Accident to the BOEING - 737- 800 registered **F-GZHA** on 1 October 2022 on Nantes - Atlantique airport

Time	Around 11:05[1]
Operator	Transavia France
Type of flight	Commercial air transport of passengers
Persons on board	Captain (PM[2], instructor), co-pilot (PF), four cabin crew members, 165 passengers.
Consequences and damage	Aeroplane substantially damaged

This is a courtesy translation by the BEA of the Final Report on the Safety Investigation. As accurate as the translation may be, the original text in French is the work of reference.

Late flare, hard bounced landing, in instruction

[1] Except where otherwise indicated, the times in this report are in Coordinated Universal Time (UTC). Two hours should be added to obtain the legal time applicable in Metropolitan France on the day of the event.
[2] The glossary of abbreviations and acronyms frequently used by the BEA can be found on its web site.

1 HISTORY OF THE FLIGHT

Note: the following information is principally based on the CVR and FDR, statements, radio communication recordings, radar data as well as images recorded by the airport's security cameras.

The flight crew were performing flight TO3943 departing from Djerba (Tunisia) bound for Nantes-Atlantique. The crew consisted of a captain, acting as an instructor (TRI) on this flight, and a co-pilot in Line Flying Under Supervision (LIFUS). The captain was PM and the co-pilot was PF. The co-pilot had resumed flying the day before the accident after a break of three months.

1.1 Cruise and arrival

At 10:13, while in cruise, the crew obtained the latest meteorological information for the destination and alternate airports via the ACARS system. Five minutes later, the co-pilot spoke to the captain about his lack of confidence about landing and specified that he did not want to repeat the same landing as the previous day at Nantes, during which the normal load factor had reached 1.7 g[3]. The captain reminded him that his last landing at Djerba with a 30 kt crosswind took place without any incident.

At 10:25, as the aeroplane descended towards FL340, the crew started their "approach" briefing. This was interrupted by an ATC communication. The crew discussed the non-precision RNP approach to runway 21 (see paragraph 4.1.6). In particular, they mentioned the "offset" and the profile of runway 21 in use (the "hump") as threats on approach and landing. They also discussed the weather conditions, saying that the wind was improving, with fewer gusts. The crew did not mention any strategy as regards the conduct of the approach and the use of automated systems. The measures to mitigate the threats identified for the flare were not repeated[4].

At 10:41, the instructor listened to the ATIS message which confirmed that runway 21 was in use, and indicated that visibility was reduced to 4,800 m and that the ceiling had descended to 600 ft in the presence of light rain and mist. The wind was blowing from 250° at 10 to 17 kt. The instructor gave this information to the co-pilot, who specified that the runway would be visible "at the last minute". After checking with the co-pilot, the instructor confirmed that it was possible to land at Nantes in these weather conditions, taking into account the unavailability of the simultaneous lead-in-strobe lights on each side of the threshold of runway 21. The crew proceeded with the approach. From 11:00, the crew configured the aeroplane for landing. The before-landing checklist was carried out after extending the flaps to 30°. During this checklist, the approach speed (Vapp) was calculated by the crew using the meteorological information available to them. The selected Vapp was 156 kt.

At 11:03:21, thirteen seconds after the radio altimeter 2,500 ft callout, the co-pilot informed the instructor that he would be flying the aeroplane manually from 2,000 ft, as on the previous day's flight, "for training purposes" following the period he had spent without flying. Approximately twenty-five seconds later, the co-pilot disconnected the autopilot and then the autothrottle and continued the flight in manual mode, in descent along a 220 heading as specified in the approach procedure (see Figure 1).

[3] Unless otherwise stated, the normal load factors mentioned in the report are those recorded in the FDR at the aeroplane's centre of gravity.

[4] However, during the briefing, the PF stated that he and the captain had already discussed the flare the day before at Nantes.

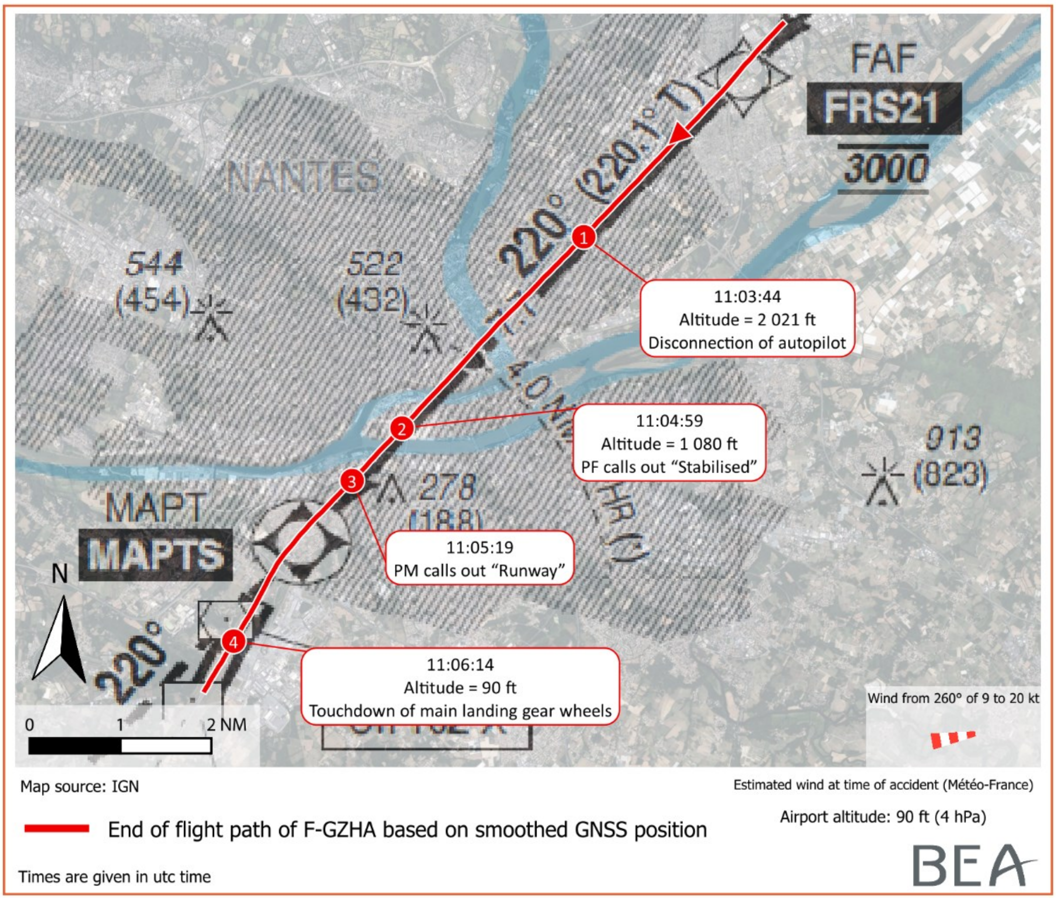

Figure 1: path of F-GZHA during the approach (source: BEA)

At 11:04:16, the crew announced that they were 4 NM from threshold 21 and the Tower controller cleared them for landing. The wind indicated by the Tower controller was a wind of 9 to 20 kt from 260°. At 11:04:59, on approaching 1,000 ft, the co-pilot announced that the aeroplane was "stabilised". The aeroplane was then on the approach slope and on the axis, in the landing configuration. Its indicated airspeed was 158 kt, 2 kt more than the Vapp, the rate of descent was 880 ft/min[5] and thrust was stabilised at 57%. About one minute later, the instructor called out "*runway*" while the aeroplane was at approximately 800 ft and 2 NM from the threshold of runway 21.

On approaching the minima and about 1.3 NM from the threshold of runway 21, the co-pilot turned left to align the aeroplane.

1.2 Final approach and landing

The co-pilot held the runway axis with a drift correction of less than five degrees. He indicated that he was monitoring the approach slope using the PAPI. The approach was stabilised, with a Vapp close to that calculated by the crew. On final for runway 21, between 500 ft and 100 ft, i.e. for about 30 s, the instructor asked the co-pilot to apply corrections to hold the runway axis several times. During this period, the aeroplane's path remained aligned with the runway axis and the slope. The speed deviations remained small.

[5] Consistent with the descent rates indicated on the approach chart.

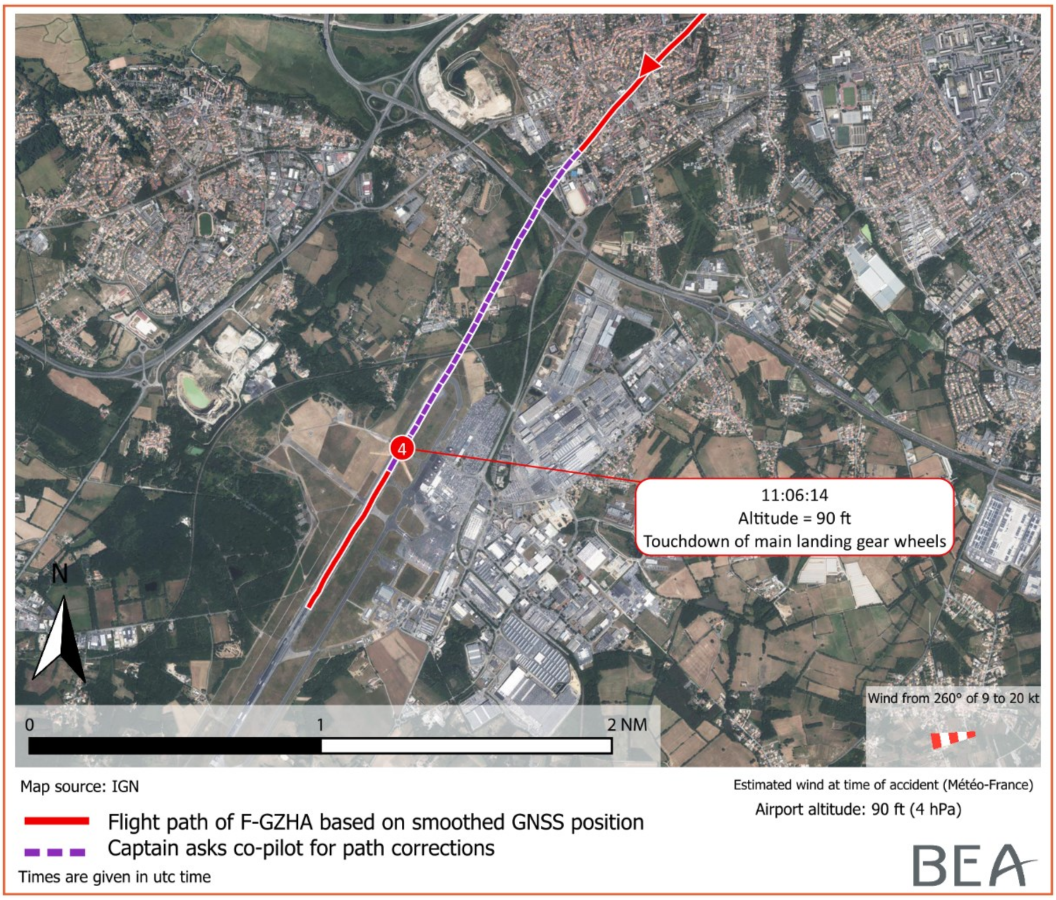

Figure 2: final flight path of F-GZHA (source: BEA)

On crossing the threshold of runway 21, at 11:06:10, the aeroplane was at a height of 50 ft with a speed of 158 kt, 2 kt above the Vapp, and decreasing (see Figure 3, point 1). The drift was about 4°, constant until touchdown, and the aeroplane was slight banked to the left. The rate of descent was approximately 800 ft/min. The aeroplane was slightly under the approach slope. Below the height of 50 ft, just before the flare, there was a decreasing headwind.

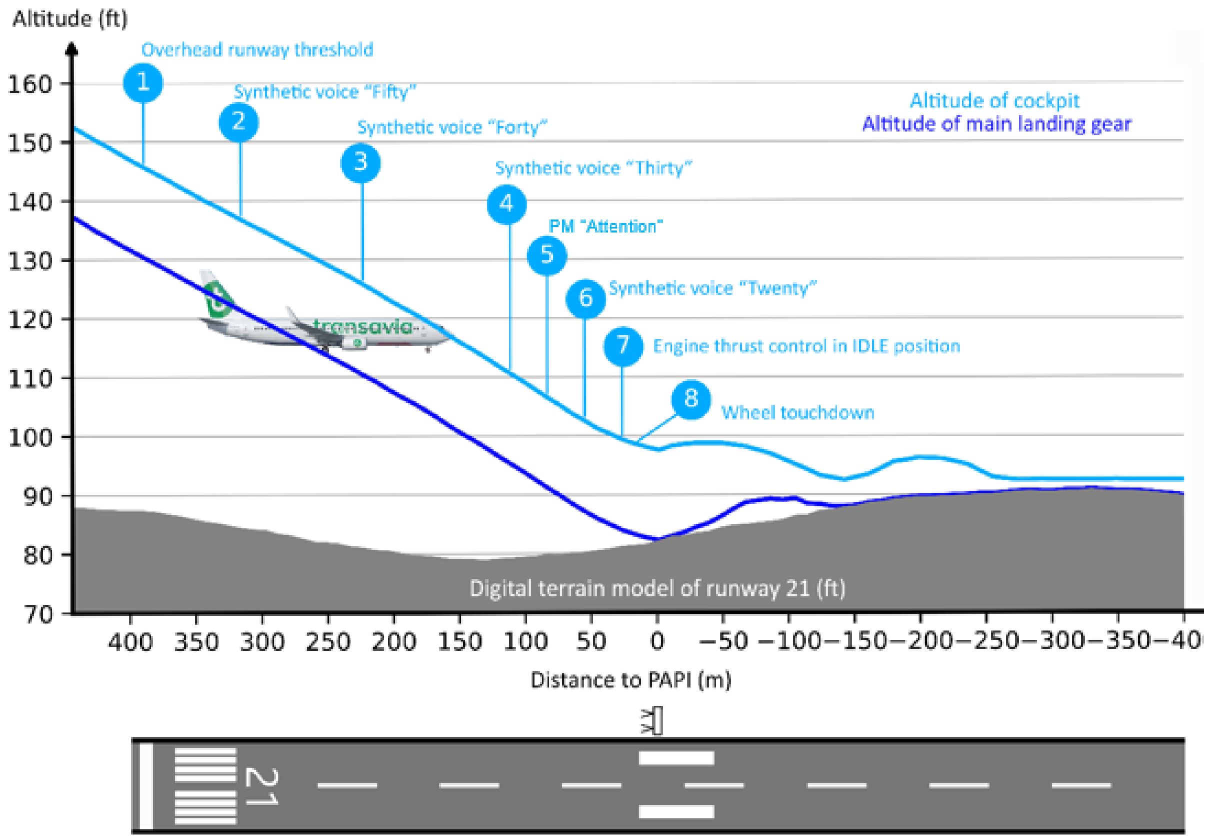

Figure 3: vertical profile of the landing (source: BEA)

Throughout the final approach and up to point 8, thrust remained stabilised at 57% of N1.

Shortly after the "forty" synthetic-voice callout (point 3), approximately 170 m from the PAPI, the co-pilot applied a slight nose-up input[6] (see Figure 4, between points 3 and 4 5 6 7), which he increased considerably two seconds later approximately 120 m from the PAPI[7] (shortly before point 4).

[6] Two-degree nose-up input with the control column in less than one second.
[7] Nine-degree nose-up input with the control column in less than one second.

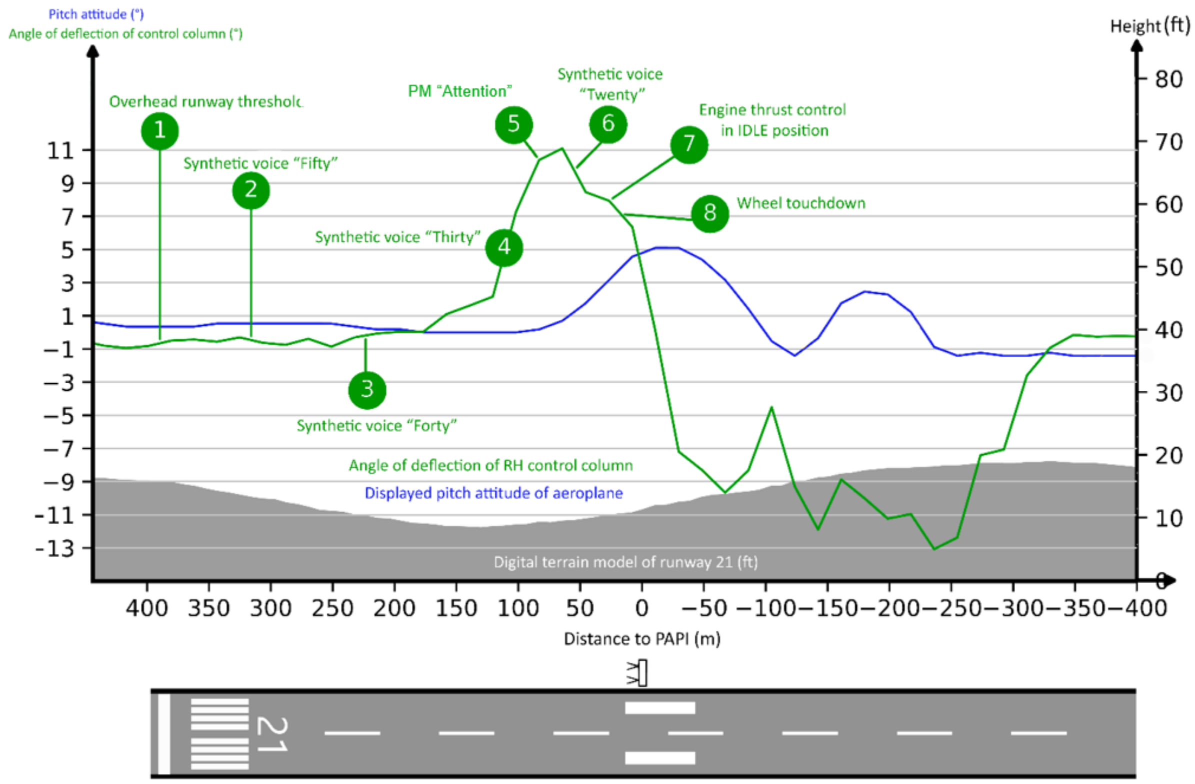

Figure 4: angle of deflection of the column and attitude of the aeroplane (source: BEA)

The aeroplane started flying over the upward-sloping part of the runway, about 110 m from the beginning of the touchdown zone markings. The speed was 2 kt below Vapp, still decreasing, and thrust was still stabilised at 57% of N1. Shortly after the "thirty" callout (Figure 4, point 4), the instructor warned the co-pilot to watch out, calling out "*Attention*" (point 5). The pitch attitude, which was stable and close to 0°, started to increase. Less than one second later, after the "twenty" callout (point 6), approximately 30 m from the touchdown zone markings, the co-pilot moved the thrust levers to the IDLE position. The aeroplane's pitch attitude was then 3° and increasing.

1.3 Touchdown and bounce

The main landing gear touched down on the touchdown zone markings[8], on the upward-sloping part of the runway[9]. The touchdown took place at a pitch attitude of approximately 5° (see point 8) and with a normal load factor of 2.95 g (see Figure 5). Thrust was close to 50%, similar to the approach, and decreasing.

[8] The PAPI is located to the left of the runway, in line with the touchdown zone markings.
[9] The runway measurements at this point indicated a gradient of 1.37% (0.78°)

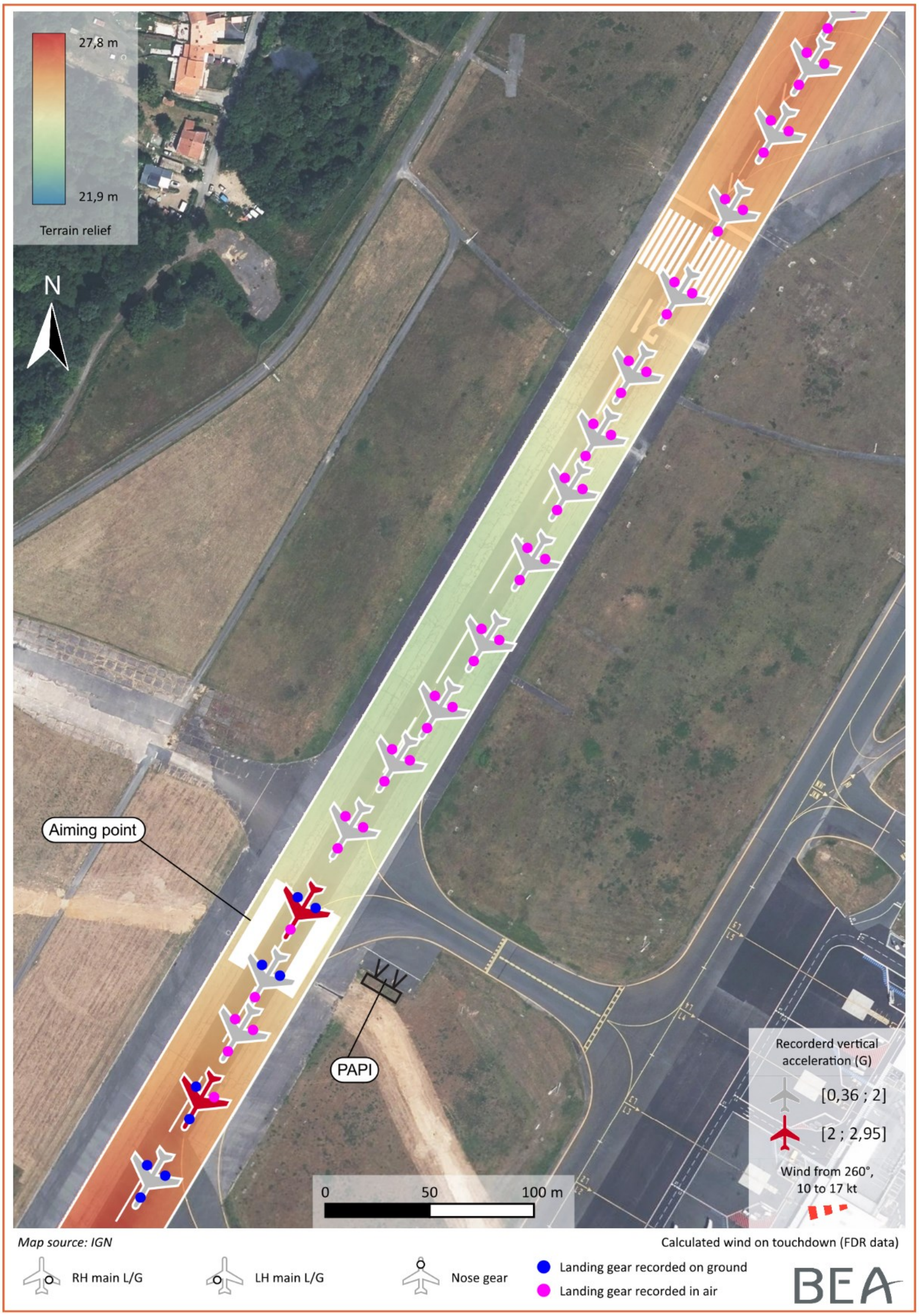

Figure 5: final path, flare and touchdown

When the main gear wheels contacted the runway, the spoilers were deployed. The crew were surprised by the violence of the contact with the runway. The aeroplane bounced and the instructor instinctively applied a nose-down input of about three quarters of the maximum possible deflection[10], without announcing to the co-pilot that he was taking the controls.

During the bounce, which lasted less than one second, the recorded normal load factor decreased to 0.2 g and the pitch rate reached approximately 8° per second nose down due to the input of the instructor. He then released his nose-down input.

[10] Approximately 10° for a maximum amplitude of 13.75°.

The right and nose landing gears contacted the runway (normal load factor recorded at 2.17 g), still on its upward-sloping part (gradient of around 1.32%). The two tyres on the nose landing gear burst and separated from the rims. On second contact with the runway, the aeroplane's attitude was 1.4° nose down. The left main landing gear contacted the runway shortly after the other two landing gears. The normal load factor increased to 2.2 g. As soon as the aeroplane was on the ground again, the instructor applied another nose-down input, this time to full deflection. As for the co-pilot, he deployed the thrust reversers. The aeroplane continued running on the runway, remaining on the centreline.

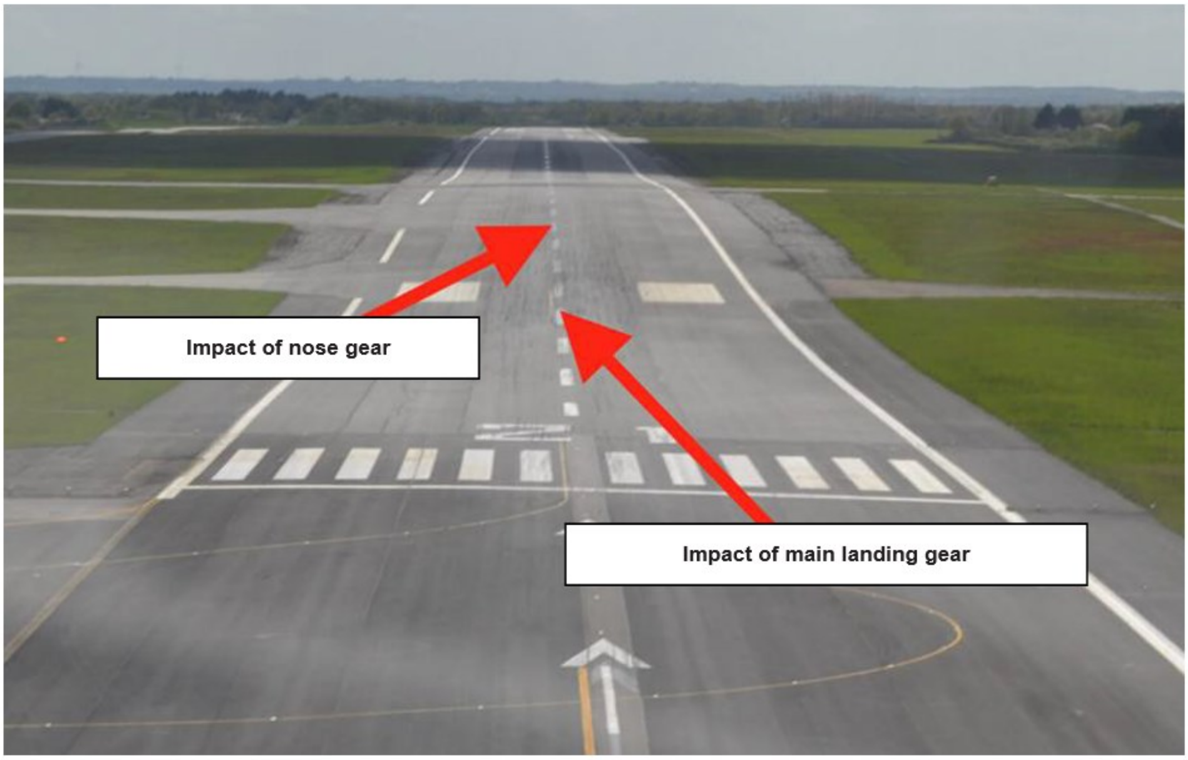

Figure 6: impact marks from the landing gears (source: Transavia)

At 11:07:07, the air traffic controller informed the crew of the loss of both nose landing gear tyres on contact with the runway. A few seconds later, the instructor turned left and stopped the aeroplane on taxiway B after vacating the runway.

A loud and unusual noise was heard on the CVR throughout the running phase until the aeroplane came to a stop.

The crew assessed the situation and checked that no passengers or crew were injured. Passenger disembarkation was organised via the aeroplane's front and rear doors.

2 AEROPLANE INFORMATION

2.1 General

The Boeing 737-800 registered F-GZHA joined the Transavia France fleet on 18 May 2007.

Its last major maintenance inspection was carried out on 25 February 2022 and the last minor inspection on 22 June 2022. On the day of the event, it had logged 50,263 flight hours.

2.2 Damage

The two tyres of the nose landing gear burst and were ejected on first contact with the ground (see Figure 7).

The nose landing gear rims failed between the bead seating area and the rim flanges (see Figures 8 and 9). These were also ejected between the point of contact with the ground and the moment when the aeroplane came to a stop.

Figure 7: burst tyre (source: BEA)

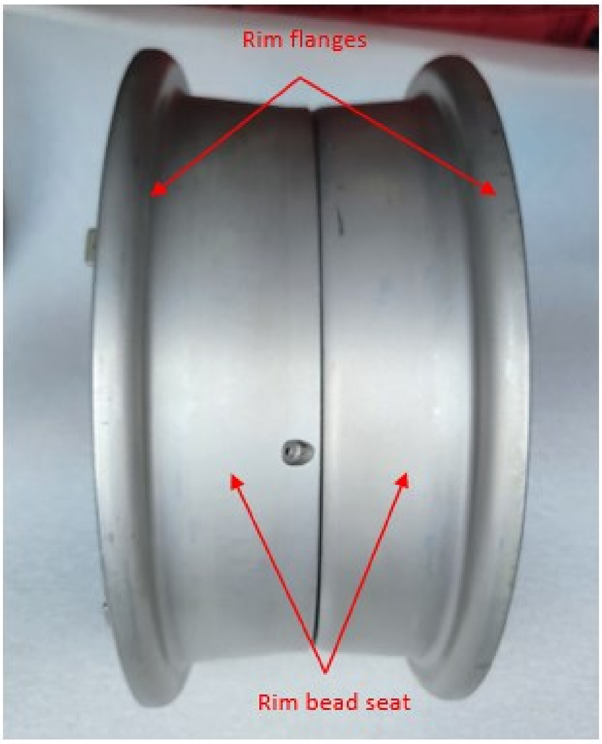

Figure 8: new rim (source: BEA)

Figure 9: ruptured wheels of nose landing gear (source: BEA)

The nose landing gear was damaged in several places and its casing was distorted. The aeroplane's frame located in line with the nose landing gear was distorted. The airframe and engines showed several signs of impact, very probably caused by parts of the wheels and tyres when they detached (See Figures 10 and 11).

Figure 10: example of damage observed on the airframe (source: BEA)

Figure 11: example of damage observed on engines (source: BEA)

Some damage required repairs. This was the case for the nose landing gear, its casing and some of the aeroplane's bulkheads located nearby. Several impacts caused by debris projected following the failure of the nose wheels also gave rise to repairs.

Based on calculations using the aeroplane model, Boeing estimated that the nose landing gear was subjected to a local normal load factor of 6.5 g (+/-20%) when it contacted the runway.

3 METEOROLOGICAL INFORMATION

The Loire-Atlantique department was in the warm sector behind a warm front, with mild and humid air in the lower layers. The sky was overcast with stratus clouds and there were spells of rain and drizzle.

The meteorological conditions observed at 11:06 by Météo-France on Nantes - Atlantique airport were as follows:

- average (2 minutes) surface wind from 260° of 10 kt, with gusts of 17 kt;
- visibility greater than 10 km;
- overcast at a height of 700 ft;
- temperature 18°C, dew point temperature 17°C;
- slight turbulence.

4 AERODROME INFORMATION

4.1 Aerodrome certification and operating conditions

4.1.1 Certification basis

In Europe, certified aerodromes comply with a set of applicable technical requirements, based on Commission Regulation (EU) No 2018/1139[11]. The design requirements known as certification specifications are issued by EASA.

ICAO Annex 14 has a reference code used to classify aerodromes. This code was incorporated in the regulations issued by EASA (requirement CS ADR-DSN.A.005).

For Nantes - Atlantique airport, the reference code is 4-E. This code means that aeroplanes with a landing distance greater than 1,800 m (number 4) and a wingspan of 52 m or more without exceeding 65 m (letter E) can use it. Taking into account the landing distance and wingspan of the B737, this aeroplane can use the Nantes-Atlantique airport without restrictions.

The 4-E classification imposes several requirements to be observed when operating the runway.

[11] Regulation of 4 July 2018 concerning common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency (Version in force on the day of the accident).

4.1.2 Requirements related to longitudinal slopes on a runway

Runway slopes and slope changes must meet specific conditions to reduce loads on landing gears, to allow safe use of the runway by aircraft and to ensure an unobstructed line of sight over all or as much of the runway as possible.

"*Longitudinal slopes of runways*" (CS ADR-DSN.B.060)
For aerodromes belonging to the same category as Nantes-Atlantique, the average "*slope computed by dividing the difference between the maximum and minimum elevation along the runway centre line by the runway length should not exceed 1% [...]. Along no portion of the runway should the longitudinal slope exceed [...] 1.25%, except that for the first and last quarter of the length of the runway where the slope should not exceed 0.8%.*"

"*Longitudinal slope changes on runways*" (CS ADR-DSN.B.065)
"*Where slope changes cannot be avoided, the slope change between two consecutive slopes should not exceed 1.5%*" for aerodromes belonging to the same category as Nantes-Atlantique. "*The transition from one slope to another should be accomplished by a curved surface with a rate of change not exceeding [...] 0.1% per 30 m (minimum radius of curvature 30 000 m)*."

"*Sight distance for slopes on runways*" (CS ADR-DSN.B.070)
"*The safety objective of minimum runway sight distance values is to achieve the necessary visibility to enable safe use of runway by an aircraft.*
Where slope changes on runways cannot be avoided, they should be such that there should be an unobstructed line of sight from [...] any point 3 m above a runway to all other points 3 m above the runway within a distance of at least half the length of the runway."

"*Distance between slope changes on runways*" (CS ADR-DSN.B.075)
"*Undulations or appreciable changes in slopes located close together along a runway should be avoided.*"

4.1.3 Special conditions

When the certification requirements cannot be met and non-conformities are identified, special conditions may be implemented if the authority considers that the certification specifications are inadequate or inappropriate for the aerodrome in question (requirement ADR.AR.C.025 of consolidated European regulation No 139/2014[12]).

These special conditions have no period of validity. They contain technical specifications, including the limitations or procedures to be complied with to guarantee that the key requirements of regulation EU No 2018/1139[13] are complied with. They are notably based on the safety studies carried out by the airport operator and are then approved, in France by the DSAC.

Three criteria are defined in requirement ADR.AR.C.025 to justify the implementation of special conditions:

- "*the certification specifications cannot be met due to physical, topographical or similar limitations related to the location of the aerodrome;*
- *the aerodrome has novel or unusual design features; or*
- *experience from the operation of that aerodrome or other aerodromes having similar design features has shown that safety may be endangered.*"

Runway 03/21 at Nantes – Atlantique airport is subject to special conditions (see paragraph 0).

[12] Commission Regulation of 12 February 2014 laying down requirements and administrative procedures related to aerodromes (Version in force the day of the accident).
[13] See paragraph 4.1.1

4.1.4 Final approach

The criteria[14] for designing instrument procedures and rules used to determine the associated operating minima provide that, as part of a straight-in approach, "*the final approach and its track guidance should be aligned with a runway whenever possible. An offset final approach increases the complexity of pilot operation. Consequently it should only be designed when siting or obstacle problems permit no other option. An offset final approach track shall not be established as a noise abatement measure.*"

4.2 Nantes - Atlantique airport information

Nantes - Atlantique airport has a paved runway 03-21 measuring 2,903 m long and 45 m wide, equipped with high-intensity runway centreline, edge and end lighting. The distances indicated in the Aeronautical Information Publication (AIP) for runway 21 are as follows:

- Landing Distance Available (LDA) = 2,690 m (threshold displaced by 212 m);
- Take-Off Run Available (TORA) = 2,900 m;
- Take-Off Distance Available (TODA) = 2,960 m;
- Accelerate-Stop Distance Available (ASDA) = 2,960 m.

4.1.5 Runway 21 characteristics

Runway 03/21 at Nantes - Atlantique airport has a runway profile with various successive slopes.

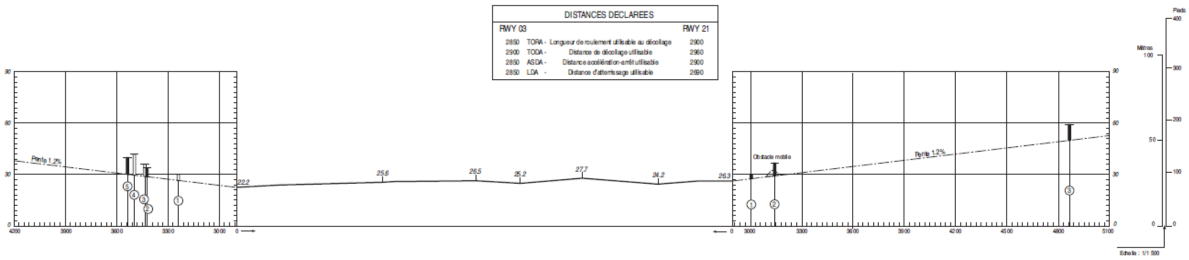

Figure 12: profile of runway 03/21 (source: AIS)

According to the measurements carried out by the airport operator in 2022 (see Figure 13), starting from the end of runway 21 and heading towards threshold 03, the runway is:

- slightly upward-sloping over 133 m (gradient of 0.40%);
- downward-sloping over 310 m (gradient of 0.80%, with a peak value of 1.37% located 323 m from threshold 21); and then
- upward-sloping over 460 m (gradient of 0.77% with a peak value of 1.75% located 643 m from threshold 21), then downward-sloping again.

Threshold 03

Threshold 21

[14] Compilation of criteria for designing instrument procedures and rules used to determine the associated operating minima, Part I, Section 4, Chapter 5, 5.2.1 of ICAO Doc 8168.

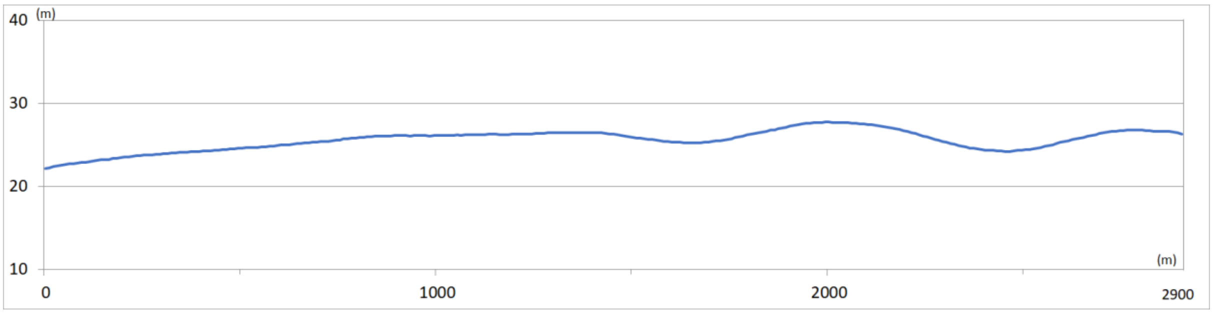

Figure 13: elevation profile of the runway from threshold 03 to threshold 21
(source: runway measurements carried out by the airport operator in 2022)

This succession of slopes takes a shape that pilots identify as a "hump" in the area of the touchdown zone markings, which start 380 m from the threshold of runway 21.

4.1.6 RNP21 approach

The RNP instrument approach procedure for runway 21 at Nantes - Atlantique airport is a non-precision approach that only takes into account lateral guidance (LNAV minima).

A specific feature of the approach to runway 21 is that the aircraft is required to fly over the city of Nantes. While the terrain on the approach path is relatively flat, certain buildings such as the Brittany Tower, located in the city centre of Nantes, determine the approach slope and the minimum altitudes of this approach.

The Minimum Descent Altitude (MDA) is set at 530 ft[15] for Category C aeroplanes, which includes the Boeing 737-800. The missed approach point (MAPt, named "MAPTS" on the chart) is located 1 NM before the threshold of runway 21.

The aircraft intercepts the final approach slope at point FRS21, at an altitude of 3,000 ft and 8.7 NM from the threshold of runway 21. The approach slope angle is 3.1°. The final approach for the RNP21 procedure is offset by 13° from the axis of runway 21. The final approach is therefore flown along a 220 heading before the runway axis is intercepted at MAPTS.

Two Step-Down Fixes (SDF) are published on the final approach chart:

- one SDF located at 1,460 ft and 4 NM from the runway threshold;
- one SDF located at 1,020 ft, at 2.7 NM.

[15] It should be noted that since 1 January 2023, the MDA has been set at 830 ft for Category C aeroplanes.

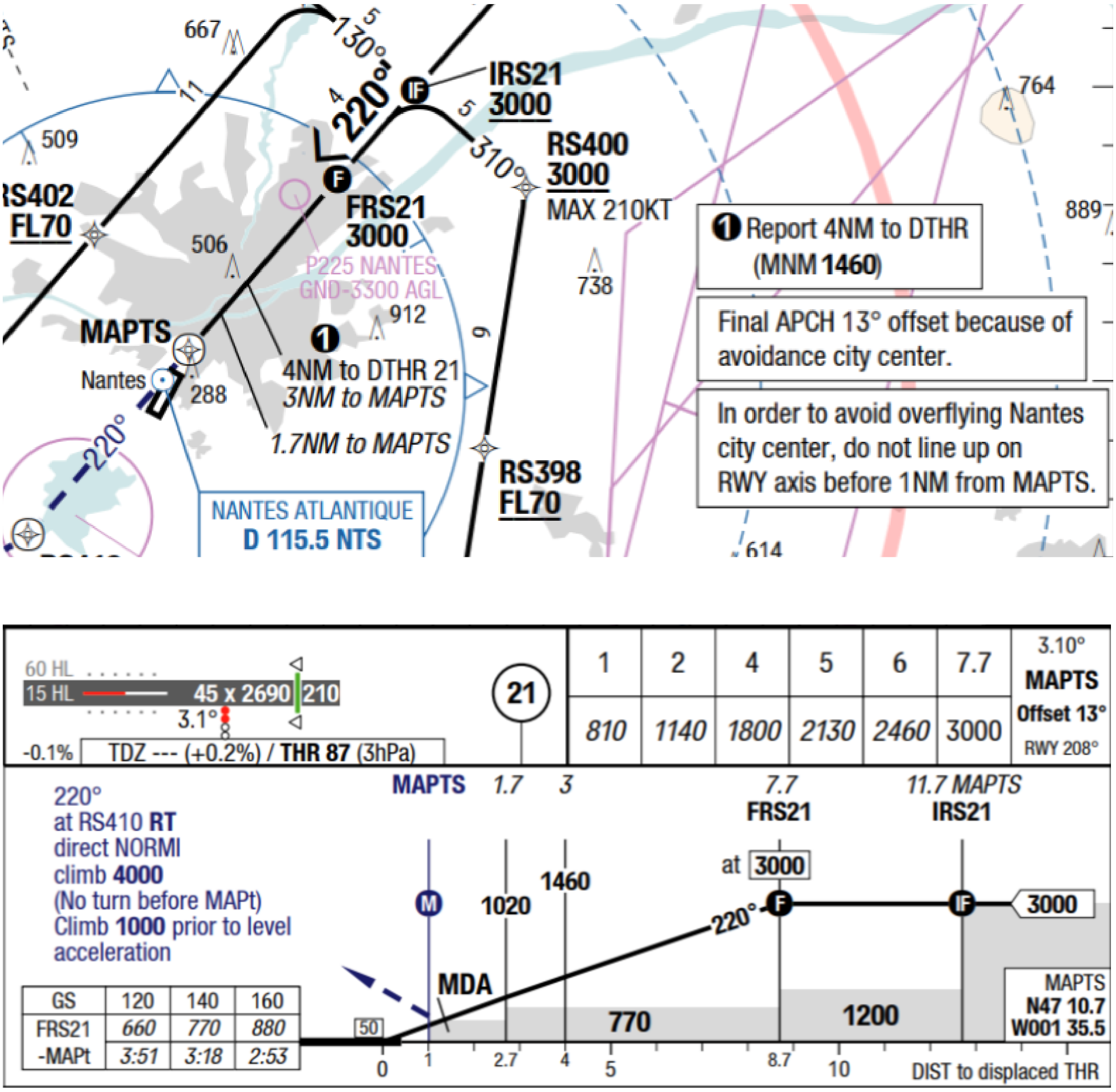

Figure 14: extracts from the approach chart used by the crew (source: LIDO[16])

The offset final approach is the result of environmental pressures in the vicinity of Nantes - Atlantique airport, in particular to avoid flying over the city centre. For this reason, and insofar as the last turn of the RNP21 approach to align with runway 21 takes place at an altitude of less than 1,000 ft and between 1 and 2 NM from the threshold of runway 21, the offset approach is also the subject of an exemption approved by the DSAC and extended in June 2021.

4.1.7 Operation exemption

Runway 03/21 is subject to special conditions for it to be usable. These special conditions were drawn up based on a safety study carried out by Vinci, the airport operator. These special conditions are grouped together in a decision which was signed by the DSAC. This safety study describes the specific features of the profile of runway 03/21, in particular on the strip starting from the middle of the runway up to threshold 21, and identifies the non-conformities of the runway that will be subject to special conditions.

The last safety study produced by Vinci[17] was issued in February 2015. It analyses the risks and defines the means to be implemented to guarantee the safe operation of aircraft during landings and take-offs.

[16] Aeronautical documentation used by Transavia.

[17] Safety study relating to runway longitudinal slopes, longitudinal slope changes, blending radii and sight distance (SC-B.060-1-2015 - *Pente de piste - Étude de sécurité, Aéroport Nantes Atlantique - Vinci Airports).*

According to this study, three elements do not comply with the certification specifications for the runway:

1. The maximum longitudinal slope of the runway is 1.25% on a section of runway located in the last quarter of runway 03 or, in other words, in the first quarter of runway 21 (see Figure 15). This is higher than the slope specified in the certification requirement, which provides for a maximum slope of 0.8%.
2. The blending radii between successive slopes are smaller than those required. These radii may therefore increase the vertical normal load factors on landing or take-off for aircraft with high landing and take-off speeds. It should be noted that at the time the safety study was drawn up, no safety event or difficulty during landing or take-off had been reported in connection with the runway profile.

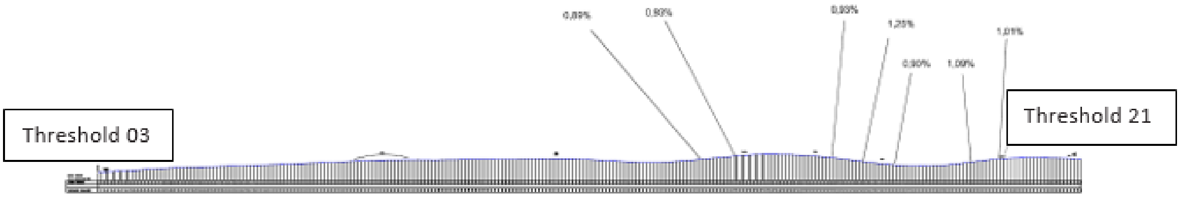

Figure 15: profile of runway 03/21 at Nantes-Atlantique
(source: operator's safety study 2015)

3. The runway sight distance at Nantes - Atlantique airport does not meet the required criteria.

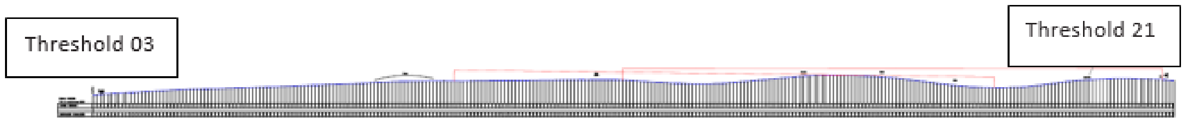

Figure 16: sight distance (source: operator's safety study carried out in 2015)

In order to mitigate the risks associated with the three points identified, Vinci implemented the following measures:

- publication of the runway profile in the AIP, without, however, mentioning that the runway is the subject of exemptions and the reasons for these;
- follow-up of pilots' reports;
- follow-up of events.

The conclusion of the safety study also stated that, given the absence of events identifying the non-conformities[18] (which are, furthermore, known to the crews who use the airport), the information provided to crews via aeronautical publications and the absence of a precision approach to the QFU 21, an acceptable safety level is maintained and the essential requirements are met. The slope and slope changes in the landing and take-off area do not create an unacceptable risk for aircraft. During the five years preceding the accident, neither the air navigation services nor the airport operator had received any notification of a hard landing at Nantes - Atlantique airport.

The Nantes – Atlantique airport operator organises annual Local Runway Safety Team *(*LRST) meetings attended by the air operators using the airport. Hard landings were not discussed during these meeting in the five years preceding the accident.

[18] The non-conformities identified by the safety study are subject to special conditions signed by the DSAC Technical Directorate.

The safety study indicates that bringing the runway profile into conformity with the certification specifications would require around 90,000 m^3 of material for the runway alone (excluding the levelled part of the runway strip and the taxiways to be raised) and would require the airport to be closed for several months.

The information gathered during the investigation confirmed that the air operators were informed by their crews of the specific features of the profile of runway 21. These were generally not the subject of specific information in the airport information sheets available to crews.

5 AEROPLANE OPERATOR INFORMATION

5.1 Crew information

5.1.1 Captain

Experience
The 54-year-old captain held an Airline Transport Pilot Licence - Aeroplanes (ATPL(A)) obtained on 14 December 2004. He had logged 13,075 flight hours, 7,906 hours of which on type including 121 hours in the previous three months, all on type. He held a multi-engine instrument rating (IR/ME) and a B737 300-900 type rating.

He also held an instructor type rating (TRI) for the B737 300-900, obtained on 12 August 2019. As a TRI, he had logged approximately 1,080 flight hours, 295 hours of which in flight simulators. He had completed four rotations in the previous three months as an instructor of trainee co-pilots in LIFUS, including the leg of the accident flight. His home base was Paris-Orly. However, as he lived in the Nantes region, he regularly carried out flights departing from and bound for Nantes. He had a very good knowledge of the RNP21 approach and the specific features of the runway.

Between January and October 2022, he carried out an average of five supervisory flights per month as a TRI.

Statement
The captain was an instructor for the accident flight. He stated that the co-pilot informed him, on their first contact on 30 September, that he was resuming flights after a period of sick leave. He specified that he established an environment of trust to enable the co-pilot to get back on his feet after a long period without flying.

During flight preparation, the co-pilot was quick and to the point with his questions. The captain felt that the co-pilot had worked during this sick leave.

The day before the accident, on 30 September, the crew were scheduled to fly from Nantes to Marseille then Rennes, followed by a return flight to Marseille then Nantes. For the first two legs, the instructor was PF. The trainee co-pilot was comfortable as PM. The objective was to get him used to commercial flights again. The co-pilot performed the following two legs as PF. The instructor found that the co-pilot's level was satisfactory and did not identify any problems for these familiarization flights. During the return flight to Nantes, the RNP21 approach was in use. They carried out the approach briefing, identifying, according to him, each threat. Each time, the co-pilot indicated the correct means of mitigation or management.

The instructor specified that the co-pilot managed the aeroplane's energy well and that his flying practices in manual mode were good. He pointed out that the landing at Nantes was a bit hard and the flare a little late. He reported that they did a positive debriefing after the flight.

The next day, Saturday 1 October, the first two legs scheduled for the day were a Nantes-Djerba round trip. The co-pilot was PF for both flights. The instructor remembered that there was a crosswind of around 30 kt on landing on runway 09 at Djerba. The co-pilot was very active on the controls to counter the crosswind. The flare was a little high and the aeroplane shifted to the right of the runway. After vacating the runway, the instructor congratulated the co-pilot for this landing in a strong crosswind. He stated that normally, a co-pilot with little experience on the aeroplane type is limited to a 15 kt crosswind and that this limitation is lifted in instruction.

For the return flight, take-off from Djerba went smoothly. In cruise, they had technical discussions about the aeroplane and flying practices. During the approach, the co-pilot took over the controls in manual mode, and the instructor specified that he flew in a controlled manner.

He pointed out that he had the impression that the aeroplane was a little high on passing through 50 ft. He then had the impression that they were moving faster towards the ground than usual. After the first contact, which was very hard, seeing that the control column was pulled backwards, the instructor pushed it forward to avoid a tail strike. A second impact occurred, harder than the first one, according to him. He remembered then taking over steering, while the co-pilot was extending the thrust reversers. The instructor then vacated the runway.

5.1.2 Co-pilot

Experience

The 34-year-old co-pilot held a Commercial Pilot Licence - Aeroplanes (CPL(A)) obtained on 31 March 2021. He had logged 448 flight hours, 63 hours of which on type, including 12 hours in the previous three months, all on type and all performed on the day of the accident and the day before. He held a single-engine instrument rating (IR/SE) and a multi-engine instrument rating (IR/ME), as well as a B737 300-900 type rating and a single-engine piston (land) rating (SEP (land)). The co-pilot was in LIFUS on the B737.

The co-pilot held a class 1 medical fitness certificate issued on 6 September 2022, which included the obligation to wear optical correction for defective distant vision.

On the Boeing B737-800, he had performed 24 landings as PF (including that of the accident):

- fourteen in May, six of which during proficiency checks;
- eight in June;
- two the day before the accident, including a landing in good weather at Nantes on runway 21 using an RNP21 approach, with a normal load factor of 1.7 g.

The accident landing was his second landing at Nantes as co-pilot (PF).

Training

The co-pilot had obtained a Private Pilot Licence - Aeroplanes (PPL(A)) in January 2012 and a Commercial Pilot Licence - Aeroplanes (CPL(A)) on 21 August 2019. He then joined the Air France/Transavia group "*Cadet*" training programme, during which he attended courses for the IR/SE, IR/ME, multi-engine piston (MEP) and multi-crew co-operation (MCC) ratings, between September 2019 and November 2020. This training programme was interrupted for four months from June to October 2020 due to the consequences of the COVID-19 pandemic.

After obtaining his MCC rating, his training was interrupted for 11 months, again due to the consequences of the COVID-19 pandemic. He then began training for his type rating in October 2021, which he obtained in January 2022. After a break of just over 3 months, he completed proficiency check training and then began LIFUS in May 2022.

After completing around twenty legs, the co-pilot was put on sick leave for 2 months, from 23 June to 24 August 2022.

After an observation flight in September 2022, he resumed LIFUS on 30 September 2022.

His training as a whole met requirements. The instructors' various comments and assessments were satisfactory.

Statement
The co-pilot reported that the day before the accident flight, he had resumed LIFUS after a period without flying of just over three months. The first day included four legs. The last two legs, for which he was PF, went well. He added that during the RNP21 approach to Nantes, in good weather, the "hump" on runway 21 gave him a strange feeling and the landing seemed a little hard to him.

He stated that he got up at around 04:00 on the day of the accident. He was PF on the first flight bound for Djerba. He specified that, for this flight, he disconnected the autopilot at 2,000 ft, once the aeroplane was configured for landing.

He added that for the return flight to Nantes, he and the instructor carried out the briefing for the RNP21 approach to Nantes, specifying the associated threats: the offset approach, the "hump" on runway 21, the weather conditions and how to take the wind into account.

He specified that he disconnected the autopilot at 2,000 ft during the approach to Nantes. He said that, in his opinion, they saw runway 21 at a late stage, about 1 NM from the runway threshold. He specified that he had planned to disengage the Flight Director (FD) on the final turn to align with the runway, but he did not remember doing so, nor whether the FD was still active during the final.

He aligned the aeroplane with the axis. The approach was stabilised. He explained that he had the feeling of being rather high when he crossed the threshold and remembered that the radar altimeter callouts came one after another a little faster than usual. He pointed out that the "hump" on runway 21 disturbed him during the approach.

Touchdown was very hard and he had the impression that something was occurring in the control column, as if he was being prevented from pulling it. He remembered hearing a relatively loud noise and that immediately afterwards there was a lot of vibration in the nose landing gear. The instructor then said that he was the PF ("*Je suis PF*"). The co-pilot specified that he was highly focused on holding the path. They then indicated to the air traffic controller that they were exiting on taxiway "B". Then, after having vacated the runway, they applied the parking brake.

They carried out a briefing, checking the aeroplane's parameters. They then spoke with the purser about starting the disembarkation of the passengers.

He specified that the sick leave he had taken between June and August 2022 was unrelated to the LIFUS training.

5.2 Operations Manual

5.1.3 Classification of aerodromes

Transavia's Operations Manual (OM), Part OM-C, stipulates that the classification of airports is determined by their complexity. Category A includes the least demanding airports; categories B and C include airports that are gradually more demanding.
The airport classification is based on the following criteria:

➢ Category A

An airport that meets all of the following requirements:

- an approved instrument procedure;
- at least one runway with no performance-limited procedure for take-off and/or landing;
- published circling approach minima not higher than 1,000 ft above aerodrome level;
- night operations capability.

- Category B

An airport that does not meet the category A requirements or which requires extra considerations such as:

- published circling approach minima higher than 1,000 ft above aerodrome level; or
- non-standard approach aids and/or approach patterns; or
- unusual local weather conditions; or
- unusual characteristics or performance limitations; or
- any other relevant considerations, including obstacles, physical layout, lighting, etc.

Category C airports are more demanding than category A and B airports.

In addition, the airport category may be followed by an extension for specific features of the airport, such as:

- minimum crew experience required;
- additional operating information available in OM-C Chapter 6 - Airport briefing (only applicable for category-A airports);
- an airport with a short runway;
- appointment of crew by the division's chief-pilot.

In the operator's OM, Nantes - Atlantique airport is classified as a category B airport.

5.1.4 Approach briefing

The operator's OM (Part OM-B, 2.6.4.2.2), stipulates that prior to starting an instrument approach, all the information relating to the arrival and the approach (environmental conditions, status of systems, flight paths, automated system management, etc.) is detailed by the PF to the PM during the approach briefing.

The manual stipulates that the focus should be on potential threats, risk assessment and the associated mitigation actions.

In the event of an RNP approach, this briefing must be supplemented to check the following elements:

- equipment required;
- approach coding and consistency with the LIDO chart;
- automated system review;
- procedures in the event of a deterioration in navigation performance;
- conditions for a go-around.

5.1.5 Taking the controls

The operator's OM (part OM A - 8.3.1.G.2) stipulates that if a captain is not satisfied with the way the pilot under his command is managing the flight, verbal instructions are normally sufficient to remedy the situation.

However, during critical phases of flight, there may be no time to wait for a response. The captain must then immediately take the aircraft controls and simultaneously announce "I have control".

5.1.6 Manual flight conditions

The operator's OM (part OM A - 8.3.1.P.2) stipulates that when conditions permit, flight crew are authorised to exercise their manual flying skills as part of normal operations. Manual flight and manoeuvres must be adapted to the given situation and take into account the following elements:

- flight phase;
- crew workload versus crew fatigue;
- airspace;
- knowledge of local conditions;

- weather conditions;
- traffic density and ATC procedures;
- crew experience.

Any intention to carry out an approach phase without autopilot, autothrottle and/or flight director must be planned, taking into account the conditions mentioned, and be the subject of a briefing.

5.1.7 Non-precision approaches

During an RNP approach with LNAV minima on an aircraft not equipped with IAN[19], which was the case for F-GZHA, no distance and source indications are displayed on the Primary Flight Display (PFD). The OM therefore specifies that, to carry out the final check of the descent path against the approach charts, the end-of-descent point can be inserted by the crew in the CDU. The reference distance is then available directly on the CDU.

During the flight, automated systems (autopilot, autothrottle and flight directors) must be used at the most appropriate level to improve flight safety and passenger comfort. The use of automated systems reduces the workload for flight crew. This enables them to spend more time monitoring the instruments, improves situational awareness (weather and local conditions) and thus guarantees operational safety. It is also specified that, for non-precision approaches, flying with automated systems is the preferred method. The operator's OM (part OM-B 2.7.1) indicates that the autopilot and then the autothrottle should be disconnected at the latest between 1 and 2 NM from the runway threshold or at a height of between 300 and 600 ft, regardless of the specific features of the approach, including an offset approach to the runway axis.

Moreover, the Boeing FCTM stipulates that during non-ILS approaches, the use of the autopilot improves the accuracy of heading and vertical path tracking, reduces the probability of unintentional deviations below the path, while providing the various autopilot alerts as well as failures of engaged modes. The FCTM recommends using the autopilot until an appropriate visual reference is established on final approach.

5.1.8 Stabilisation of approach

The operator's OM specifies that all approaches must be stabilised at 1,000 ft above the altitude of the aerodrome. It indicates that an approach is considered stabilised when all of the following criteria are met:
- the aeroplane is on the correct flight path;
- only small changes in heading and pitch are required to hold the correct flight path;
- the aeroplane must be at the approach speed. Deviations of +10 kt to -5 kt are acceptable if the aeroplane's speed tends towards the approach speed;
- the aeroplane is in the landing configuration;
- the rate of descent is not greater than 1,000 ft/min; if an approach requires a rate of more than 1,000 ft/min, a special briefing must be carried out;
- the thrust setting is appropriate for the aeroplane configuration;
- all the briefings and checklists have been completed.

It is specified that during a circling approach and a visual traffic pattern, the wings must be kept horizontal on final when the aeroplane reaches the height of 500 ft. Approach procedures requiring a deviation from the above must be the subject of a special briefing.

[19] Integrated Approach Navigation. IAN draws information from a selected approach type in the Flight Management Computer (FMC) database to generate a descent path from the final approach fix up to the runway threshold. In doing so, it displays visual references similar to those of the Instrument Landing System (ILS). Flight path guidance is provided by the FMC, radio-navigation means or a combination of both.

5.3 Landing technique

5.1.9 General

As a general rule, the flare is considered to be a flight phase which is difficult to learn and teach, for a number of reasons. Its length, compared with the duration of a flight, gives little time to perform the associated sequence of exercises. Moreover, many factors (wind direction and strength, runway gradient, type of aeroplane, etc.) may affect the flare. Two points are particularly important: when to start the flare, and how to flare. Some aeroplane manufacturers' manuals for pilots provide advice on how to manage this flight phase.

From an airport infrastructure perspective, depending on the type of aeroplane, the start of the touchdown zone markings coincides with the source of the visual indicator's approach slope, in this case the PAPI for runway 21 at Nantes-Atlantique. When these touchdown zone markings or the PAPI are targeted, without flare, the main landing gear comes into contact with the runway before these touchdown zone markings, around 100 m before the markings for a Boeing 737.

5.1.10 Flare technique

The landing information detailed in the Boeing FCTM is based on runways with touchdown zone markings located 300 m from the runway threshold and a 3° approach slope. The practices and techniques for landing described in this manual are intended to help pilots (use of approach lighting, control of the aeroplane during crosswind landings, control on the ground). It also provides information on the factors affecting landing distance and landing geometry.

The FCTM recommends that the pilots plan the disconnection of the autopilot and autothrottle sufficiently early to give them time to take control of the aeroplane before starting the flare (approximately 1 to 2 NM before the runway threshold or at a height of between 300 and 600 ft above the runway threshold).

The approach must be stabilised (speed, slope and trim) before landing. When the runway threshold passes under the nose of the aeroplane, the pilot's gaze must be focused on "*the far end of the runway*". This transition of the gaze makes the pitch attitude easier to control during the flare.

According to the manual, on final approach on a 3° slope, in landing configuration with flaps 30 and at V_{REF} +5 kt, the Boeing 737-800's pitch attitude is between 2° and 4°, reduced by 1° for every 5 kt above V_{REF} +5 kt (see Figure 17). The flare must be initiated from a (radar altimeter) height of 20 ft above the runway by increasing the pitch attitude by 2° to 3° (see Figure 18). This reduces the rate of descent. The pitch attitude must then be adjusted to hold the rate of descent. At the same time, the pilot starts to reduce thrust. The thrust levers must then be moved smoothly and continuously to the IDLE position, to make it easier to control the nose-down torque generated by the reduction in thrust by means of the control column. The thrust levers should reach the IDLE position when the main landing gear makes contact with the ground.

Figure 17: geometry of the Boeing 737-800 on approach

Figure 18: geometry of the Boeing 737-800 on landing

Based on the Boeing FCTM and Flight Crew Operating Manual (FCOM), it is possible to estimate the landing distances on runway 21 at Nantes airport, between the runway threshold, the flare starting point, the aiming point and the touchdown point. This last point is located on the upward-sloping part of runway 21.

Part OM-B of Transavia's OM does not fully incorporate Boeing's information on landings. In particular, there is no mention of the distance between the various characteristic points of the landing or the variations in pitch attitude to be made to the flare.

5.1.11 Flare on an upward slope

The FCTM does not provide information for landing on a runway with an upward slope.

As a general rule, the assessment of height and distances when in flight is based on geometric references acquired through experience. A runway with an upward or downward slope therefore modifies the way dimensions of the runway usually appear when observed from a 3° angle. An upward-sloping runway can give the illusion that the aeroplane is higher than its actual position.

An upward slope may affect the radar altimeter synthetic-voice callouts shortly before the flare, leading to late flares. Moreover, as the variation in the aeroplane's attitude during the flare is greater than usual, it is often recommended to start the flare earlier.

5.1.12 Bounced landing

The Boeing FCTM recommends going around in the event of a high bounce. For other bounces, the normal landing attitude must be held and thrust adjusted if necessary to control the rate of descent. For slight bounces, it is not necessary to add thrust. The FCTM does not describe the difference between slight and high bounces.

The information about a bounced landing included in the Transavia OM is identical to that contained in the Boeing FCTM.

5.1.13 Landing the day before at Nantes

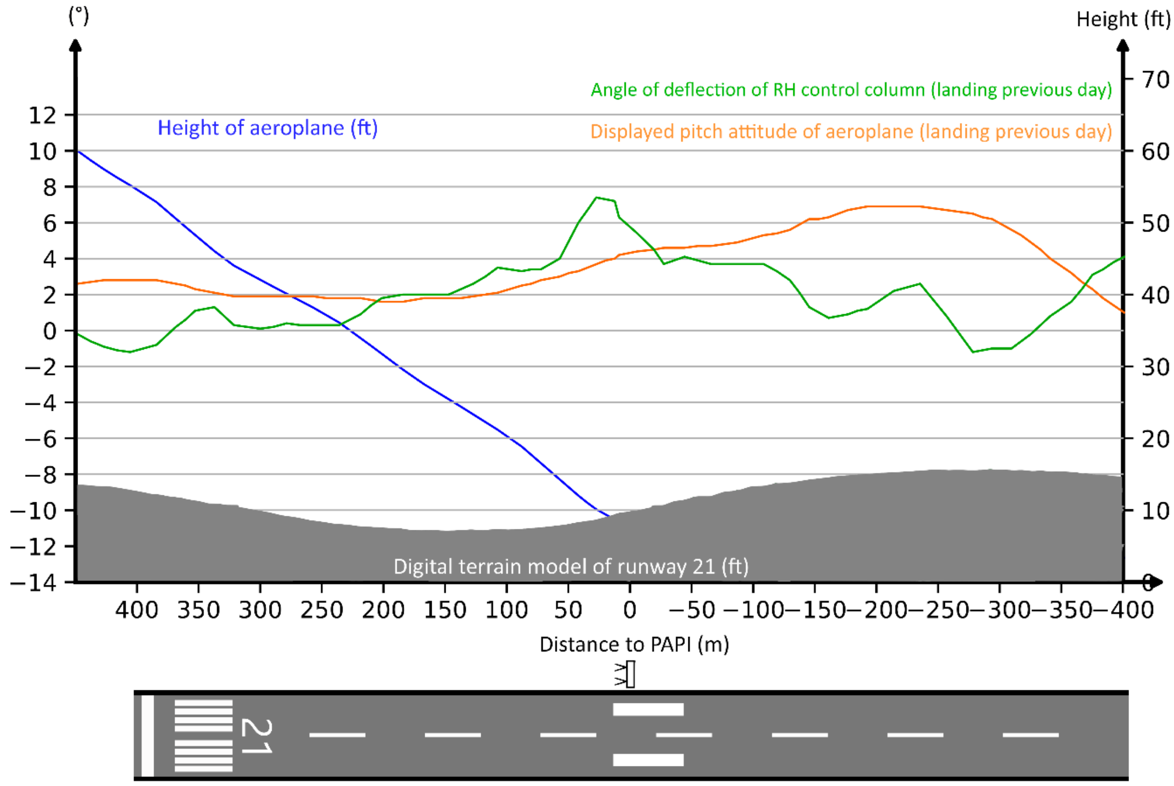

Figure 19: angle of deflection of column during landing on previous day (source: BEA)

During the landing at Nantes on the previous day, the co-pilot was PF. He started the flare about 220 m from wheel touchdown at a height of 37 ft, with a slight nose-up input (2° of control column deflection) which did not affect the aeroplane's pitch attitude. When the aeroplane reached the runway depression, he then made a more gradual input by pulling on the control column by a deflection of just over 3°. The aeroplane's pitch attitude then started to increase gradually.

At a height of approximately 20 ft, he continued his input on the elevator control in a more pronounced manner up to a position of 7.5°, whilst the aeroplane's pitch attitude continued to increase linearly until it reached around 4.5°. At the same time, the co-pilot instantly reduced the aeroplane's thrust by moving the levers to the IDLE position. When the wheels touched down, the normal load factor was 1.7 g.

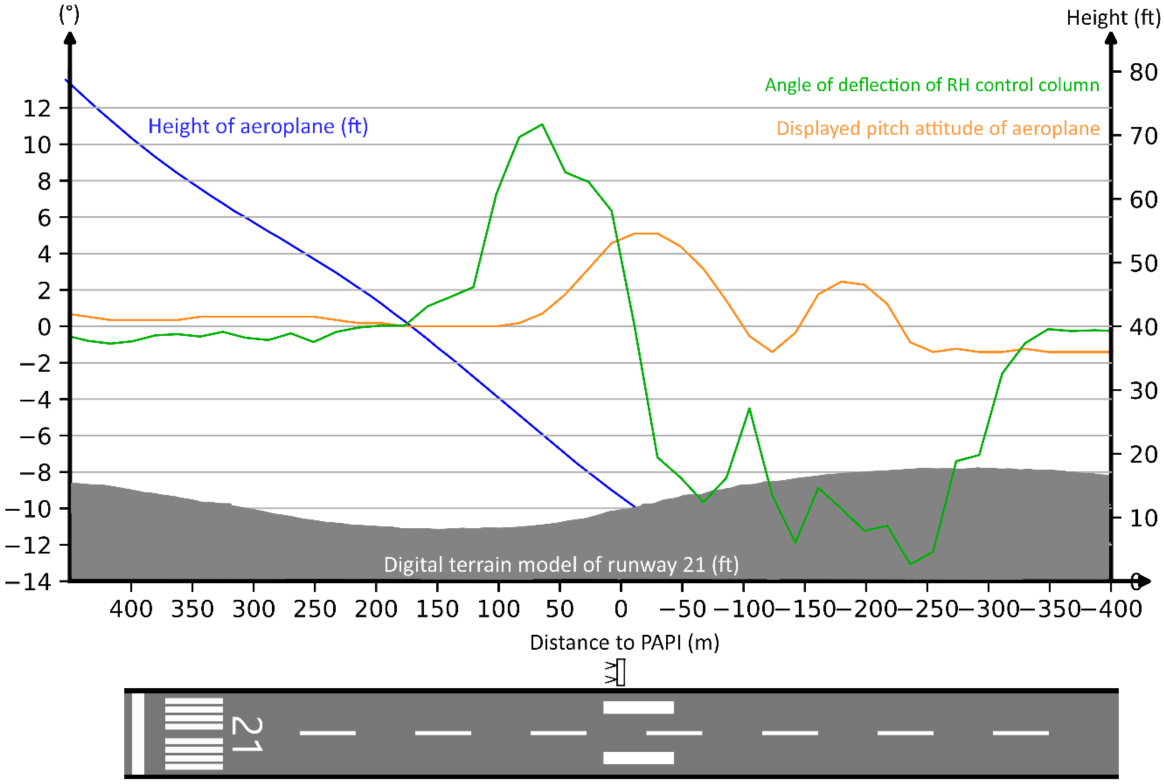

Figure 20: angle of deflection of column during accident landing (source: BEA)

The flare on the previous day had some similarities with the flare of the occurrence, in particular as regards the pitch attitude taken, the marked nose-up input and the late reduction in thrust just before touchdown (not illustrated in the previous figures).

5.4 Risks on landing

5.1.14 Hard landings

According to the manufacturer's Aircraft Maintenance Manual (AMM), for the Boeing 737-800, a landing is considered as hard when it is reported by the flight crew and the inspection criteria are met. These criteria notably include the normal load factor at the centre of gravity being greater than or equal to the specified thresholds, determined according to the roll angle and weight of the aeroplane on landing.

The table below sets out the reference values for the roll angle and normal load factor to assess whether a landing can be considered hard according to the weight of the aeroplane on landing.

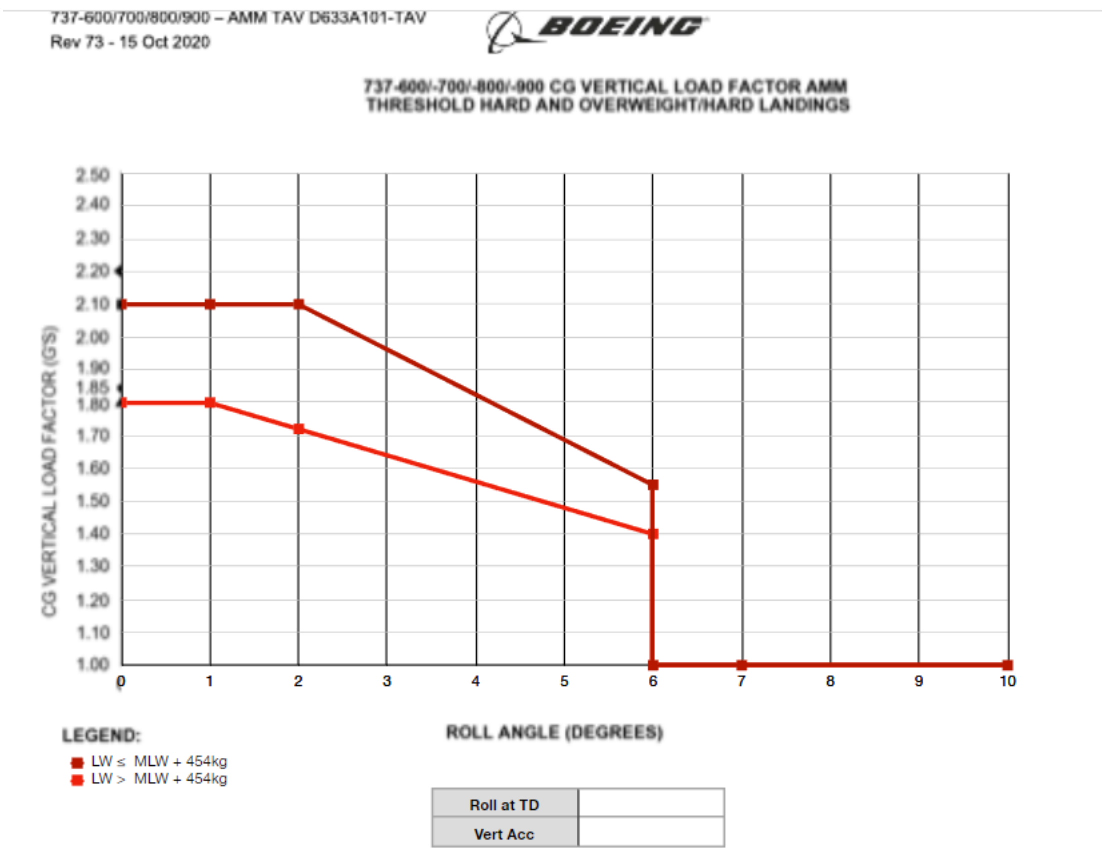

Figure 21: graph to determine hard landing (source: Boeing AMM)

Transavia uses these criteria to determine the hard landings in the scope of its flight analysis.

From 1 January to 16 November 2022, an analysis of flights by Transavia identified 40 hard landings, including the accident flight.

These hard landings included:

- ten (25%) during LIFUS[20], nine of which involved co-pilots acting as the PF, including the co-pilot of F-GZHA. Of these ten hard landings in LIFUS, the accident flight was the only hard landing at Nantes;
- six (15%) at Nantes, all on runway 21. Over the same period, around one third of landings at Nantes occurred on runway 21.

From 1 January to 16 November 2022, landings at Nantes were divided as follows:

- 1,106 landings on runway 21;
- 2,331 landings on runway 03.

The two airports with the highest number of hard landings during this period were Mykonos (Greece) and Nantes, with six hard landings recorded by Transavia at each airport. The other airports concerned had a number of hard landings less than or equal to three over the same period. It should be noted that most of the hard landings at Transavia occurred on runways with an upward slope.

By way of comparison, in the Transavia OM (part OM-C), Nantes airport is classified as a category B airport, while Mykonos airport is classified as B-q. The "-q" extension means that minimum crew experience is required.

[20] LIFUS flights represented approximately 9% of Transavia's total flights in 2022.

For Mykonos, part OM-C also specifies that the captain must hold a "specific qualification" given by an instructor. It also specifies that, for the approach to runway 34, the narrowness of the runway and the steep upward slope of the terrain on final for runway 34 give an unusual visual impression of being above the descent path on final approach. Moreover, the AIP for Mykonos airport (ICAO code: LGMK) specifies the non-conformities accepted under special conditions[21].

2.23.2 Accepted deviations in aerodrome certificate

Specification	Description of Non-Compliance	Deviation type
M.745 Runway guard lights	(b)(1) non-compliant: high traffic density during summer period prevails, however no RWY guard lights installed (b)(2) non-compliant: no RWY guard lights installed	ELoS
B.045 Width of runways	(a) non-compliant: according to AIP, RWY width 30m, required is 45m as A/D code is 4C	ELoS
M.670 Runway threshold identification lights	(a) compliant: RTILs installed symmetrically and in line with both RWY THRs (type is ADB 360) non-compliant: for both RWY directions, the distance between RTILs and line of RWY edge lights >20 m	ELoS
T.910 Equipment frangibility requirements	Non-compliant: WDI and anemometer pole with adjacent control boxes are not frangible,	ELoS
B.160 Width of runway strip	75m wide laterally measured from RWY C/L established	Special Condition
B.165 Objects on runway strips	(a) non-compliant: endangering objects can be found within the 150 m wide RWY (chapel, trees or bushes, rocks and boulders, fence foundation) and the 300 m wide RWY strip (Buildings, public roads).	Special Condition
C.210 Runway end safety areas (RESA)	(b)(1) non-compliant: no RESA established at both RWY ends	Special Condition
D.260 Taxiway minimum separation distance	(b) non-compliant: Aircraft stand taxilane is too close to RWY (approx. 100m) instead of 176m	Special Condition
S.885 System design	(b) non-compliant: SPS is fed by three generators (one dedicated to AGL, 2 others for the rest) feeding two supply buses; however, the GENs are not physically separated	Special Condition

Figure 22: extract from AD 2 LGMK of Greek AIP on 13 June 2024 (source: Greek Aeronautical Information Service)

Nantes airport has no such indication in the OM-C.

As specified by the regulations, Transavia sends all Air Safety Reports (ASR) written by crews, including those concerning hard landings, to the DSAC (via the ECCAIRS database) within 72 h of receipt. It indicated that the hard landings identified as part of its flight analysis are not notified to either the air navigation service or the airport's managing body.

Furthermore, Transavia regularly participates in LRST meetings organised once a year by the Nantes airport operator. During these meetings, Transavia discusses with the operator, the occurrences reported by its crews while using the airport and the associated flight safety topics.

5.1.15 Risks associated with runway 21 (hump and crosswind)

In Part OM-C of the operator's OM, the RNP21 13°-offset approach is indicated, without any other information. There is no mention of the specific features relating to the various successive slopes of runway 21, the weather conditions or the difficulties associated with crosswind.

[21] AIP AD 2 LGMK-11, 2.23.2 *Accepted deviations in aerodrome certificate*

Just like the OM, the LIDO documentation used by Transavia crews makes no mention of the specific features relating to runway 21, apart from information on the offset approach. However, in the section regarding weather for Nantes airport, this documentation specifies that windshear was reported by pilots upstream of threshold 21, abeam the forest (located to the west of the runway threshold, outside the airport perimeter), when there is a westerly wind. This information is based on the Collaborative Aerodrome Safety Highlights document concerning Nantes airport distributed by the DGAC. It is indicated in the departure/weather section that when there is a westerly wind, the presence of the wood to the south-west of runway threshold 03 and the quarry to the west create special weather conditions. Downdrafts are regularly mentioned by pilots, particularly during the rotation for take-off from runway 21.

Part OM-A 8.1.3 of the company's OM stipulates that when the crosswind exceeds 15 kt, co-pilots who have logged less than 600 flight hours on type must not act as PF during take-off, approach and landing, except for training flights.

The manual specifies that in the event of an instruction flight, the instructor must pay particular attention to the co-pilot's piloting and management of the aeroplane's energy. The approach briefing should list the threats and also the strategies for the approach, landing and management of the aeroplane in case of bouncing.

Two air operators which fly in and out of Nantes and contacted by the BEA indicated that at the time of the accident, they had no specific training or instructions for this airport, even though it is recognised as having specific features that are sometimes difficult to manage.

5.1.16 Risks associated with tail strike and bounces

According to Transavia, on the date of the accident, the risk associated with a tail strike was considered greater than that associated with a hard bounced landing. The company underlined that, historically, pilots might have been more aware of this risk, notably through messages from instructors, interventions by flight safety officers, through training or various publications concerning flight safety. Consequently, at the time of the accident, this situation could have given rise to an erroneous feeling that the risk of a tail strike was of particular importance, which could lead to a form of distortion in pilots' risk awareness.

As a result, the topic of hard bounced landings was rarely discussed in training. Moreover this threat was recalled during flight preparation briefings, or in flight, according to the characteristics of certain runways. Furthermore, the actions to be taken in the event of a bounce were only taught in a theoretical part and not in practice by Transavia.

The operator took actions regarding this topic after the accident (see paragraph 7).

5.5 General information about training

5.1.17 Training in flare

During their training on 737s, pilots learn how to start nosing up at around 20 ft, while gradually reducing thrust so that the thrust levers reach the IDLE position when the main landing gear makes contact with the ground. This gradual reduction allows the crew to manage the aeroplane's energy during the flare and avoid a hard landing.

5.1.18 Line flying under supervision (LIFUS)

According to Transavia, the approach and landing on runway 21 at Nantes - Atlantique airport are considered to be potentially difficult. The offset approach, followed by a flare performed on a downward and then an upward slope, may be complex for a co-pilot in LIFUS.

Transavia also indicated that, on the date of the accident, it had not drawn up any specific instructions regarding the selection of destinations during LIFUS flights. Nor were there any instructions for instructors enabling them to decide whether they should perform the approach and landing or have it performed by co-pilots as part of their LIFUS training. The operator has taken actions regarding this topic (see paragraph 7).

Depending on the weather conditions and the specific characteristics of certain approaches, a TRI may be torn between taking the controls and becoming PF or leaving this role to a co-pilot in LIFUS. In the latter case, the resources implemented by the crew may be increased. It could also become difficult for the instructor to act rapidly during a dynamic phase such as the flare.

For the accident flight, the fact that the TRI lived close to Nantes, regularly flew out of and into Nantes airport and was therefore used to the 21 approach and the characteristics of the runway, may have minimised:

- how difficult it could be for the co-pilot to land on this runway in these conditions;
- his perception of the risks associated with the fears mentioned by the co-pilot about landings.

Moreover, the TRI might have wanted to let the co-pilot act, to allow him to regain confidence after his sick leave. That is certainly also the reason why he let him disconnect the automated systems early on in the approach.

6 CONCLUSIONS

The conclusions are solely based on the information which came to the knowledge of the BEA during the investigation.

Scenario

On descent bound for Nantes, the co-pilot in LIFUS training reminded the instructor captain (TRI) of his difficulties with flaring and his apprehension about not reproducing the same type of rough landing as the one carried out the previous day on runway 21 at Nantes. During the briefing, the co-pilot discussed the offset approach to the axis of runway 21, the profile of this runway ("the hump") and the changing weather conditions. These threats were not taken up by the instructor. The visual perception caused by the upward-sloping part of the runway and the stress linked to the difficulty of landing at Nantes were not the subject of any particular management strategy on the part of the instructor. The moment at which automated systems would be disconnected was not discussed either at that point.

During the approach, at around 2,500 ft, the co-pilot announced to the instructor that he would disconnect the automated systems at an altitude of 2,000 ft, i.e. approximately two minutes before reaching minima. The co-pilot wanted to take advantage of the instructor's presence to fly more in manual mode and regain experience. It is possible that the instructor let the co-pilot proceed as he wished to help him regain confidence. However, given the presence of crosswind, the ceiling close to the minima and the co-pilot's lack of recent experience, flying in manual mode probably resulted in a high workload for the co-pilot.

At 1 NM from the MAPTS and at an altitude of approximately 800 ft, the co-pilot turned left to intercept the runway axis. The approach was stabilised, the co-pilot held the descent slope following the PAPI indications, and the speed remained close to the reference approach speed. The instructor's correction call outs up to very low height showed that his attention was mainly focused on holding the runway axis.

After crossing the threshold of runway 21, the aeroplane first flew over the downward-sloping part of the runway. At a height of between 40 and 30 ft, the co-pilot started his nose-up input on the control column in order to flare, without reducing thrust, but this input remained insufficient to change the aeroplane's pitch attitude. The aeroplane then began to fly over the upward-sloping part of the runway. Between the "Thirty" and "Ten" callouts, spaced by one second and representing around 80 m of flight, the co-pilot applied a marked and rapid nose-up input to the control column, pulling it to more than three quarters of its travel, before setting the thrust levers to IDLE. At the same time, the instructor probably became aware of the delay in starting the flare and instinctively warned the co-pilot to watch out, by calling out "*Attention*". These marked and rapid inputs at low height above the upward-sloping part of the runway did not reduce the aeroplane's energy before contact with the runway.

It is very likely that the late flare resulted from an erroneous perception of the final part of the approach slope due to the upward slope of the runway and to the fact that until reaching a low height, the two pilots were mainly focused on holding the runway axis.

The effect the runway characteristics (downward and then upward-sloping) had on the synthetic-voice height callouts did not help the co-pilot to start the flare and reduce thrust early enough, given the upward slope before the hump. Moreover, the instructor did not consider taking the controls during the flare, and very probably did not have the time to do so.

The touchdown of the main landing gear on the upward-sloping part of the runway was hard, with a recorded normal load factor of 2.95 g for a sink rate of 12 ft/s. The spoilers deployed, then the aeroplane bounced.

The strength of the impact on landing and the bounce surprised the two crew members. The instructor instinctively applied a marked nose-down input to the control column, up to the nose-down stop, which resulted in a rapid decrease in the aeroplane's pitch attitude. This reduction in pitch attitude combined with the deployed spoilers led to a rapid decrease in the aeroplane's lift. The nose and right main landing gear touched the runway simultaneously. The violence of the impact on the nose landing gear caused both tyres to be ejected from the landing gear, and the aeroplane continued the landing, running on its wheel rims.

The instructor then held the aeroplane on the runway centreline during its deceleration before turning left onto a taxiway to stop the aeroplane and vacate the runway.

The fact that the TRI was familiar with the 21 approach to Nantes and the characteristics of the runway may have minimised:

- his perception of how difficult it could be for the co-pilot to land on this runway in these conditions;
- his perception of the risks associated with the apprehension mentioned by the co-pilot about landings. It is also possible that the TRI wanted to let the co-pilot act without adding any extra stress, with a view to allowing the co-pilot to regain confidence after his period without flying. The landing performed by the co-pilot in a strong crosswind at Djerba may have boosted the TRI's confidence and diminish his alertness during the approach and landing.

Contributing factors

The following factors may have contributed to the hard landing:

- the copilot's inappropriate actions to increase the pitch attitude and reduce thrust during the flare manoeuvre;
- the workload induced by an early disconnection of the automated systems in adverse weather conditions and at an airport with an offset approach path, leading to an alignment at a late stage on final approach, at an altitude below 1,000 ft and close to the minima;
- the absence of a framework or decision-making aid for instructors to help them assess whether the difficulty of a flight is consistent with the level of the trainee co-pilot performing the flight as PF;
- a failure by the operator, on the date of the accident, to take into account the specific features of certain aerodromes when planning flights for co-pilots in LIFUS;
- insufficient consideration given by the operator and instructor to the co-pilot's fragmented training and recent experience in LIFUS;
- insufficient consideration given by the instructor to how difficult it could be for the co-pilot to carry out the approach to runway 21 in the conditions of the day;
- an approach briefing that identified the threats but did not mention the means to mitigate their effects;
- an erroneous perception of the final part of the approach slope due to the upward slope of the runway;
- the instructor's failure to anticipate taking the controls during a dynamic flight phase.

The following factors may have contributed to accentuating the damage after the hard landing:

- Transavia pilots having excessive and ill-proportioned awareness of the risk of a tail strike compared with the risk of a hard landing;
- insufficient training in actions to be taken in the event of a bounce, which led the instructor to react instinctively, applying the inputs specified to avoid a tail strike without verbalising that he was taking the controls.

The lack of feedback from air operators about the use of the runway meant that the airport operator's safety study relating to the longitudinal slopes of the runway, the longitudinal slope changes, the blending radii and the sight distance were not updated.

Safety lessons

Visual perception of slope changes on runway 21

Approach 21 at Nantes - Atlantique airport is offset and is therefore operated under an exemption signed by the DSAC. The runway at Nantes - Atlantique airport is the subject of special conditions, notified by the DSAC, due to its physical and topographical limitations.

Since the slope changes with the steepest angle occur at the start of runway 21, these can affect the visual perception of pilots, who may encounter difficulties in determining when to start the flare and in performing it correctly. These slope changes also induce a delay in the activation of radar altimeter callouts. These difficulties are accentuated in adverse weather conditions or when arriving at night.

The special conditions signed by the DSAC mention the economic dimension of the work to level the runway. The cost of this work, which is high according to the current operator, would lead to the airport being closed for several months, with substantial economic consequences for the airport operator. The DSAC also stipulates that the safety level is acceptable given the absence of events identifying non-conformities and the information provided to crews through aeronautical publications (publication of the runway profile).

Data from the analysis of Transavia flights shows that Nantes is, along with Mykonos, the airport with the highest number of hard landings, and that all these hard landings occurred on runway 21. Indeed, air operators study every landing as part of their flight analysis, with the aim of improving safety.

The safety study carried out by the airport operator regarding the non-conformities of the profile of runway 21 was drawn up to substantiate the special conditions of this runway for the DSAC, in order to operate it. This study, carried out in 2015, mentions the absence of events identifying the non-conformities of runway 21.

This accident shows that the offset approach to runway 21, implemented for environmental rather than safety reasons, combined with the non-conformities of the runway profile, can be conducive to "hard" landings. Although detected by operators, these "hard" landings were not reported to the air navigation services or to the airport operator. The lack of notification of these events to the airport operator prevents the safety study from being updated. Taking these occurrences into account would contribute to updating this safety study, and could lead to, if necessary, a re-assessment of the safety level associated with the slope and slope changes on runway 21.

Since the runway profile does not comply with the applicable requirements, the publication of information giving a clearer warning of the specific characteristics of Nantes airport would help air operators and their crews to take these specific features into account.

Instructor's self-analysis of the threats posed by the pilot-in-training's apprehensions

The progress curve of pilots-in-training may vary depending on many factors. The flying conditions, the specific features of the infrastructure used, the environment, the recent experience or the difficulties encountered during training can cause some apprehension which can alter the pilot-in-training's performance level.

The instructor must thus identify and assess this threat during the flight preparation and in flight, and implement means to reduce the associated risk. The instructor shall then discuss with the pilot-in-training the actions to be taken or procedures to be implemented in the event that the approach or landing do not go according to plan.

In the case of the approach to Nantes, it may be worthwhile for the instructor to consider the acceptable level of automated systems that will reduce the workload. The instructor can also discuss the specificity of performing a flare manoeuvre on a surface that is not perfectly flat with the pilot-in-training and review some FCTM procedures such as the "Bounced Landing", "Rejected Landing" or "Balked Landing" procedures with him.

In some cases, the instructor may have to not let the pilot carry out the approach or landing. The latter decision can only be taken effectively if the instructor is not under pressure to have the pilot-in-training complete a certain number of approaches as part of the validation of his LIFUS.

This strategy for analysing the threats associated with the training situation is identical to that used by the crew during briefings (TEM strategy). However, as it is specific to the instructor, it could effectively complement the crew briefing.

7 ACTIONS TAKEN BY THE OPERATOR

After the accident flight, Transavia implemented several measures aimed mainly at improving the progress and monitoring of pilots in LIFUS with respect to destinations that can be complex in relation to their level and the conditions at the time, including:

- withdrawal of destinations with specific features considered to be complex from the flight schedule of co-pilots in LIFUS;
- adjustment of the division of the PF/PM roles between the co-pilot and the instructor according to the destination and any context-related difficulties (complex approach, adverse weather conditions, etc.);
- standardised instruction in the landing technique;
- training in the actions to take in the event of a bounced landing;
- information for instructors on taking the controls and formalising this action during the flight;
- training in awareness of the risk of a hard landing in comparison to a tail strike.

These measures are also designed to help instructors understand their role, by providing them with a framework for adapting their strategy in the different contexts encountered during training flights and critical phases of a flight.

8 RECOMMENDATION

Note: in accordance with the provisions of Article 17.3 of Regulation No 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, a safety recommendation in no case creates a presumption of fault or liability in an accident, serious incident or incident. The recipients of safety recommendations report to the issuing authority in charge of safety investigations, on the measures taken or being studied for their implementation, as provided for in Article 18 of the aforementioned regulation.

Aeronautical information services and aerodrome data

Data relevant to an aerodrome and services available at the aerodrome must be provided to the users, relevant air traffic service providers and aeronautical information services providers by means of an aeronautical information (EU regulation No 139/2014 requirement ADR.OPS.A.005 Aerodrome data).

This data shall include the altitudes of the aerodrome, the runway end and any significant intermediate points along the runway (AMC1 ADR.OPS.A.005). Longitudinal slopes can also be described (AMC1 ADR.OPS.A.005).

In order for aeronautical information services providers to meet the need for relevant information for aerodrome operations, aerodrome operators must ensure the completeness of the aeronautical data (ADR.OPS.A.010 Data quality requirements) and transmit any information of particular importance to aerodrome operations (ADR.OPS.A.015 Coordination between aerodrome operators and providers of aeronautical information services).

As an example, the Aeronautical Information Publication (AIP) for Mykonos aerodrome specifies the non-conformities accepted under special conditions. Transavia considers Mykonos to be a special airport and requires a minimum level of crew experience, as well as a "specific qualification" awarded to a captain by an instructor.

Consequently, the BEA recommends:

- ***whereas the longitudinal slopes of the runway at Nantes - Atlantique airport exceed the certification specifications at several points along the runway;***
- ***whereas these exceedances are neither published nor known to air operators;***
- ***whereas all information of particular importance for aerodrome operations must be transmitted in accordance with requirement ADR.OPS.A.015;***
- ***whereas the publication of information giving a clearer warning of the specific features of Nantes - Atlantique airport would help air operators and their crews to better take these specific features into account;***

the airport operator, Vinci, in coordination with the AIS, include the non-conformities identified for the approach and runway in the AIP [FRAN-2024-0019].

The BEA investigations are conducted with the sole objective of improving aviation safety and are not intended to apportion blame or liabilities.