerodynamic fairing for the engine.

1.6.2.1 Last overhaul of the no. 3 engine

This engine was last overhauled at ESA’s facilities in Singapore in September 2010. At the time the engine had the following hours/cycles:

- TSN: 60046
- CSN: 11139
- TSO: 13219
- CSO: 2630
- LPT TSO: 13219
- LPT CSO: 2630

The following tasks were performed:

1. After carrying out heavy maintenance work[3], the following modules/fittings were reinstalled:
    a. High-pressure compressor
    b. Bell crank assembly
    c. Diffuser case
    d. Turbine nozzle assembly
    e. High-pressure turbine

2. The following modules were inspected and re-installed without heavy maintenance:
    a. Fan case
    b. Low-pressure compressor
    c. LPC/LPT coupling
    d. Intermediate case
    e. Low-pressure turbine
    f. Turbine exhaust case
    g. Main gearbox
    h. Angle gearbox

3. The forward and rear engine mounts were reinstalled after being overhauled.

4. Main bearings:
    a. Nos. 2 and 3 reinstalled after being overhauled.
    b. No. 1.5 reinstalled after a visual inspection

1.6.2.2 Status of compliance with airworthiness directives and service bulletins

1.6.2.2.1 Airworthiness directive FAA-2012-14-09

This airworthiness directive became effective on 7 November 2012, and is applicable to different models of PW4000-94” and PW4000-100” engines, including the engine involved in this event.

It was issued in the wake of several 3rd and 4th stage vane fractures in the stators of the low-pressure turbine (LPT), leading to uncontained failures. The goal of this AD is to prevent similar failures.

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[3] Core heavy maintenance.

Compliance with the AD is required on the next overhaul of the LPT, and basically consists of the following tasks:

I. At the next LPT overhaul:

   a) Remove LPT 4th stage vanes that have a P/N listed in the AD if more than one strip and recoat has been performed.
   b) Re-assemble the 3rd stage LPT rotor blades by alternating heavy blades next to light blades and balancing blades of similar weights 180 degrees across the rotor.
   c) Dimensionally examine certain vane clusters.
   d) Dimensionally examine certain vane engagement slots on the rear turbine case.
   e) Inspect the 44 LPT 4th stage vane cluster assemblies and remove the vanes with the identification number shown.

II. At the next HPT overhaul:

   a) Re-assemble the 2nd stage HPT rotor blades by alternating heavy blades next to light blades and balancing blades of similar weights 180 degrees across the rotor.

This AD had not been implemented on the engine in question as it had yet to be overhauled following the issue date of the AD.

Despite the AD not being implemented, during the prior overhaul the 2nd stage of the HPT was bladed per revision 92 of the engine manual which specifies the blading pattern mandated by this AD.

1.6.2.2.2. Service bulletin 72-798

The objective of SB 72-798 is to inspect the stator on the 4th stage of the LPT to check for the presence of vane clusters that are not acceptable as a result of having been produced with an under minimum airfoil fillet radius. If confirmed, the affected clusters must be replaced by clusters with acceptable numbers. This bulletin was first issued on 07/08/2009, and was later revised on two occasions, the last being on 17/02/2011. It was recommended to be implemented the next time the engine was disassembled enough to provide access to carry out the task. There is no time limit on the SB.

This SB had not been implemented on the engine in question since it had not been sufficiently disassembled following the issue date of the SB.

1.6.3. Inspection of the no. 3 engine

There were no signs of any oil, fuel or hydraulic fluid stains.

The oil tank level was normal. The oil did not have an acrid smell and there was no detectable fuel smell.

The chip detectors for the main gearbox, bearing compartment nos. 1, 1.5, 2, 3 and 4, as well as in the angle gearbox (AGB) were free from chips.

The spinner was in place and showed nothing of any significance.

The fan appeared to be properly centered in its case and correctly situated axially. The blades were all in their positions, intact and with no evidence of foreign object damage. The fan rub strip showed signs of recent wear from the 3 to 12 o’clock positions as seen from behind.

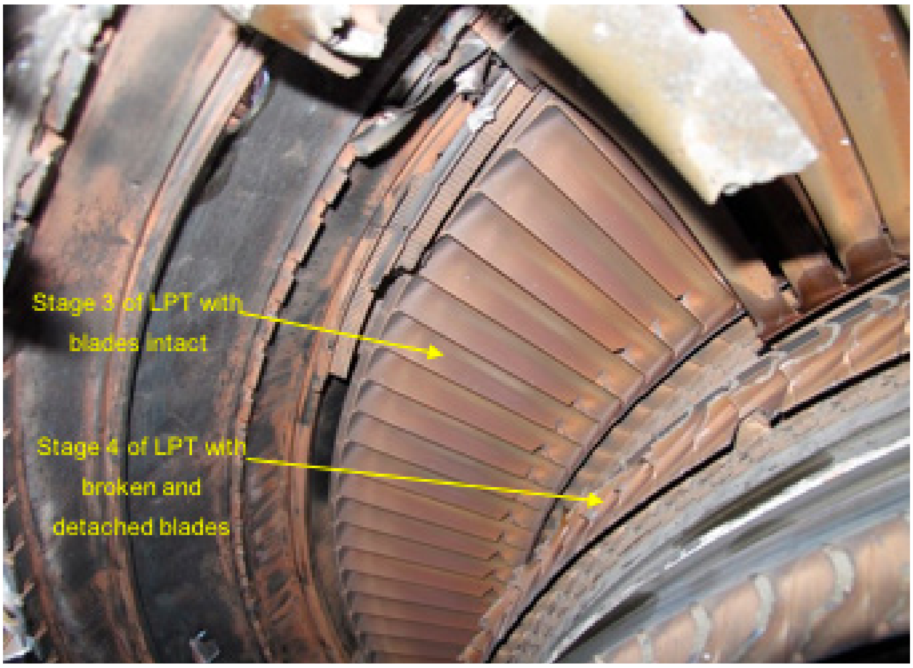

Figure 2. Low-pressure turbine (LPT)

There were multiple impact notches along the entire surface on the inside of the exhaust nozzle.

The fan and low-pressure compressor could be turned smoothly clockwise by hand. It was impossible, however, to turn them counterclockwise at first. The turbine turned along with the fan.

The inspection of the engine revealed that there had been an uncontained failure of the LPT, specifically in the plane of the 5th stage, which affected stages 3 through 6[4], as detailed below:

- Blades in stage 3 rotor: damaged, in proper position
- Vanes in stage 4 stator: severely damaged, some missing
- Blades in stage 4 rotor: all airfoils missing
- Vanes in stage 5 stator: severely damaged some missing.
- Blades in stage 5 rotor: all airfoils missing
- Vanes in stage 6 stator: numerous missing
- Blades in stage 6 rotor: all airfoils missing
- LPT case: penetrated from the inside outward.

1.6.4. Disasembly and inspection of the engine in workshop

Once the engine inspection at the site of the event was completed, it was decided to remove it from the aircraft and send it to the P&W Eagle Services Asia (ESA) facility in Singapore for disassembly and inspection.

The no. 4 bearing housing was intact, oil wetted showed a dark coloration that, in ESA's experience, is indicative of normal operation. The oil was clean, the supply and return lines were intact and there were no leaks.

The LPT and the exhaust case were removed from the engine as a single assembly, exposing the 2nd stage of the HPT.

Every blade in this stage was in its position and with no material missing. No damage was found on the trailing edges and the HPT rotated freely by hand.

Every blade showed discoloration on the suction side affecting the outer 10% of the blades. This discoloration was, according to ESA, darker than usual. All of the blade outer air seals (BOAS) on the second stage of the HPT were in their position. They exhibited minor material loss from their surfaces, which is normal.

The gap between the end of the blades and the BOAS seemed larger than usual.

The vanes on the second stage of the HPT were observed through the rotor blades and all were confirmed to be in their positions and intact.

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[4] In keeping with Pratt & Whitney's nomenclature, the turbine stages are numbered from front to back, starting with the most forward high-pressure turbine (HPT) stage. Thus, stages 1 and 2 are the two stages in the HPT, with stage 3 being the first disk in the low-pressure turbine (LPT).

The HPT module was removed. The combustion chamber and the injectors were inspected through the 1st vanes and found to be normal. Every blade and vane on the first stage of the HPT was in its position, intact and in good condition. Some of the vanes and blades had lost portions of their thermal barrier coating (TBC).

All of the blades in the second stage of the HPT were in their slots and exhibited loss of the thermal barrier coating in conditions similar to those in the first-stage blades. Only two 2nd stage vanes showed signs of thermal damage.

According to the maintenance data, the set of blades in the first stage of the HPT consisted of 2 new blades and 58 overhauled blades. The second stage had 22 new blades and 60 overhauled blades. None of the second-stage blades had been overhauled more than once. The blades in the HPT rotor had been installed as per the instructions in revision 92 of the engine maintenance manual.

The turbine exhaust case (TEC) was separated from the LPT module. The front part of the exhaust case showed signs of impact damage.

The LPT module was removed, with the most significant finding being that the shaft on the LP assembly had several circumferential friction marks.

Stage 3 of the LPT

Every blade in the stage 3 of the LPT was in its location, had no material missing and was correctly attached to the disk. Approximately ¾ of the blades showed impact marks on their trailing edge, most of which were close to the inner platform of the blade.

BOAS no. 2 and 3 were missing and no. 4 was partially overlapping no. 5. The remaining BOAS were in their location, though they were somewhat loose and could be easily moved by hand.

All of the vanes were in their locations and intact.

Stage 4 of the LPT

All of the blades on this stage were fractured at different points, but all of them close to the root. All of the roots were engaged in their slots in the disk. The fracture surfaces on the blades were dark and discolored, and had a rough appearance, with the exception of blades 34, 59 and 60, which had an area next to the leading edge that was flat and shiny.

Of the 22 BOAS in this stage, only eight were present, and they were severely damaged.

The stator consists of 44 vane clusters, each one containing 3 vanes. The clusters numbered 2 through 8 were completely missing, including the insulation underneath.

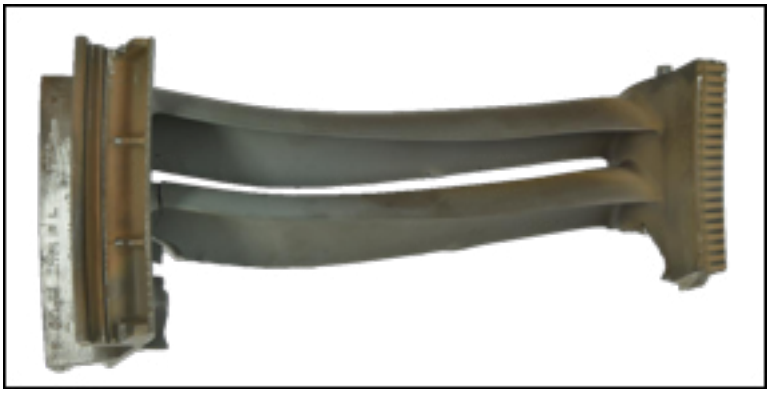

Figure 3. No. 22 vane cluster in the stator of stage 4 in the LPT

The remaining clusters remained in place, though they exhibited impact damage and loss of material. They were all complete except for no. 22, which had lost one of the three vanes in the cluster (see Figure 3). Most of the fracture surface was flat and dark. Vane clusters 15, 27 and 30 to 33 exhibited signs of internal corrosion. Of these, only groups 30 and 31 had sustained a loss of material.

Stage 5 of the LPT

All of the rotor blades were fractured at the root or very close to it. All of the roots were engaged in their slots on the disk. The fracture surfaces on the blades were dark and discolored and had a rough appearance.

Of the 19 BOAS, those numbered 16 to 3 were completely missing. The remaining BOAS were significantly worn, exhibiting dents and loss of material.

The stator consists of 38 vane clusters, each of which contains 3 vanes. The clusters numbered 28 to 7 were completely missing, including the underlying insulation. Clusters 24 and 25 were completely missing, though the insulation was still in its place. Clusters 8 and 14 had lost the inner platform, though the outer platform remained attached to the case. Clusters 9 to 12, 15 to 17, 19 to 21 and 27 were complete but exhibited severe impact damage with loss of material. The vanes in cluster 23 had almost no material missing, though the inner platform was missing. Clusters 13 and 18 had lost one vane each (the third one in the direction of rotation).

Stage 6 of the LPT

All of the blades in stage 6 were fractured at the platform or very close to it. The roots remained in their slots in the disk.

The 12 BOAS were whole and in their positions.

The stage 6 stator consists of 36 vane clusters, each of which contains 3 vanes. For identification purposes, they are numbered clockwise starting from the 12 o’clock position. Clusters 29 to 1, 4, 5, 6, 9 and 10 were completely missing, including the underlying insulation. Clusters 18 and 28 were completely missing, though their insulation remained in place. The inner platform and airfoils were missing on clusters 2, 3, 7, 8, 11 to 17, 19 to 24 and 27, though the outer platform remained attached to the case. Clusters 25 and 26 were complete but exhibited severe impact damage with loss of material.

Conclusions

In light of the damage found, it was decided to conduct a metallurgical study (see 1.16.3) on the following components:

- Vanes from stage 4 of the LPT.
- Blades from stage 4 of the LPT.
- LPT case.
- Blade from stage 2 of the HPT.

1.7. Meteorological information

The METARs for the Tenerife South issued between 00:00 and 01:30 on the day of the event were as follows:

0000Z 35004KT 9999 FEW035 17/10 Q1014 NOSIG

0030Z 05003KT 020V080 9999 FEW035 18/13 Q1014 NOSIG

0100Z 31004KT 280V340 9999 FEW035 17/13 Q1015 NOSIG

0130Z VRB02KT 9999 FEW033 17/12 Q1015 NOSIG

1.8. Aids to navegation

Not applicable.

1.9. Communications

The first contact between the crew and ground control at the Tenerife South airport took place at 23:40:48, during which the crew requested to take off from runway 26, which was the runway in use at the time.

At that time there was a single controller manning the control tower and handling both the ground and tower (local) frequencies.

Six minutes after the initial contact, the controller called the aircraft to inform the crew that the wind was variable at both thresholds and that a runway change was possible.

At 23:49:18 the crew requested information on traffic on final and the wind, after which they reported their intention to take off from runway 26. After this, the controller issued the crew their departure clearance: destination SBKP, initial standard departure LPC4E, FL200, upon reaching FL70 proceed straight to LIMAL, squawk 6220. The crew correctly acknowledged the clearance.

The runway in use was changed to 08 at 23:51:08.

The crew called ATC again at 00:05:38 to ask about the wind once more. The controller informed them that the runway in use had changed to 08.

The crew requested start-up clearance and pushback at 00:09:42, which was granted.

Around ten minutes later, the crew requested clearance to taxi to the runway 08 holding point.

At 00:25:14 the controller cleared the aircraft to take off from runway 08 and to climb uninterrupted to FL200, and instructed the crew to contact approach on 127.700 MHz once in the air.

At 00:29:32 the crew of the aircraft declared an emergency, reporting a severe engine failure and that they were continuing on the runway heading.

Around two minutes later, the controller asked the crew about their intentions, to which the crew replied to stand by and that they intended to jettison fuel.

Immediately afterwards the crew reported they were climbing to 6000 ft to jettison fuel, which would take them around 25 minutes, and that they would then head to the airport. They added that they had severe damage to engine no. 3.

The controller instructed them to continue on heading 220° and climb to FL070, and to await further vectors. He transferred them to the approach frequency 127.7 MHz.

The crew called ATC at 00:35:26 to report they had started jettisoning fuel.

Two minutes later the crew called ATC to provide information on the people and cargo onboard, which included three live animals (horses) and three flammable liquid containers, as well as on their fuel remaining.

After this the supervisor coordinated with the airport to halt all arrivals and departures at the airport until after the incident aircraft landed.

The controller provided vectors to the crew for the duration of the fuel jettison operation.

At 01:01:38 the crew informed ATC they had completed jettisoning fuel. The controller gave them a new radar vector and cleared them to descend to 4000 ft.

Three minutes later the crew reported they were ready for the approach.

At 01:04:19 the crew called ATC to report they would leave the runway via the opposite threshold and requested an escort during their landing run to check for fuel leaks.

The controller gave them the final vector and cleared them for a direct ILS approach to runway 08. The crew reported having the airport in sight.

Approach transferred control of the aircraft to TWR at 01:07:22.

TWR cleared the aircraft to land at 01:07:48, informing the crew that the wind was calm.

At 01:11:12 the firefighting service (FFS) informed the TWR controller that they had followed the aircraft during its landing run and had not noticed anything unusual.

Shortly afterwards the crew confirmed they were taxiing normally. The controller instructed them to taxi to stand 18.

Finally, at 01:15:39, the crew called the controller to cancel the emergency.

1.10. Aerodrome information

The Tenerife South/Reina Sofía airport has one runway, 08/26, that is 3,200 m long and 45 m wide.

The incident aircraft took off from runway 08.

The crew had been assigned standard departure LPC4E (see Figure 4). As this chart indicates, after takeoff the aircraft is to continue climbing on the 076 radial of the TFS VOR/DME. Upon reaching 10.0 DME on this navaid, they would then turn right to heading 158° to intercept the 120 radial on the TFS VOR/DME.

According to the departure instructions provided by the controller, when the aircraft reached FL70, it was to proceed directly to point LIMAL. This reporting point is located south of the Canary Islands at coordinates 25° 00′ 00″ N 17° 37′ 32″ W, where airways UB623, UT770 and UN873 intersect.

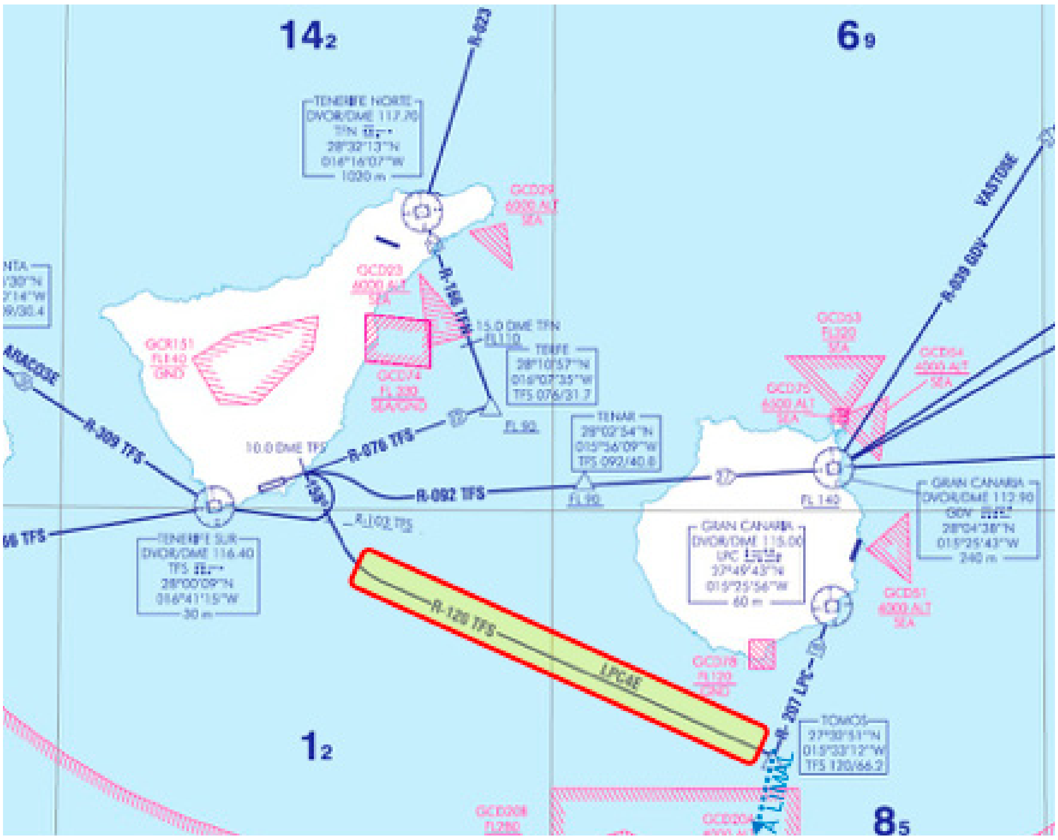

Figure 4. Section of the standard instrument departure (SID) chart for runway 08 at the Tenerife South/Reina Sofía airport, with departure LPC4E highlighted.

1.11. Flight recorders

1.11.1. *Flight data recorder (FDR)*

The aircraft was equipped with a solid-state Fairchild F1000 digital flight data recorder (DFDR), P/N S800-2000-00 and S/N 00277, whose contents were downloaded at the CIAIAC laboratory.

1.11.2. *Cockpit voice recorder (CVR)*

The aircraft was equipped with a Fairchild A100A cockpit voice recorder (CVR), P/N 93A100-80 and S/N 55745, whose contents were downloaded at the CIAIAC laboratory.

The CVR was capable of recording for 30 minutes.

The CVR was verified to contain information from the incident flight, though due to its 30-minute recording limit, the conversations it held were subsequent to the engine failure.

The recorders were synchronized based on the time the autopilot was disengaged, the aural warning for which was recorded on the CVR 12:14 minutes into the recording. According to the DFDR parameter that records the ON/OFF status of the autopilot, it was disengaged at 01:07:02 UTC.

Based on the above information, it was determined that the CVR recording started at 00:54:48 UTC.

At that time the crew were in the process of jettisoning fuel, which concluded five minutes later.

The information contained on this recording spans from the end of the fuel jettison process until the aircraft was parked at the Tenerife South airport after landing.

1.11.3. Quick access recorder (QAR)

Since some of the parameters that are stored on the FDR are recorded infrequently, the investigators resorted to the information stored on the quick access recorder (QAR), since the frequency at which parameters are recorded on this unit is much higher than that of the FDR, thus allowing for a more detailed analysis.

The engine start sequence was started at 00:15 with the start-up of engine no. 3.

All of the engine parameters (fuel flow, EPR, N1, N2, EGT, oil pressure and temperature, etc.) were normal throughout the start sequence.

At 00:17 engine no. 1 was started, and a minute later engine no. 2.

By 00:20 the parameters on all three engines had stabilized. The table below shows the values of several parameters at that time:

Parameter	No. 1 engine	No. 2 engine	No. 3 engine
EGT (°C)	**352**	**356**	**357**
N1 (%)	26.3	27.6	28.4
N2 (%)	66.6	67.1	68.3
FF (kgh)	740	766	816
EPR	1.01	1.01	1.01
Oil pressure (psi)	124	116	96
Oil temperature (°C)	94	90	98

At 00:20:56 the crew released the parking brake, and the aircraft started moving 12 s later.

At 00:27:31 the crew applied takeoff thrust and the aircraft started to accelerate. The engine parameters were all normal during the takeoff run.

The takeoff occurred at 00:28:12. The engine parameter values at that time were as follows:

Parameter	No. 1 engine	No. 2 engine	No. 3 engine
EGT (°C)	**568**	**589**	**587**
N1 (%)	101.6	101.9	100.1
N2 (%)	97.9	97.6	98.0
FF (kgh)	10876	10868	10694
EPR	1.60	1.60	1.60
Oil pressure (psi)	288	276	252
Oil temperature (°C)	98	102	103

At 00:29:08 the aircraft was at a radio altitude of 1500 ft, with an indicated airspeed (IAS) of 237 kt and climbing at a rate of 1149 ft/min. NAV mode was engaged, the autopilot was off and the autothrottle was connected. The engine parameters were still normal.

At 00:29:10 there was a sudden drop in the N1 value for engine 3, which fell to 87.4. The table below shows the values of the parameters at that time and in the two seconds that followed. At that moment the aircraft was at coordinates 28° 03′ 50.4″ N, 16° 30′ 43.8″ W, which is along the extension of the runway 08 centerline, some 4750 m away from the threshold (see Figure 5).

	N1 (%)	N2 (%)	EPR	EGT (°C)	FF (Kg/h)	OIL PRES (psi)	OIL TEMP* (°C)
00:29:10	87,4	102,8	0,77	646	8622	240	-
00:29:11	49,6	104,8	0,77	689	6724	252	108
00:29:13	48,7	105,1	0,77	709	6514	256	-

* This parameter is recorded every 4 seconds.

At that point the aircraft was flying with the autopilot off, the autothrottle engaged, at an uncorrected barometric altitude of 1559 ft, flaps 0°, slats extended, the gear up, at a ground speed of 244 kt on a heading of 82.5°. Its pitch angle was 11.3° (nose up) and its climb rate was 1147 ft/min.

At 00:29:13 a master caution was received in the cockpit.

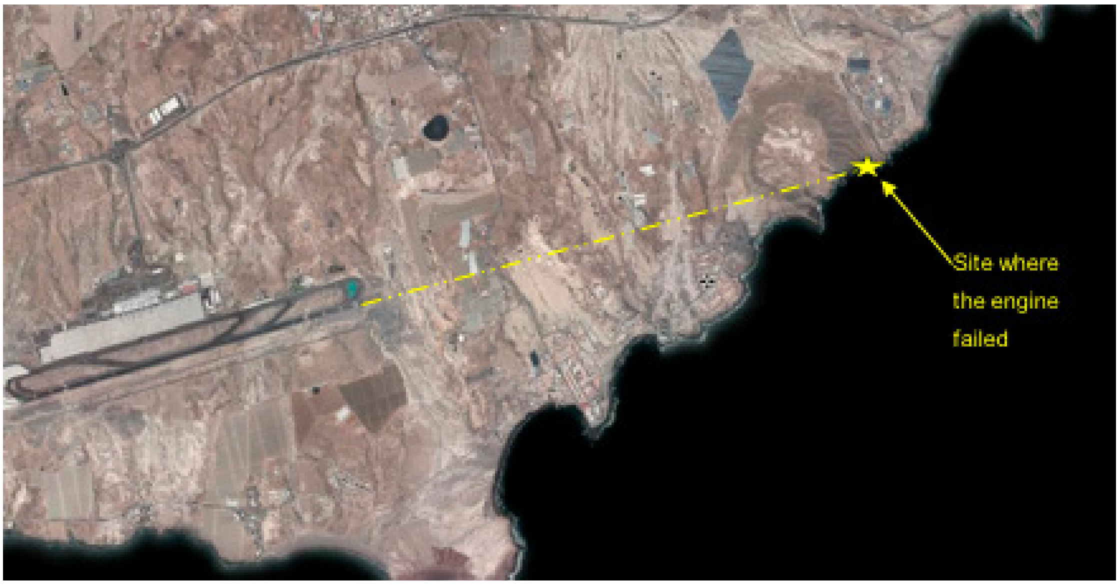

Figure 5. Aerial view of the general location of the Tenerife South/Reina Sofía Airport, showing the flight path of the aircraft and its location when the engine failed

The no. 3 engine throttle was pulled back to the idle position 7 s later. The crew reduced the aircraft's pitch angle. The climb rate also decreased and the aircraft accelerated to the selected speed of 260 kt. Once at this speed, the climb rate was increased to 1200 ft/min.

At 00:30:09 the fire warning for the no. 3 engine was received.

The slats were retracted at 00:30:16. The altitude was 2964 ft, the pitch angle 7°, the climb rate 794 ft/min and the heading 58.5°. At 3000 ft engines 1 and 2 were set to maximum continuous thrust (MCT).

At 00:30:53 the fuel switch for the no. 3 engine was turned off. The altitude was 3700 ft.

At 00:30:58 the fire warning for the no. 3 engine cleared.

At 00:31:02 the fire lever for the no. 3 engine was pulled. The aircraft's altitude was 3881 ft.

At 00:34:50 the aircraft reached FL70 and the autopilot was engaged. At that time the crew began a turn to heading 270°.

At 00:35:31, established on FL70 on heading 240° at a speed of 280 kt, the fuel jettison was started. The aircraft's weight was 277300 kg and the fuel load was 80451. At 00:59:55, on heading 340° and a speed of 245 kt, the crew completed jettisoning fuel, with the aircraft's weight reduced to 222900 kg (below the maximum landing weight of 222942 kg) and 25850 kg of fuel remaining.

At 01:01:02, the aircraft started descending to 3000 ft at a sink rate of 1000 ft/min while maintaining its speed of 240 kt.

At 01:05:17 they reached 3000 ft and the crew started a turn to heading 120°. During the turn they selected flaps 15° and reduced the speed to 190 kt.

At 01:07:08 the aircraft intercepted the runway 08 ILS localizer. The crew then disengaged the autopilot. Once the glide path was intercepted, the crew set flaps 28° and maintained the speed at 180 kt.

At 01:08:36, at 1700 ft, the crew lowered the landing gear.

At 01:08:56, at 1300 ft, they selected the final flaps configuration of 35° for landing.

The aircraft landed with no further incident on runway 08 at 01:10:10.

1.12. Wreckage and impact information

Not applicable.

1.13. Medical and pathological information

Not applicable.

1.14. Fire

There was no fire.

1.15. 1.15. Survival aspects

Not applicable.

1.16. Tests and researchs

1.16.1. *Crew statements*

The crew members were interviewed with the help of the Dutch Safety Board, the investigation authority of the country of the operator involved in the event and where the incident aircraft is registered.

The interviews were conducted in The Hague by the accredited representative of the Dutch Safety Board.

Two captains were appointed for the flight, although the airline formally designated one as the pilot in command (seated in the LH seat), with the other acting as the first officer.

They arrived in Tenerife two days before the event as part of the crew of another aircraft flying from Amsterdam to Tenerife. The incident aircraft was piloted to Tenerife by another crew, which were relieved by the incident crew for the rest of the flight from Tenerife to Viracopos (Brazil).

There was a third person in the cockpit during the incident flight whose role was to care for the three horses that were being transported in the cargo bay.

The crew stated that the runway in use at Tenerife South was 26. While preparing for the flight, they heard the crew of another aircraft report that they had had a significant tailwind while landing on runway 26. They asked the controller about the wind, and he informed them that it was changing from east to northeast. As this favored the use of runway 08, they decided to request it.

They did the performance calculations assuming a 5 kt headwind and a takeoff weight of 280300 kg. They noted the possibility of encountering windshear on takeoff and the option of setting the thrust to 62,000 lb instead of the usual 60,000 lb, as this would give them extra margin.

Since no windshear was reported, they finally decided to use a thrust of 60,000 lb.

The aircraft log book did not contain any entries of any operational significance.

The pilot seated in the LH seat would act as the pilot monitoring (PM), whereas the first officer would act as the pilot flying (PF).

During the takeoff briefing[5] they discussed, as per company guidelines, the abnormal engine failure procedure and the flight profile to follow in such an event.

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[5] Meeting during which the pilots discuss the flight plan and potential adversities.

The aircraft took off from runway 08. When they were at about 1500 ft, they heard a loud noise, similar to an explosion, and felt the aircraft yaw to the right. At the time the captain was changing the range on his navigation display and he saw a white flash, like a faint cloud, in the front right of the aircraft. At first he thought they might have entered a cumulonimbus cloud, which surprised him, since the sky was clear.

Right away they started feeling vibrations and checked the engine gauges, noticing that the N2 reading for the right engine was 106% and the EGT for this engine was around 870-880 °C.

After discussing it they concluded that the right engine had been severely damaged.

Since they had started accelerating at 1000 ft AGL to improve their climb performance, the flaps were already retracted by the time the engine failed, but the slats were not.

They called ATC and issued an emergency (MAYDAY) call.

In keeping with the operator's procedures, the captain became the PF. They did the memory items for the relevant checklist, which consisted of pulling back the throttle for the no. 3 engine to the idle position. After this they considered doing the severe engine damage checklist.

In the meantime they reported the problem to ATC, informing that they would maintain runway heading as per the established procedure for an engine failure at TFS.

Just then the fire warning for the right engine was activated.

They did the engine fire checklist, which is the same as the severe damage checklist. The warning cleared after discharging the first extinguisher. As per procedure, they also discharged the second bottle.

Although at first they considered returning to the airport immediately, they ruled out that option because the fire warning had cleared, the aircraft's controllability was good and they had not received any other warnings.

They concluded that the situation allowed them to jettison fuel so as to land with a weight below their maximum landing weight, which was 222900 kg. This would require jettisoning 55 tons of fuel[6] (approximately 25 minutes).

They requested permission from ATC to jettison fuel at FL070, which was granted. ATC offered them a holding pattern for the operation, but the crew stated they would rather fly radar vectors, thus avoiding flying through the wake of their own jettisoned fuel.

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[6] According to the FCOM, fuel is dumped at a rate of 2268 kg/min.

They also informed ATC of their cargo, which included three live horses.

During the approach briefing, they reviewed the landing limitations associated with the runway length and the maximum speed imposed by the tires, since in addition to their high landing weight, their braking capacity was diminished by the unavailability of the no. 3 engine reverser.

After completing the fuel jettison, they made the approach to runway 08 at the Tenerife South/Reina Sofía airport, where they landed normally using minimum auto-braking.

They asked the tower to have the firefighting service follow them while they taxied to look for signs of a fuel or hydraulic fluid leak in the area of the no. 3 engine.

Upon reaching the stand, they canceled the emergency declaration and asked the firefighting service to stand by and monitor the landing gear, since the brake temperature was continuing to rise.

A short time later the firefighters reported that they had measured the brake temperature and obtained a reading below 200° C. The brake temperature shown on the gauge in the cockpit was 480° C[7]. Once the brake temperature stabilized, and since no leaks had been observed, they called the tower to inform that the firefighters could withdraw.

They added that upon reviewing the event afterward, they thought they had handled the situation properly. They also noted that the assistance offered by the FFS and ATC had been correct.

1.16.2. Flow area of the second stage rotor in the HPT

Simply stated, the flow area can be defined as the sum of the areas of every gap that exists between the blades through which air can flow.

The surface area of each of these gaps would result from multiplying the height by the minimum width of the gap between two adjacent blades. Typically, the minimum distance is found between the trailing edge of the blade and the suction side of the adjacent blade.

Similarly, since this distance is not normally constant, but varies from the root of the blade to its tip, several measurements must be taken at different locations so as to obtain a more precise reading. For this reason, each gap was measured at five different locations.

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[7] The brake overheat warning is activated at 550° or higher.

The resulting flow area value was approximately 10% higher than nominal.

Figure 6 shows a representation of the average values measured for each flow area, the shape formed by these areas, as well as the average for the stage.

1.16.3. Metallographic study

The components selected after the engine was disassembled at the Eagle Services Asia (ESA) facilities were sent to Pratt & Whitney's material and process engineering laboratory in East Hartford, Connecticut (United States), where a metallographic analysis yielded the following findings:

Vanes from stage 4 of the LPT

The 37 vane clusters recovered from the 44 that comprise this stage were sent to the laboratory.

A visual inspection revealed that cluster 22 had fractured and the lower vane had detached. Each cluster consists of three vanes called the lower, middle and upper vanes.

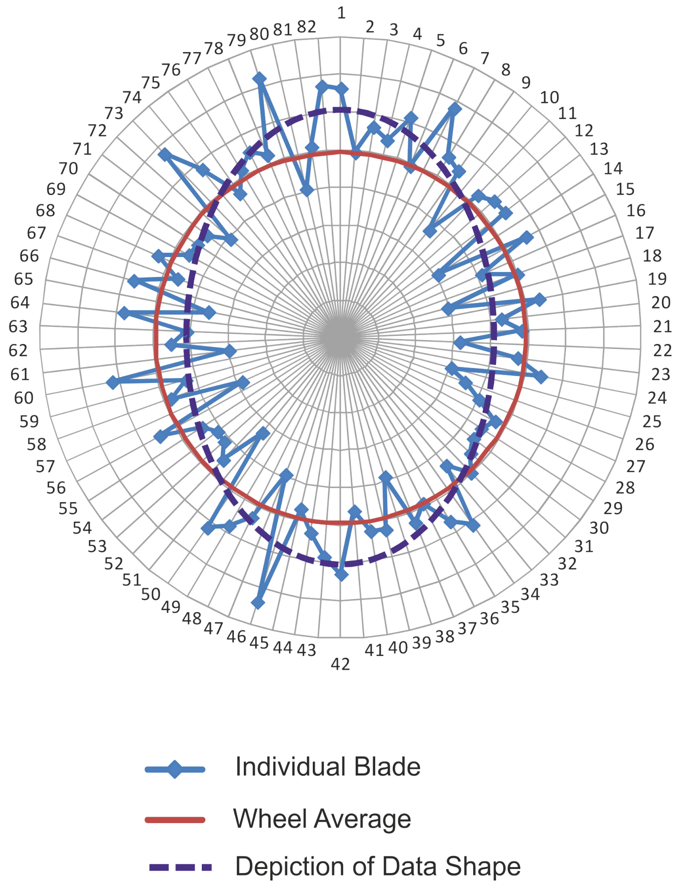


Figure 6. Representation of the sizes of the flow areas in stage 2 of the HPT

No fractured vanes were found in the remaining clusters, though numerous cracks and other damage were detected, such as:

- Impact damage to the aft face.
- Wear, friction, etc.
- Oxidized fatigue cracks on the part of the leading edge of the vane next to the outer shroud.
- Oxidized fatigue cracks on the inner shroud.
- Oxidized fatigue cracks on the outer shroud of the middle vane.
- Cracks in the fillet radii of the brace that seemed to be confined by the coating.
- Cracks in the upper and lower vanes that seemed consistent with internal corrosion.

Blades from stage 4 of the LPT

All of the 130 blades that comprise this stage were available. They were all fractured at different heights with respect to the platform.

An inspection with binocular loupes revealed evidence of fatigue on 8 of the fracture surfaces. Blade no. 60 exhibited the most fatigue damage, which extended for a distance of approximately 0.25 in from its origin near the leading edge.

A check of the remaining blades showed that all of the fatigue areas had originated in the vicinity of the leading edge and progressed backwards.

LPT case

There was a large hole in the plane of the 5th stage blades at the location corresponding to the detached 4th stage vanes, nos. 2 to 8. Other, smaller holes, dents and impact damage were also apparent on the planes of stages 4 and 5 blades.

Two sections were inspected under a microscope, one next to the large hole and another 180° away. The microstructure found indicated that the processing had been correct. The thickness of the case was measured at points next to these sections and found to comply with specifications.

The hardness of these areas was also measured and found that in the section next to the larger hole, the hardness value was below specification, while that of the other section was within specification.

Blade from stage 2 of the HPT

An analysis of the metal temperature at a point located halfway along the blade showed that the maximum temperature to which this component had been exposed was 2100° F, equivalent to 1149° C.

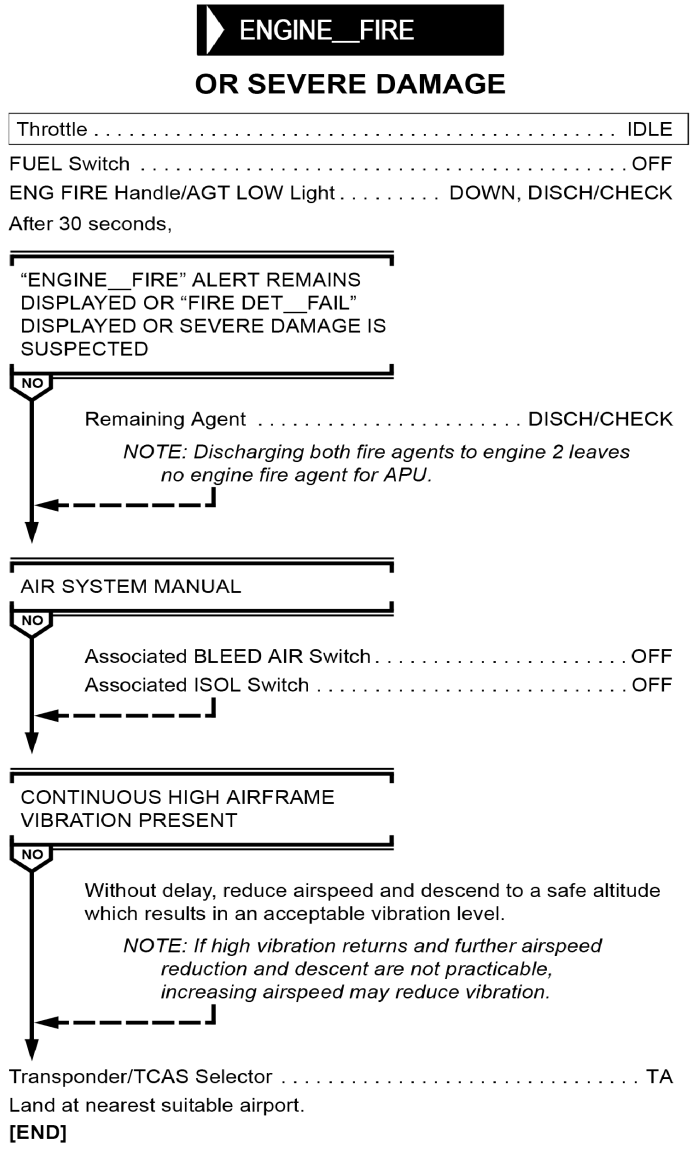
1.17. Organizational and management information

Part B of the aircraft operator’s Operations Manual specifies that the references for the emergency procedures are:

a) The MD-11 Quick Reference Handbook (QRH).

b) For additional information (time permitting), the Flight Crew Operations Manual (FCOM), Volume II, Operating Procedures, Chapter EP – Emergency Procedures.

The figure below shows the engine fire/severe damage procedure that is included in the aircraft’s QRH.



ENGINE__FIRE

OR SEVERE DAMAGE

Throttle . . . . IDLE

FUEL Switch . . . . OFF

ENG FIRE Handle/AGT LOW Light . . . . DOWN, DISCH/CHECK

After 30 seconds,

“ENGINE__FIRE” ALERT REMAINS DISPLAYED OR “FIRE DET__FAIL” DISPLAYED OR SEVERE DAMAGE IS SUSPECTED

NO

Remaining Agent . . . . DISCH/CHECK

NOTE: Discharging both fire agents to engine 2 leaves no engine fire agent for APU.

AIR SYSTEM MANUAL

NO

Associated BLEED AIR Switch . . . . OFF

Associated ISOL Switch . . . . OFF

CONTINUOUS HIGH AIRFRAME VIBRATION PRESENT

NO

Without delay, reduce airspeed and descend to a safe altitude which results in an acceptable vibration level.

NOTE: If high vibration returns and further airspeed reduction and descent are not practicable, increasing airspeed may reduce vibration.

Transponder/TCAS Selector . . . . TA

Land at nearest suitable airport.

[END]

Figure 7. Engine fire/severe damage procedure
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The FCOM states that when a crewmember identifies an emergency situation, the condition should be called out and the warning system should be reset, if applicable.

As for jettisoning fuel in flight and landing with excess weight, Part A of the operator's Operations Manual contains the following instructions:

a) General.

During normal operations, landings with a weight in excess of the certified maximum landing weight must be avoided. If required, the aircraft's weight must be lowered before starting the approach so as to avoid landing overweight.

b) Overweight landing.

During abnormal or emergency conditions, the maximum landing weight may be exceeded, at the captain's discretion, subject to the following:

1. Do not land in automatic.
2. Keep in mind that the increase in landing distance will be proportional to the square of the final approach speed.
3. The appropriate landing distance table must be used, if available, and the estimated landing distance extrapolated must be applied with extreme caution.
4. The speed limits must be observed when possible.
5. After landing, an authorized AMT (aviation maintenance technician) must conduct an "overweight landing" inspection as per the maintenance manual.

c) Dumping fuel.

This must only be considered during abnormal or emergency operations. Unless fuel must be jettisoned due to the immediacy of the emergency or as a result of aircraft performance, the following limitations shall apply:

1- Inform and coordinate with ATC before commencing the fuel dump.
2- Do not dump fuel in areas with static electricity.
3- Do not dump fuel at less than 6000 ft AGL (as recommended by the ICAO).
4- Do not dump fuel in severe or moderate turbulence.
5- Do not use HF transmitters during the dump.
6- Do not dump fuel in a holding pattern with other aircraft flying underneath.

The operating guidelines for ATC when an aircraft requests to quickly dump fuel are contained in point 4.2.20 of Spain's Air Traffic Regulations (RCA). This article defines the communications and authorizations that are required, the information to be given to the aircraft dumping fuel, the distances to keep from the ground and other aircraft, and the separations required from nearby traffic.

1.18. Additional information

1.18.1. Previous fractures/detachments of vanes in stage 4 of the LPT

According to information provided by the engine manufacturer, prior to and including 2009 there had been eight cases, the root cause of which was attributed to the fact that the vanes had characteristics that reduced their durability margins, such as:

- Non-uniform fillet radius from casting non-conformance.
- Strip/Recoat without a dimensional inspection.
- Unauthorized blend in fillet radius.

In 2009, two events were reported in engines whose 4th stage LPT stators complied with requirements. The root cause of these two events was attributed to the installation pattern for the blades in stage 2 of the HPT.

So as to confirm the presence of 2E excitation, the engine manufacturer carried out an inspection of engines installed on aircraft by selecting an engine series that could potentially be affected by this phenomenon.

The engines selected were removed from the aircraft and sent to a workshop where stage 2 of the HPT was measured and confirmed to have a pattern of dimensions that was prone to generating 2E excitation.

The engines were subjected to various tests, the data from which indicated a significant response to 2E excitation that was on the order of 10 times greater than in other engines.

The disks in stage 2 of the HPT were reassembled using a new method, and the tests were conducted once more. This time, the 2E excitation had been significantly reduced.

1.18.2. Measures adopted by the engine manufacturer prior to the event

The engine manufacturer has been adopting measures to address the problems detected. These actions have been grouped into three categories, depending on the detached component: vane clusters (solids), vane clusters (hollow) and vanes (detached from a cluster).

This has led to a series of service bulletins and airworthiness directives being issued, including those listed in point 1.6.2.2.

1.18.3. Service bulletins and other information issued after the event

1.18.3.1 Pratt & Whitney Service Bulletin 72-826

Issue date: 31/03/2014.

Problem: several vane clusters had been found with cracks or damage from internal corrosion that could propagate toward the outer surface and that were not repairable.

Cause: a structural analysis revealed that some vane clusters had areas with high stress, while other had a non-uniform internal coating that could result in lower protection against corrosion.

Solution: a new vane cluster is offered with an improved geometry that reduces stress and improves crack resistance. The uniformity of the internal coating has also been improved to increase corrosion resistance.

1.18.3.2 Pratt & Whitney Service Bulletin 72-827

Issue date: 31/03/2014.

This service bulletin proposes an alternative solution to that offered in the previous bulletin. It presents a new vane cluster that in addition to featuring the changes and improvements contained in SB 72-826, is made from a tougher material.

1.18.3.3 Special airworthiness information bulletin. SAIB: NE-16-01

Issued by the FAA on 5 October 2015.

Alerts operators, owners and certified repair facilities of airplanes equipped with Pratt & Whitney Division (P&W) PW4000 series engines with low pressure turbine (LPT) 4th stage vane cluster, part number (P/N) 51A357 installed, to potential structural degradation due to hot corrosion (sulfidation[8]) of the vane internal passages.

The SAIB states that the FAA had received several reports of vane liberations, which had resulted in two engine failures with low-energy case uncontainment events on PW4000-94 model engines. Both failures resulted in safe landings. Investigations revealed sulfidation of the vane internal passages corroding the parent material and the subsequent weakening of the structure.

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[8] During combustion, the sulfur in the fuel and the sodium chloride in the air react to produce sodium sulfate, which is deposited in some parts of the hot section of the engine, such as blades and vanes, accelerating the oxidation processes.

On 15/01/2015, task no. 72-53-24-200-002 was published in the Clean, Inspect, Repair (CIR) Manual for PW4000 series engines, P/N 51A357, for the purpose of inspecting the dimensions of the LPT 4th stage vanes using a magnetoscope.

The SAIB states that while borescope inspections are useful for detecting sulfidation on the outer surface of the vanes, it is not capable of detecting it on internal surfaces prior to failure, since the material deterioration takes place primarily in the internal passages. A magnetoscope inspection, however, which is a non-destructive method, can be used to measure the amount of unaffected material.

Through this SAIB, then, the FAA recommends that, in addition to the borescope inspection of the LPT, a magnetoscopic inspection be performed on the LPT 4th stage vanes, as per task no. 72-53-24-200-002 of the Clean, Inspect, Repair (CIR) Manual for PW4000 series engines, P/N 51A357, and that the degraded parts be removed.

On 14 January 2016, the FAA issued a revision to this SAIB (NE-16-01R1) to correct and clarify the instruction, background and recommendations.

In the introduction, this revision modifies the identification of the affected engines to those
with low-pressure turbine (LPT) 4th stage vane clusters with a hollow internal airfoil configuration installed, instead of engines with clusters with specific P/N, as indicated in the first version of the SAIB.

It also amends the information on the contents of task no. 72-53-24-200-002 of the Clean, Inspect, Repair (CIR) Manual for PW4000 series engines, P/N 51A357, indicating that the purpose of the magnetoscope inspection is to detect the permeability of the 4th stage LPT vane airfoils, not their dimensions.

Finally, the recommendation paragraph is amended to adapt it to the changes made.

1.18.4. Incident involving aircraft PH-MCW in Puerto Rico

On 30 August 2013, another MD-11 aircraft from the same operator, which was preparing to fly from the Aguadilla airport (Puerto Rico) to the Stansted airport (United Kingdom), experienced an uncontained failure of the no. 1 engine during the takeoff run that forced the crew to abort the takeoff.

According to the information provided by the engine manufacturer, Pratt & Whitney, the inspection of the engine revealed that the failure had started in the 4th stage LPT, and was determined to have been caused by corrosion of the vanes in the 4th stage LPT.

On April 2016, the NTSB updated the information related to this event, which included as the probable cause, the following:

"An insufficiently robust flange attachment hardware design, which failed to contain engine components that were liberated during an LPT mechanical failure, resulting in engine/nacelle/ uncontainment.

A factor in the incident was a lack of a module-level LPT inspection and the lack of an inspection requirement to detect/monitor the LPT S4 for advanced sulfidation attack".

1.18.5. Risk monitoring and evaluation of engines conducted by the operator

The aircraft's operator, Martinair Cargo, has a risk monitoring and evaluation system for the engines in its fleet, including engines of the same type as the one involved in this incident.

The risks have been categorized into four groups, one each for the following aspects:

- 2E excitation.
- Structural integrity (based on the number of recoatings of the 4th stage LPT vanes). AD-2012-14-09 specifies that vanes with more than one strip and recoat must be replaced.
- Casting used to cast the 4th stage LPT vanes. Identified in SB 72-798.
- Corrosion.

Based on these factors, the engine that failed posed a low 2E excitation risk but a high risk from two other factors (integrity and casting) and a medium risk from the last factor (corrosion).

- Structural integrity: the 4th stage LPT vanes had been recoated three times.
- Neither service bulletin had been implemented.
- The 4th stage LPT vanes had more than 4000 hours since the last overhaul.

1.18.6. HPT 2E excitation

The so-called 2E excitation (twice per revolution) is a vibratory phenomenon that is generated in the HPT as a result of variations in the pressure pulses generated by each blade pair.

The source of the pulse variation lies in the different dimensions of the flow areas in two pairs of adjacent blades.

The differences in the air flow areas can be due to various causes: tolerances, service history, combination of blades with different time/cycle histories, etc.

The circumferential variation in the flow areas of a turbine stage can cause pressure distribution patterns that generate cyclical pressure pulses that could potentially affect downstream components.

If the pulse frequency matches the natural resonance frequency of a specific component, it could be affected. In fact, the vanes in the 4th stage LPT are sensitive to 2E harmonics from the HPT rotors under normal operating conditions.

1.18.7. Overweight landing or fuel dump

When, as in events like the one studied in this report, a situation arises that requires the aircraft to return to the departure airport or to divert to an alternate shortly after takeoff, it is quite likely that the aircraft will reach the airport at which it will land with a weight that is well in excess of the maximum landing weight.

The "Boeing Aero" issue published in the third quarter of 2007 featured an article titled "Overweight Landing"[9] that was devoted specifically to these situations and that analyzed the aspects to be considered when determining what action to take.

This article offers general information and aircraft structural and performance data that are intended to assist airlines in determining the best operational option in a given situation.

According to the information in this article, both an overweight landing and dumping fuel are regarded as safe procedures, there being no record of any accidents having been caused as a result of either of these operations.

The article states that overweight landings are safe since the design standards for aircraft certified under FAR Part 25 are fairly conservative. Specifically, the design criteria for landing gear are based on:

- A sink rate of 10 ft/s at the maximum landing weight, and
- A sink rate of 6 ft/s at the maximum takeoff weight.

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[9] http://www.boeing.com/commercial/aeromagazine/articles/qtr_3_07/article_03_1.html

The typical sink rate during a landing is on the order of 2 to 3 ft/s. Even in a hard landing the sink rate will rarely exceed 6 ft/s.

The table below provides a summary of the main factors involved in each option. The goal of burning fuel in flight is equivalent to that of dumping excess fuel, the most significant difference being the longer time required to reduce the aircraft's weight.

Overweight landing	Dumping/burning fuel
Reduced operational margins.	With one engine out or a fault in one system, the delay in landing from dumping/burning fuel can lead to a worsening of the situation.
Increased landing distance.	Fuel cost.
Requires inspecting the gear after landing.	Environmental aspects, though studies indicate that if fuel is dumped from higher than 5000/6000 ft, all the fuel evaporates before reaching the ground.
Auto-landing not recommended, since the autopilots on Boeing aircraft are not certified for weights higher than the maximum landing weight.	

1.19. Useful or effective investigation techniques

Not applicable.

2. ANALYSIS

2.1. Analysis of the flight (prior to the event)

The engine start sequence commenced with the start-up of engine 3, as per the procedure.

This was followed by the start-up of engine 1 and then engine 2 a minute later; thus, by 00:18 all three engines were running.

The engine manufacturer recommends running the engines at idle for at least 5 minutes before takeoff if the engines had been stopped for more than 2 hours prior to start-up. There is no recommended minimum warn up time if the engine has been stopped for less than 2 hours.

The incident flight falls under this supposition, meaning that the engine warm-up period should have lasted at least 5 minutes.

After start-up, the engines remained at idle for more than 11 minutes before takeoff thrust was selected, meaning that the warm-up requirements specified by the manufacturer were amply satisfied.

During the takeoff run and subsequent climb, prior to the sudden drop in N1 for engine 3, all of the engine parameters were within their operating limits.

From the time the first engine, no. 3, was started until the no. 3 engine failed, the crew correctly executed the engine start-up and warm-up procedures and they were operated according to procedures.

2.2. Analysis of the handling of the emergency

The crew had done flight performance calculations for the takeoff and altered the departure flight profile to avoid the likelihood of encountering windshear, which can occur at TFS when there is a change in wind direction.

An engine failure during takeoff just after V1 (decision speed) or Vr (rotation speed) is routinely covered in simulator training. The circumstances under which the catastrophic failure occurred were different, but the crew were able to adapt their actions to the required procedure.

The crew's actions were coordinated and in keeping with the company's guidelines, with control of the aircraft being transferred to the pilot in command. An emergency declaration (MAYDAY) was issued so as to obtain the maximum assistance from airport services and from ATC in resolving the situation.

Since they were clearly over the maximum landing weight, and as the fire warning had cleared and the aircraft was behaving normally, the crew decided to avoid an overweight landing and to jettison fuel, as specified in the company's manuals.

They continued climbing above 6000 feet, the altitude given in the Operations Manual as the minimum for commencing a fuel dump, and above the minimum safe altitude.

The crew coordinated the procedure with ATC, which gave them vectors, thus avoiding entering a racetrack circling pattern that could have forced the aircraft to fly through its own vaporized fuel wake. ATC's coordination and actions facilitated the crew's efforts, as did the fact that the event took place at a time of low traffic, which made it easier to apply the procedures specified in Spain's Air Traffic Regulations for this operation.

The crew took into account the possible problems involved in landing with so much weight and with the diminished braking capacity resulting from having one reverser inoperative.

The landing occurred without further incident. The brakes did not overheat, although the crew requested the airport's FFS to monitor their temperatures.

The crew's actions are deemed to have been appropriate and highly professional.

2.3. Analysis of the failure sequence

The turbine on this engine is divided into two sections: high and low pressure. The HPT has two stages, while the LPT has four.

Each stage consists of a fixed structure (stator), which is located in front of a bladed disk that can rotate (rotor). The main function of the stator is to direct the flow of air such that it strikes the rotor blades at the optimum angle.

As described in point 1.6.4, the two stages that comprise the HPT retained all of their blades (rotors) and vanes (stators), which were found whole and with no significant damage.

The next stage aft is the first of the four stages in the LPT which, according to the manufacturer's nomenclature, is identified as the LPT 3rd stage. Every blade in this stage was attached to the disk and had no material missing. Approximately 75% of them had impact marks on the trailing edge, that is, at the rear of the blade. Moreover, some of the segments that comprise the air seal on this stage had detached.

Aft of the LPT 3rd stage is the stator of the LPT 4th stage.

Significant damage was found in this stator, consisting primarily of the detachment of seven vane clusters and the fracture airfoil in vane cluster 22.

The seven detached vane clusters were adjacent to the large puncture in the LPT case over the 5th stage and were consistent with secondary damage associated with this case damage.

The finding of fatigue associated with the liberated airfoil from the 4th stage cluster 22 is consistent with this fracture being an initiating event.

The detached vane airfoil from vane cluster 22 would have been quickly entrained in the jet of gases inside the engine toward the exhaust.

As the fractured airfoil traveled inside the engine impacted other rotating parts. The next component it struck would have been the rotor disk in the same (4th) stage. The damage to this disk, namely the fracture of all its blades, is consistent with the detachment of the cluster 22 vane airfoil.

The blades that detached from the rotor joined the vane detached from the stator to produce the damage found downstream.

Thus, most of the fractures resulted from impacts by detached components, meaning they were a consequence of the initial failure, which would have been at the fracture area located furthest upstream, which would be the LPT 4th stage stator, specifically vane cluster 22.

The metallographic study detected fatigue cracks in 8 of the 130 blades that comprise the rotor of the LPT 4th stage. Based on this same study, the cracks originated from impacts. The timing of these impacts could not be determined from the study, but it is possible that this damage either developed during the event or existed prior to the event.

In fact, an impression left on a blade as the result of an impact can cause a fatigue crack to form. Once this happens, the growth process begins, during which the crack propagates until it reaches a critical size, at which point the propagation speed increases significantly. As the crack grows, the unaffected part of the component is reduced and the fatigue crack will progress until the remaining portion is unable to withstand the load, causing the part to fracture from static overload.

The fatigue cracks found on several of the blades are fully compatible with the mechanism described above. The metallographic analysis indicated that the cracks were in the growth stage, meaning they would not have caused the blades to fracture without the impact associated with the detached hardware.

In light of this, the failure sequence most likely began in the LPT 4th stage stator, specifically with the fracture of the airfoil from vane cluster 22. This detached airfoil impacted the rotor of the same stage, which is located just behind the stator, causing every blade on the rotor to fracture at its weakest point. It is possible that those blades already had fatigue cracks which would have produced a lower strength in the area of the crack and the consequent fracture of the blade at that point. Although, it is possible that the initiating impact damage and progression occurred during the event, as the rotor was being de-cobbed.

The damage found in the engine is fully consistent with a failure sequence scenario in which the lower vane in vane cluster 22 in the LPT 4th stage stator was the first to detach.

The metallurgical investigation has not been able to determine if the corrosion was a contributing factor in the development of the failure, or not.

2.4. Analysis of the initial failure

As noted in section 1.16.3, the metallographic analysis of the vane clusters recovered from the LPT 4th stage revealed the presence of numerous fatigue cracks and wear.

Based on the engine manufacturer’s experience, the damage found in the metallographic study was consistent with a scenario in which the vanes were subjected to relative motion and high levels of vibratory excitations (HPT 2E excitation), as described in section 1.18.6.

The pattern of mixing and assembling the blades in the HPT 2nd stage, alternating heavy and light blades, was in keeping with the latest instructions from the engine manufacturer, the main objective of which was to prevent the 2E excitation.

Due to this and other conditions, the risk monitoring/evaluation conducted by the operator/manufacturer indicated that this engine was considered “safe” against the risk posed by HPT 2E excitation.

In contrast, the measurement of the HPT 2nd stage rotor (see 1.16.2) revealed that the disk had a pattern of flow areas that was susceptible to producing the pressure pulses that generate the 2E excitation.

From this it may be concluded that this disk’s actual condition was significantly different from the condition that would be expected based on the risk analysis. This calls into question both the reliability of this analysis and the knowledge of the factors involved in generating the pulses that result in 2E excitation.

The information available provides no indications as to the cause of the failure. This could be due either to the conditions involved in the evaluation and how they are weighed, or to the presence of a condition that is not among those considered.

In either case, this event makes it reasonable to question the reliability of the other engines included in the operator's analysis that have also been deemed "safe" against the risk of 2E excitation.

At this juncture we should mention the presence of significant differences in the fracture mechanisms observed in this case and in the incident that took place in Puerto Rico.

While the incident analyzed in this event involved the presence of extensive fatigue damage and, to a lesser extent, corrosion damage, in the Puerto Rico incident most of the damage was due to corrosion. This indicates that the two events were caused by different mechanisms.

2.5. Measures taken by P&W

Following this incident, the engine manufacturer, Pratt & Whitney, issued service bulletins 72-826 and 72-827, aimed primarily at improving the corrosion resistance of the vanes in the 4th stage of the LPT, though they also introduced changes to their geometry in an effort to lower stresses and improve their fatigue resistance.

SAIB NE-16-01 also recommends conducting magnetoscope inspections of the vanes on the 4th stage of the LPT to detect sulfidation (corrosion) in the internal passages of the vanes.

While this mechanism (corrosion) was the root cause of several in-service failures, it was not the cause in the case analyzed in this report (HPT 2E excitation), meaning that it is not known if these measures help lower the risk of failures due to this phenomenon. While the service bulletins do indicate the redesigned clusters improve fatigue resistance, the bulletins themselves do not how effective these improvements may be against HPT 2E excitation.

Pratt & Whitney is evaluating the practices for installing the blades on the 2nd stage of the HPT, and determining whether to revise existing procedures and/or to adopt additional corrective measures to address the HPT 2E excitation problem.

3. CONCLUSIONS

3.1. Findings

- All of the crewmembers had valid and in force licenses and medical certificates.
- All of the aircraft's documentation was in order and it was airworthy.
- During the takeoff run and subsequent climb, until the sudden drop in the N1 value for the no. 3 engine, all of the engine parameters were within their operating limits.
- While the aircraft was climbing, at a barometric altitude of about 1559 ft, there was a sudden drop in the value of the N1 parameter for the no. 3 engine.
- The crew correctly carried out the severe engine damage procedure.
- Immediately afterwards, the fire warning for the no. 3 engine was activated.
- The crew applied the relevant procedure, which is the same as for severe engine damage.
- The engine fire warning cleared.
- The crew reported the situation to ATC and declared an emergency.
- After evaluating the situation, they decided to jettison fuel so as to lower their weight below the maximum landing weight.
- The aircraft landed normally on runway 08 at the Tenerife South/Reina Sofía airport.
- After landing, the no. 3 engine was verified to have experienced an uncontained failure.
- The source of the failure was the detachment of a vane from vane cluster 22 in the 4th stage stator of the low-pressure turbine (LPT).
- The metallographic study of the vanes recovered from the 4th stage of the LPT detected the presence of numerous fatigue cracks and wear.
- The blades on the second stage disc (rotor) of the high-pressure turbine (HPT) had been installed as per the latest procedure in the engine manual.
- The risk monitoring/assessment conducted by the operator/manufacturer indicated that this engine was deemed "safe" against the risk of being affected by HPT 2E excitation.

3.2. Causes/Contributing factors

The failure of the aircraft's no. 3 engine occurred due to the detachment of a vane in vane cluster 22 in the 4th stage stator of the low-pressure turbine (LPT).

The root cause of this failure was probably the pressure pulses (HPT 2E excitation) generated by the second stage of the high-pressure turbine (HPT), which caused elevated levels of vibration in the LPT 4th stage stator, resulting in fatigue cracks forming on the vanes.

Although the investigation has not been able to determine if the corrosion was a contributing factor in the development of the failure, this mechanism cannot be rule out.

4. SAFETY RECOMMENDATIONS

The investigation into this incident underscored the failure of the operator's/manufacturer's risk monitoring/evaluation, which considered the engine involved in the event as safe against the risk of being affected by the 2E HPT excitation phenomenon, the cause of which is unknown for the time being. This has led to doubts as to the reliability of the entire risk study as concerns 2E excitation, meaning there could be engines that are deemed safe but are in fact at high risk of an in-service failure. As a result, and until more is known about the reasons for the failure, it seems prudent to evaluate the appropriateness of taking some immediate action to quantify the risk of 2E excitation.

Similarly, given the possibility that an engine deemed safe against the 2E excitation risk could be susceptible to an in-service failure, it seems prudent to evaluate the suitability of conducting inspections to check the actual conditions present in the LPT 4th stage stators on these engines.

As a result, the following safety recommendations are issued:

REC. 33/16 It is recommended that the engine manufacturer, Pratt & Whitney, take immediate measures in terms of how the 2E excitation risk is quantified in its risk monitoring/evaluation studies for PW4000 engines.

REC. 34/16 It is recommended that the engine manufacturer, Pratt & Whitney, take the necessary measures to ensure additional inspections are carried out on those engines that were deemed "safe" in terms of the 2E excitation so that the actual conditions of the LPT 4th stage stators on these engines can be ascertained, thus preventing future in-service failures.