Transportation Safety Board of Canada
Bureau de la sécurité des transports du Canada

AVIATION INVESTIGATION REPORT A17F0052

Risk of collision with terrain

WestJet
Boeing 737-800, C-GWSV
Princess Juliana International Airport, Sint Maarten
07 March 2017

Canada

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Summary

On 07 March 2017, a WestJet Boeing 737-800 aircraft (registration C-GWSV, serial number 37158), operating as flight 2652 (WJA2652), was conducting a scheduled instrument flight rules flight from Toronto/Lester B. Pearson International Airport, Ontario, to Princess Juliana International Airport, Sint Maarten. During the approach to Runway 10, the aircraft deviated from the normal descent path. At 1534 Atlantic Standard Time (AST), the aircraft was 0.30 nautical miles from the runway threshold and had descended to an altitude of 40 feet above the water. The crew then initiated a missed approach. Given that visibility was below the limits for conducting a second approach, the flight was cleared to hold until conditions had improved. After visibility improved, the crew conducted a second approach and landed at 1618 AST without further incident.

Le présent rapport est également disponible en français.

Table of contents

1.0 Factual information

1.1 History of the flight

On 07 March 2017, a WestJet Boeing 737-800 aircraft (registration C-GWSV, serial number 37158), operating as flight 2652 (WJA2652), was conducting a scheduled instrument flight rules (IFR) flight from Toronto/Lester B. Pearson International Airport (CYYZ), Ontario, to Princess Juliana International Airport (TNCM) in Sint Maarten, an autonomous country within the Kingdom of the Netherlands. There were 158 passengers, 2 flight crew members, and 4 cabin crew members on board.

Before departure, WestJet dispatch issued a flight release package to the crew containing all of the information pertinent to the flight, including current and forecasted weather and winds-aloft data, notices to airmen (NOTAMs), and airport and runway analysis data. The forecasted conditions for TNCM indicated wind from 070° true (T) at 16 knots, visibility greater than 6 statute miles (sm)[1] in light rain showers, few clouds at 1800 feet, scattered cloud at 2200 feet, and another scattered cloud layer at 3000 feet.

The aircraft departed from CYYZ at 1137.[2] The planned duration of the flight was 4 hours and 24 minutes at flight level (FL) 350.[3] The captain occupied the left seat and was the pilot monitoring (PM), while the first officer occupied the right seat and was the pilot flying (PF).

While approaching their destination, the flight crew listened to the automatic terminal information system (ATIS)[4] information Mike,[5] which was issued at 1501 and reported winds from 060° magnetic (M) at 18 knots, unlimited visibility, few clouds at 1400 feet, and no weather conditions of significance in the vicinity of TNCM. In addition to preparing for a

1 One statute mile is equivalent to 5280 feet.

2 All times are Atlantic Standard Time (Coordinated Universal Time minus 4 hours), which is the local time in Sint Maarten.

3 Flight level (FL) is "the altitude expressed in hundreds of feet indicated on an altimeter set to 29.92 in. of mercury or 1013.2 mb." (Source: Transport Canada, TP 14371, *Transport Canada Aeronautical Information Manual* [TC AIM], GEN – General [13 October 2016], section 5.1.) In this case, flight level 350 refers to 35 000 feet above mean sea level.

4 The automatic terminal information system (ATIS) is "the continuous broadcasting of recorded information for arriving and departing aircraft on a discrete VHF/UHF [very high frequency / ultra high frequency]. Its purpose is to improve controller and flight service specialist effectiveness and to relieve frequency congestion by automating the repetitive transmission of essential but routine information." (Source: Ibid., RAC – Rules of the Air and Air Traffic Services, section 1.3.)

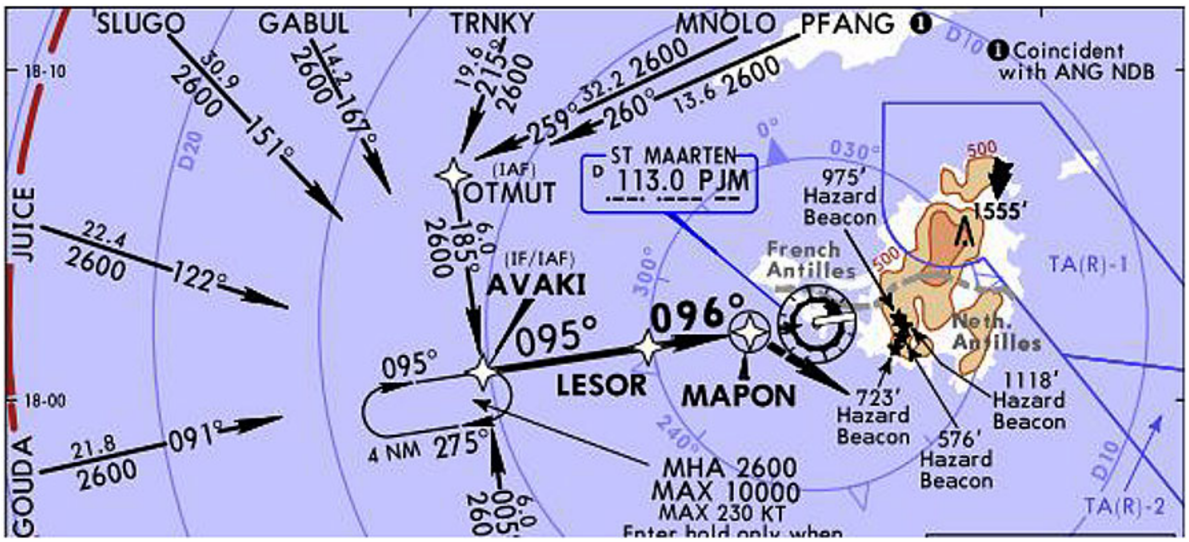
5 "Each recording [is] identified by a phonetic alphabet code letter, beginning with Alfa. Succeeding letters are used for each subsequent message." (Source: Ibid.)

visual approach[6] to Runway 10, the flight crew loaded the RNAV (GNSS)[7] approach to Runway 10 (Appendix A) in the flight management system (FMS) and conducted the briefing as a precaution in the event of a change in weather conditions.

At 1518:14, the TNCM air traffic controller (controller) instructed the flight crew to report when they were over the SLUGO waypoint[8] (Figure 1) and to expect descent instructions at that time, and advised them that the current ATIS information was Mike and the altimeter was 30.09 inches of mercury.

At 1523:12, the crew were instructed to descend to 4000 feet, and, at 1523:12, they reported that they were over the SLUGO waypoint.

Figure 1. Plan view of the RNAV (GNSS) Rwy 10 approach to Princess Juliana International Airport (TNCM), showing the SLUGO, AVAKI, and MAPON waypoints (Source: Jeppesen Sanderson Inc., approach chart)



At 1524:36, the controller informed the flight crew of another aircraft that was on approach to TNCM, ahead of WJA2652, that rain showers were approaching the airport.

At 1524:48, the flight crew of WJA2652 were instructed to fly direct to the AVAKI initial approach waypoint[9] (Figure 1) once they had descended through 8000 feet above sea

[6] "A visual approach is an approach wherein an aircraft on an IFR flight plan (FP), operating in VMC [visual meteorological conditions] under the control of ATC [air traffic control] and having ATC authorization, may proceed to the destination airport." (Ibid., section 9.6.2.)

[7] RNAV refers to area navigation. An RNAV (GNSS) approach indicates a procedure requiring GNSS (global navigation satellite system).

[8] "A specified geographical location, defined by longitude and latitude, that is used in the definition of routes and terminal segments and for progress-reporting purposes." (Source: Transport Canada, Advisory Circular 100-001, *Glossary for Pilots and Air Traffic Services Personnel* [17 September 2017].)

[9] "The waypoint of an instrument approach procedure (IAP) at which the aircraft leaves the en route phase of operations to commence the approach." (Source: Ibid.)

level (ASL). One minute later, when the aircraft was approximately 25 nautical miles (nm) northwest of TNCM and descending through 9800 feet, the controller advised the flight crew that there were moderate to heavy rain showers at the airport. The crew did not acknowledge this information.

At 1526, ATIS information November was issued, indicating that visibility was 2000 m.[10] The crew did not receive this updated visibility information, but they observed clouds and rain showers around the airport and decided to switch from the visual approach to the RNAV (GNSS) Rwy 10 approach. A minimum visibility of 3600 m (1.94 nm) is required for WJA2652's aircraft category to conduct the RNAV (GNSS) approach.

At 1527:02, the controller instructed the flight crew a second time to fly direct to the AVAKI initial approach waypoint. One minute later, when the aircraft was 15 nm northwest of the airport and descending through 6700 feet, the controller directed them to descend to 2600 feet.

At 1528:56, when the aircraft was 13 nm west of the airport and descending through 4900 feet, the flight crew were cleared to fly the RNAV approach to Runway 10. Approximately 1 minute later, the controller informed the crew a second time that there were moderate to heavy rain showers at the airport. The flight crew acknowledged the information when they were 12 nm west of the airport and descending through 3700 feet.

At 1530:32, the flight crew of an aircraft that had just landed at the airport reported that there had been steady winds and reduced visibility during the approach, but that they had visually acquired the runway while over the MAPON missed approach point (MAP)[11] (Figure 1). The WJA2652 flight crew acknowledged the information when they were 10 nm from the airport, on final approach and descending through 2100 feet.

At an undetermined point during the approach, because of the moderate to heavy rain showers, the controller illuminated the runway lights using an automatic setting for night operations that sets the runway lights at 3% intensity and the precision approach path indicator (PAPI) lights at 10% intensity. The controller did not tell the crew about the change in lighting intensity, and was not required by regulation to do so.

At 1532, when the aircraft was 4.5 nm from the runway and descending through 1600 feet, the flight crew were cleared to land and informed that the winds were from 060°M at 17 knots. The aircraft's rate of descent varied between 700 and 800 feet per minute (fpm), and the aircraft was established on a 3° angle of descent. About 0.5 nm before crossing MAPON, the flight crew noticed a rain shower ahead and to their left; however, given that they had the shoreline in sight and expected to see the runway shortly afterward, they decided to

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10 Visibility is reported in metres at Princess Juliana International Airport (TNCM); 2000 m is equivalent to 1.079 nm.

11 "The point on the final approach course that signifies the termination of the final approach and the commencement of the missed approach segment. […]." (Source: Transport Canada, Advisory Circular 100-001, *Glossary for Pilots and Air Traffic Services Personnel* [17 September 2017].)

continue their approach visually. The PF disconnected the autopilot and reduced the pitch from 0.5° nose up to 1.2° nose down. Three seconds later, the engine thrust decreased from 62% to 52% N_1.[12] Shortly afterward, the rate of descent increased to 1150 fpm, and the aircraft began to deviate below the 3° descent angle of the standard approach path. Approximately 2 seconds after the aircraft's descent rate was increased, the crew cycled the flight directors, in accordance with WestJet's approach procedures for landing at TNCM.[13] The autothrottle changed from speed mode to ARM mode[14] when the flight directors were cycled, and thereafter did not provide automatic thrust control.

At 1533:30, the aircraft crossed MAPON at approximately 700 feet above ground level (AGL). The PF indicated that he had the runway in sight and began to roll the aircraft to the left, deviating to a point approximately 250 feet left of the inbound final approach course. The flight crew saw neither the runway lights nor the PAPI lights during the approach, and did not request that the intensity of the lights be increased. After crossing MAPON, the aircraft entered the rain shower, which had moved toward the final approach path, reducing the visibility significantly. Eleven seconds later, when the aircraft was 1.5 nm from the runway on final approach and descending through 500 feet, the flight crew were advised that the wind was 060°M at 14 knots, gusting to 25 knots.

Approximately 1 nm from the runway, the aircraft exited the shower; the visibility sharply improved, and the crew realized that they had been tracking toward an incorrect visual reference, which was a hotel situated to the left of the runway. At this point, the aircraft was 190 feet AGL, descending at 940 fpm, rather than 320 feet AGL on a standard 3° angle of descent. Now able to see the actual runway, the crew recognized that the aircraft had deviated laterally to the left of the inbound final approach course, but they were not immediately able to assess their height above water. The PF advanced the throttles from 52% to 75% N_1 and began to correct the lateral deviation, but the aircraft continued to descend at about 860 fpm.

At 1534:03, when the aircraft was 63 feet above the water, the aircraft's enhanced ground proximity warning system (EGPWS) issued an aural alert of "TOO LOW, TERRAIN" and the PF increased the pitch to 4° nose up. The aircraft continued to descend, and a second aural alert of "TOO LOW, TERRAIN" sounded as it passed from 54 feet to 49 feet AGL (Figure 2).

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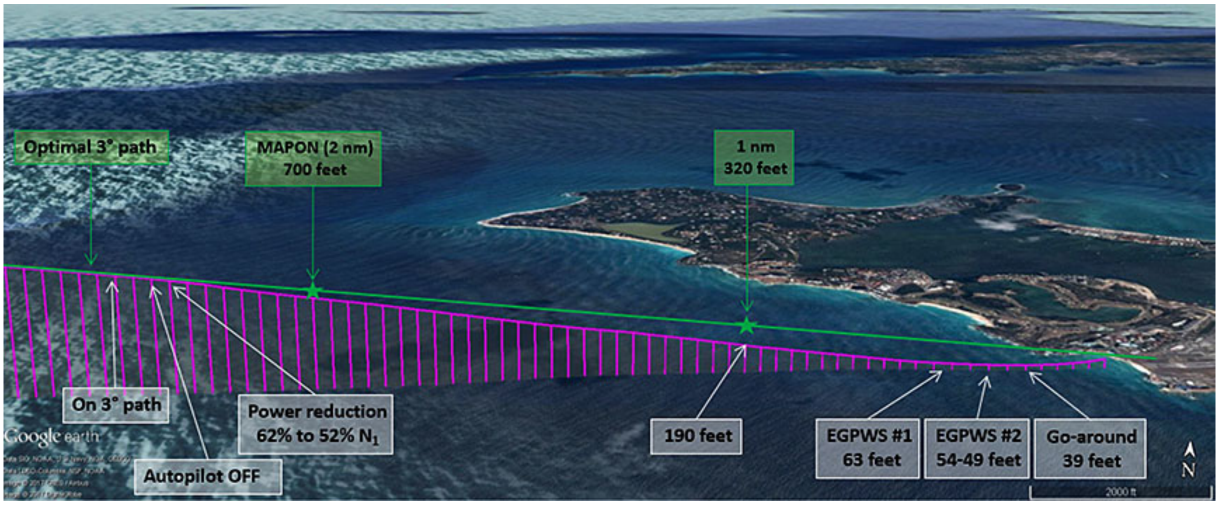
12 N_1 refers to engine power (low-pressure compressor speed in revolutions per minute [rpm]).

13 Cycling of a flight director (FD) refers to the action of commanding the FD system OFF and then ON again. This procedure prevents the system from proceeding in sequence to the next waypoint, and prevents the FD command bars from displaying a turn. The command bars then disappear from view until selection of another mode.

14 In SPEED mode, the autothrottle is designed to adjust thrust automatically when there is a change in airspeed from the commanded speed. ARM mode provides only minimum speed protection in the event that the aircraft slows to minimum manoeuvrable speed.

Figure 2. Standard 3° angle of descent versus the aircraft vertical approach path



At 1534:12, when the aircraft was 40 feet above the water and 0.3 nm from the runway threshold, the crew initiated a go-around. The lowest altitude recorded by the EGPWS during the descent had been 39 feet AGL.

After the go-around, the controller instructed the crew to conduct a holding pattern. Because the visibility was below the level required to conduct an approach (3600 m), the controller then closed Runway 10 for departures and instructed several other aircraft on approach to conduct holding patterns.

About 45 minutes later, the visibility at TNCM increased and WJA2652 was cleared for the RNAV (GNSS) Rwy 10 approach. The aircraft landed safely at 1618:19.

1.2 *Injuries to persons*

There were no reported injuries.

1.3 *Damage to aircraft*

There was no damage to the aircraft.

1.4 *Other damage*

There was no damage to property or objects.

1.5 Personnel information

Table 1. Personnel information

	Captain	First officer
Pilot licence type	Airline transport pilot licence (ATPL)	Airline transport pilot licence (ATPL)
Medical expiry date	31 May 2017	31 May 2017
Total flying hours	14 000	12 500
Flight hours in the last 7 days	19	25
Flight hours in the last 30 days	78	99
Flight hours in the last 90 days	275	241
Flight hours on type in the last 90 days	275	241
Hours on duty prior to occurrence	Approximately 7	Approximately 7
Days off duty prior to work period	3	2

1.5.1 General

Records indicate that both flight crew members were certified and qualified for the flight in accordance with existing regulations. It was the 7th time the captain had flown to TNCM and the 2nd time that the first officer had done so. The captain and the first officer had never flown together in the past.

There were no indications that the performance of either the captain or the first officer had been degraded by fatigue or physiological factors.

1.5.1.1 Captain

The captain had been employed by WestJet for almost 10 years prior to this occurrence. The captain had completed a line check[15] and received simulator training in November 2016. He had completed annual training and crew resource management (CRM) training in April 2016.

1.5.1.2 First officer

The first officer had been employed by WestJet for 7 years prior to this occurrence. He had completed a line check in June 2016 and received simulator training in October 2016. He had also completed annual training and CRM training in 2016.

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15 A line check is a pilot proficiency check that is conducted in accordance with *Canadian Aviation Regulations* paragraph 705.106(1)(d). It is undertaken upon completion of line indoctrination and annually thereafter.

1.6 *Aircraft information*

1.6.1 *General*

Records indicate that the aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures.

The Boeing 737-800 is a twin-engine, narrow-body, single-aisle passenger transport aircraft. It is equipped with a retractable landing-gear system, which includes 2 main landing gears and 1 nose landing gear.

Table 2. Aircraft information

Manufacturer	Boeing
Type-model, registration	737-800, C-GWSV
Year of manufacture	2009
Serial number	37158
Certificate of airworthiness issue date	20 March 2009
Total airframe time	31 823
Engine type	CFM56-7B27
Maximum allowable take-off weight (kg)	79 016
Fuel type used	Jet A

1.6.2 *Enhanced ground proximity warning system*

The aircraft is equipped with a Honeywell Mark V EGPWS, a type of terrain awareness and warning system (TAWS) that alerts pilots if the aircraft is in imminent danger of controlled flight into terrain. The system "uses aircraft inputs [in combination] with internal terrain, obstacles, and airport runway databases to predict a potential conflict between the aircraft flight path and terrain or an obstacle."[16] When there is potential for a collision, the EGPWS provides a visual and aural caution or warning alert to the flight crew.

Among the features of the system is a terrain clearance floor (TCF)[17] function, which is used for non-precision approaches. Using the aircraft's radar altitude and distance from the centre of the nearest runway in the EGPWS database, this feature detects a descent by the aircraft below the TCF and alerts the crew, regardless of the aircraft configuration. When the aircraft penetrates the TCF, a caution light illuminates and the crew receives the aural message "TOO LOW, TERRAIN." If the aircraft does not exit the TCF, the caution light remains illuminated and the aural message is repeated at every 20% decrease in radar altitude.[18]

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16 Honeywell International Inc., *Mark V and Mark VII EGPWS Pilot's Guide*, Revision H (08 August 2011), p. 1.

17 TCF is a virtual geographic area, or envelope, calculated by the EGPWS system to identify a zone within which aircraft proximity to the ground is hazardously low.

18 Honeywell International Inc., *Mark V and Mark VII EGPWS Pilot's Guide*, Revision H (08 August 2011), p. 28.

Following the occurrence, the EGPWS unit was removed from the aircraft and sent to the TSB laboratory for data extraction and analysis. Its data were then sent to the EGPWS manufacturer for decoding. Six files of decoded information were returned, 3 of which contained the occurrence flight data.

1.6.3 Rain removal systems

1.6.3.1 Wipers

Boeing 737 series aircraft are equipped with windshield wipers, which serve as the aircraft's certified rain removal system, to reduce the effects of rain on forward visibility. The investigation could not determine whether the wipers were used during the approach.

1.7 Meteorological information

1.7.1 General

The Meteorological Department of Sint Maarten is responsible for conducting and publishing hourly weather observations and, in cases of significant changes in weather conditions, for conducting special weather observations.

1.7.2 Weather conditions during flight

1.7.2.1 Prior to departure

The flight release package received by the flight crew prior to departure contained all information pertinent to the flight, including current and forecasted weather.

The 0900 aviation routine weather report (METAR) for TNCM indicated

- wind 060°T at 12 knots;
- unlimited visibility;
- scattered clouds at 1800 feet and some towering cumulus clouds in the vicinity of the airport;
- temperature 25 °C, dew point 21 °C;
- altimeter 30.11 inches of mercury (in. Hg); and
- recent rain and no significant weather conditions.

The aerodrome forecast (TAF) for TNCM for the period of arrival, issued at 0743, indicated

- winds 070°T at 16 knots;
- visibility greater than 6 sm;
- light rain showers; and
- few clouds at 1800 feet, scattered clouds at 2200 feet, and another scattered cloud layer at 3000 feet.

1.7.2.2 *En route*

While en route, the crew received updated weather information through the aircraft communications addressing and reporting system.[19] Based on a METAR for TNCM issued at 1400, the update indicated

- wind 050°T at 16 knots;
- unlimited visibility;
- a few clouds at 1400 feet with some towering cumulus clouds, and a broken layer of cloud at 1800 feet;
- temperature 25 °C, dew point 21 °C;
- altimeter 30.09 in. Hg; and
- no significant weather conditions.

1.7.2.3 *Prior to approach*

Prior to commencing the approach for landing on Runway 10, the flight crew received ATIS information Mike, which was issued at 1501 and reported

- wind from 060°M at 18 knots;
- unlimited visibility; and
- few clouds at 1400 feet and a broken ceiling at 3500 feet.

1.7.2.4 *Approach*

The crew observed clouds and showers around the airport as they were approaching their destination. As the approach continued, the rain showers passed over the airport area, significantly reducing visibility.

At 1525, during the approach, an aerodrome special meteorological report[20] was issued, reporting that visibility had decreased to 2000 m and that there were light rain showers at the airport. ATIS information November, reflecting the updated conditions, was issued 1 minute later. The controller did not inform the flight crew of the reduced visibility, but advised them that there were moderate to heavy rain showers at the airport.

1.7.2.5 *Following missed approach*

At 1600, the ATIS information Oscar for TNCM was as follows:

- wind 060°M at 15 knots;
- visibility 2000 m with light rain showers;
- few clouds at 1600 feet and overcast clouds at 3500 feet;

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19 The aircraft communications addressing and reporting system (ACARS) is an air–ground communications system used by air operators to communicate data to crews in flight. The data is received via a printer in the cockpit.

20 An aerodrome special meteorological report (SPECI) is issued when changes in weather conditions that are of significance to aviation are observed.

- temperature 22 °C;
- dew point 22 °C; and
- altimeter 30.09 in. Hg.

1.8 *Aids to navigation*

Navigational aids at TNCM include a non-directional beacon and a VOR (VHF omnidirectional range) with associated distance measuring equipment. Runway 10 is served by an RNAV (GNSS) approach and a VOR approach.

The aircraft was equipped with the appropriate navigational aids to conduct an RNAV (GNSS) approach, and there were no reported outages involving these aids at the time of the aircraft's approach to TNCM.

1.9 *Communications*

No anomalies in the quality of radio transmissions were noted during the flight.

1.10 *Aerodrome information*

1.10.1 *General*

TNCM has 1 asphalt runway (Runway 10/28), which is 7546 feet in length and 148 feet wide. Runway 10 is oriented 096°M; its threshold is displaced by 98 feet and its touchdown zone elevation is 12 feet ASL.

Runway 10/28 is equipped with a medium-intensity runway lighting system, which includes green threshold lights, red runway end lights, and white runway edge lights.

Runway 10 is not serviced by approach lights, but is equipped with a PAPI, which consists of a wing bar with 4 light units and is "designed to provide visual indications of the desired approach slope to a runway (usually 3°)."[21] At TNCM, the PAPI indicates a 3° angle of descent, and its lights are situated on both sides of the runway.[22]

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21 Transport Canada, TP 14371, *Transport Canada Aeronautical Information Manual* (TC AIM), AGA—Aerodromes (12 October 2017), section 7.6.1.

22 Dutch Caribbean Air Navigation Service Provider (DC-ANSP), Aeronautical Information Publication (AIP) of Curaçao, Aruba, Sint Maarten, Bonaire, Saba and St. Eustatius (effective 30 March 2017), Part 3: Aerodromes (AD), section 2.14.

1.10.2 Aerodrome lighting intensity

In its *Procedures for Air Navigation Services – Air Traffic Management* (PANS-ATM), the International Civil Aviation Organization (ICAO) specifies the following regarding aerodrome lighting:

> At aerodromes equipped with lights of variable intensity a table of intensity settings, based on conditions of visibility and ambient light, should be provided for the guidance of air traffic controllers in effecting adjustment of these lights to suit the prevailing conditions. When so requested by an aircraft, further adjustment of intensity shall be made whenever possible.[23]

However, the *Princess Juliana International Airport Air Traffic Services (ATS) Standard Operating Procedures Manual*[24] does not provide guidance to TNCM controllers on adjusting the intensity of the runway lights or PAPI lights. The operation of the lighting system at TNCM, including light intensity control, is at the controller's discretion. By comparison, air traffic controllers in Canada are provided with direction regarding aerodrome lighting operation and when to employ specific intensity settings based on reported visibility.[25]

1.11 Flight recorders

The aircraft is equipped with a digital flight data recorder (DFDR) and a cockpit voice recorder (CVR). Because the occurrence was originally assessed by WestJet as a non-reportable event, it was not reported directly to the TSB. The CVR and the DFDR data were overwritten and were not available to the investigation.

The quick access recorder (QAR) data file was sent to the TSB laboratory for analysis. QAR data is recorded by the aircraft's digital flight data acquisition and management unit, which stores the data on a Personal Computer Memory Card International Association (PCMCIA) card for flight data monitoring (FDM) purposes. The data on the card is an exact duplicate of that collected by the DFDR; however, the DFDR is crash-protected whereas the QAR is not, and the latter typically holds many more hours of data.

1.12 Wreckage and impact information

Not applicable.

1.13 Medical and pathological information

Not applicable.

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23 International Civil Aviation Organization, *Procedures for Air Navigation Services: Air Traffic Management* (PANS-ATM), Doc 4444, Sixteenth Edition (10 November 2016), section 7.15.2.3.

24 Princess Juliana International Airport Air Traffic Services (ATS) Standard Operating Procedures Manual, (October 2016), Part 3, Chapter 2, p. 97.

25 NAV CANADA, *Manual of Air Traffic Services – Control Services – Tower*, Aerodrome Lighting – Intensity Settings (31 August 2016), p. 83.

1.14 Fire

Not applicable.

1.15 Survival aspects

Not applicable.

1.16 Tests and research

1.16.1 Simulator session

On 26 July 2017, the TSB conducted a session in one of WestJet's 3 B737-700 flight simulators in Calgary, Alberta. The simulator, a full-flight, level D unit certified by Transport Canada (TC), is used to train WestJet B737-800 crews.[26] The purpose of the session was to assess WJA2652's approach under similar virtual weather conditions, while familiarizing TSB investigators with procedural workflow in the B737; with the operation of its autopilot, flight director, and navigation systems; and with the user interface of each of these components.

The simulator did not allow for an exact replication of all of the visual conditions at the time of the occurrence, such as the effect of the rain on the windshield. However, the exercise demonstrated a significant reduction in the visual discernibility of the runway environment when visibility diminished to 2000 m. It also highlighted the necessity for runway and PAPI lights to be illuminated at high intensity to clearly demarcate the runway edges under conditions of low visibility.

Through a series of approaches conducted in the simulator, the visual cues available to the flight crew were assessed, beginning from approximately 1000 feet AGL until the height at which the aircraft conducted its go-around, i.e. 40 feet AGL. The assessments indicated that, although the shape of a hotel to the left of the runway (Figure 3) differed from that of the actual runway, its discernible geometric features changed (as with most visual references) according to the approach angle and distance of the aircraft. From a distance, the hotel appeared wider at its base and narrower on top, similar in aspect to a runway. As the aircraft approached, however, its shape became more apparent as that of a building.

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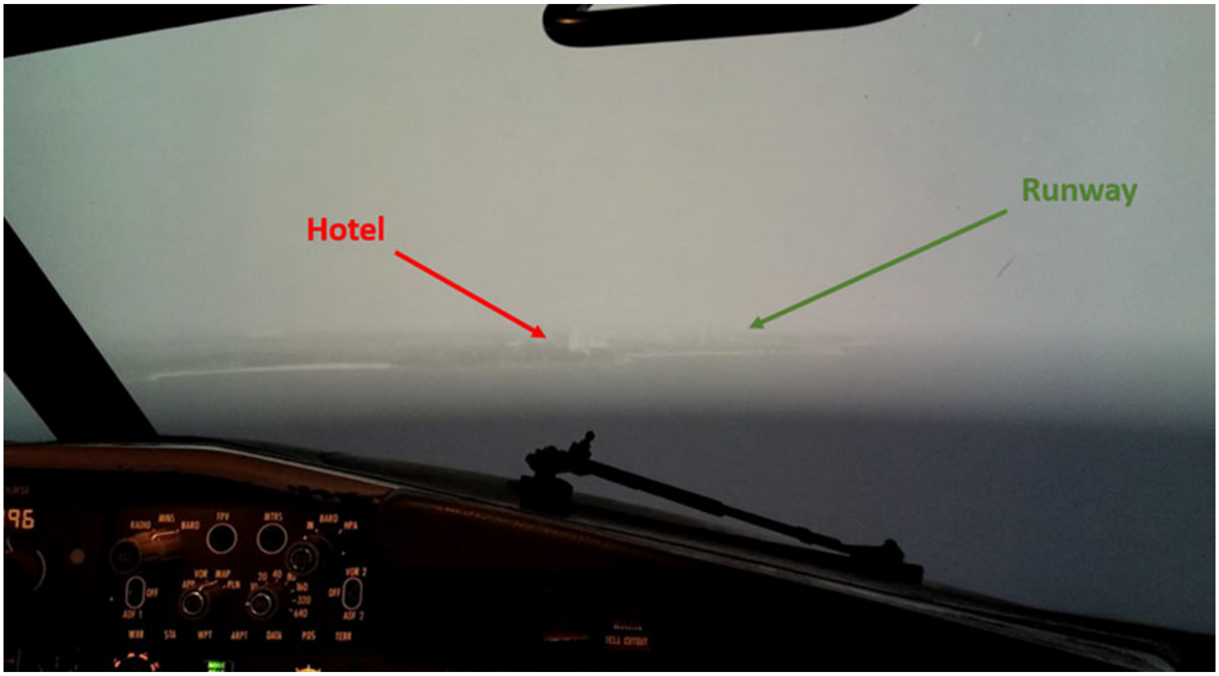
26 WestJet uses the B737-700 simulator to train pilots who fly its Boeing 737 series aircraft. Adjustments can be made in the simulator to replicate the performance of the appropriate model.

Figure 3. Visual references as seen in a flight simulator at approximately 500 feet AGL in poor visibility



1.16.2 *TSB laboratory reports*

The TSB completed the following laboratory reports in support of this investigation:

- LP074/2017 – EGPWS Download
- LP124/2017 – Analysis of Maintenance Records
- LP054/2017 – QAR Data Analysis

1.17 *Organizational and management information*

1.17.1 *General*

WestJet is a Canadian airline operator certified for flight operations under *Canadian Aviation Regulations* (CARs) Subpart 705 and an approved maintenance organization under CARs subpart 573. The airline is also a TC-approved flight-training organization.

Its fleet consists of 104 Boeing 737-600, -700, and -800 series aircraft and 4 Boeing 767 aircraft. WestJet also has 3 B737-700 pilot training simulators, located in Calgary. Initial and recurrent classroom training take place at the company's headquarters in Calgary.

1.17.2 *Safety management system*

WestJet monitors and addresses operational risk using a TC-approved safety management system (SMS) with the following elements:

- standardized policies, procedures, and training
- a non-punitive go-around policy
- a hazard/risk reporting system

- flight data monitoring (FDM)
- safety investigators
- periodic updates to policies, procedures, and training

Used in combination, these elements generate a feedback loop in which operational hazards are reported by crews or unsafe profiles are identified through FDM, then flight-safety personnel follow up on safety-related issues, and these are mitigated accordingly. In addition to the SMS elements listed above, WestJet issues safety letters and other internal safety communications to keep crews informed of safety-related changes to policy and procedures.

1.17.3 WestJet flight data monitoring

WestJet uses tools such as FDM, a flight operations quality assurance program (FOQA), explicit standard operating procedures (SOPs), and non-punitive go-around policies to identify and mitigate safety risks.

WestJet's FDM program is set up to monitor 100% of its scheduled flights; however, the nature of the monitoring system and the process used for retrieval of the data are such that occasionally, the data can be overwritten inadvertently or the system can experience software issues. As a consequence, the actual percentage of flights monitored can vary, resulting in less than the intended 100% monitoring rate. Flight data from these scheduled flights are downloaded and monitored, and when an instance occurs in which specific flight parameters are exceeded, the program captures it as an event. Incorrect aircraft configuration and exceedances of parameters for airspeed and rate-of-descent are among the numerous aircraft parameters that are tracked by the FDM on every flight.

The development of and adherence to stabilized approach criteria by air operators is widely recognized as an important strategy in reducing approach-and-landing accidents.[27] WestJet has monitored and addressed unstable approach criteria and ground-proximity exceedances. The company's stabilized approach criteria require that an approach be stable at 1000 feet above field elevation.[28] According to WestJet's *Flight Operations Manual*:

- A stabilized approach is defined as:
  - Aircraft in the final landing configuration;
  - Power setting appropriate for aircraft configuration;
  - Airspeed no greater than target + 20 knots and trending towards target; and
  - On glidepath, gradient path or assumed 3° glidepath.
- Descent rates above 1,000 fpm should be avoided;

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27 Flight Safety Foundation, "FSF ALAR Briefing Note 7.1 – Stabilized Approach," in: *Reducing the Risk of Runway Excursions: Report of the Runway Safety Initiative* (May 2009), pp. 133–138.

28 WestJet, *Flight Operations Manual – Boeing B737NG*, Volume 1, Revision 027 (19 January 2017), section 4.13.17, p. 4-72.

- Avoid any tendency to 'duck under' the profile approaching the threshold; and
- If the approach is not stabilized at 1,000 feet above field elevation or the approach becomes unstable below 1,000 feet, a go-around must be executed.[29]

Given that some of the approaches used by WestJet require a rate of descent of 1000 fpm or more, the FDM program is set to capture only rates of descent that exceed 1300 fpm for more than 2 seconds.

Should an aircraft exceed any of the monitored parameters during an approach, the FDM program identifies the event as an unstable approach, and the data is used by WestJet to compile unstable-approach and go-around statistics. In 2016, 1596 unstable approaches were captured, which equates to 0.86% of all approaches conducted by WestJet.[30] Of those, 1452 (approximately 91%) continued to a landing and 144 (approximately 9%) resulted in a go-around.

The majority of WestJet's 1596 unstable approaches in 2016 were characterized by rate-of-descent exceedances, and during 609 of them the aircraft exceeded 1300 fpm for more than 2 seconds during descent between 1000 feet AGL and 500 feet AGL.

The exceedances captured in the FDM program are assessed by designated line pilots to determine which require further investigation. Not all exceedances result in feedback to crew, investigation, or updates to training or procedures. As EGPWS alerts are monitored under WestJet's FDM program, the EGPWS alert that sounded during WJA2652's approach was captured when it was triggered at 63 feet AGL.

1.17.4 WestJet procedures

1.17.4.1 Pilot monitoring role

In its *Company Operations Manual*, WestJet provides crews with guidance regarding general phase of flight responsibilities for normal procedures (Table 3).

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[29] Ibid.

[30] WestJet conducted 185 581 approaches in 2016.

Table 3. General phase of flight responsibilities (normal procedures) (Source: WestJet, *Company Operations Manual*, Revision 047 (31 January 2017), section 10.1.3)

Pilot flying (PF)	Pilot not flying (PNF)*
• Flight path and airspeed control; • Airplane configuration; and • Navigation.	• Monitoring aircraft flight path performance; • Checklist reading; • Communications; • Tasks requested by PF; and • Start levers and fire switches (with PF concurrence).

* WestJet refers to the flight crew position of pilot monitoring (PM) as "pilot not flying" (PNF).

The Adverse Weather section of WestJet's *Flight Operations Manual* emphasizes the importance of crew coordination and awareness by requiring that crews

> [c]losely monitor the vertical flight path instruments such as vertical speed, altimeters, and glideslope displacement. The Pilot Not Flying should call out any deviations from normal.[31]

1.17.4.2 *Enhanced ground proximity warning system alerts and recovery procedures*

When ground proximity warning systems (GPWSs) were introduced in the aviation industry, "nuisance alerts"[32] were common. In an effort to limit unnecessary go-arounds due to nuisance alerts during daylight visual meteorological conditions (VMC), aircraft manufacturers recommended procedures for pilots to visually assess the terrain hazard identified by an alert before deciding on a course of action, and operators adopted these procedures. However, advancements in GPWS technology have reduced the incidence of nuisance alerts.

Over the past decade, only 29 EGPWS terrain alerts were reported through WestJet's SMS: 25 during daylight VMC, and 4 during night VMC. One third of those alerts occurred at the same airport during the same year.

WestJet's procedure for flight-crew response to EGPWS caution alerts is as follows:

> Correct the flight path, airplane configuration, or airspeed. […]
>
> **Note**: If a terrain caution occurs when flying under daylight VMC, and positive visual verification is made that no obstacle or terrain hazard exists, the alert may be regarded as cautionary and the approach may be continued.[33]

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31 WestJet, *Flight Operations Manual – Boeing B737NG*, Volume 1, Revision 027 (19 January 2017), section 5.14.12.4, p. 5-116.

32 The term "nuisance alert" refers to an aural or visual system alert that is unnecessary or not useful but requires a pilot to direct attention to deciding whether action is needed.

33 WestJet, *737 Quick Reference Handbook*, Revision 2 (16 November 2015), p. MAN 1.7.

That procedure is consistent with Boeing's recommendation[34] that, during day VMC, pilots may assess whether a terrain hazard exists before deciding whether to correct the flight path or continue the approach.

The EGPWS manufacturer, Honeywell, states the following in its guide:

> **Note:** Climbing is the only recommended response unless operating in visual conditions and/or pilot determines, based on all available information, that turning in addition to the climbing is the safest course of action. Follow established operating procedures.[35]

Honeywell recommends the following response to a caution alert:

> 1. Stop any descent and climb as necessary to eliminate the alert. Analyze all available instruments and information to determine best course of action
> 2. Advise ATC [air traffic control] of situation as necessary.[36]

While the EGPWS manufacturer's guidance document does not supersede Boeing and WestJet manuals, operators may impose a more restrictive procedure as part of their approved programs.[37]

1.17.4.3 Route and aerodrome qualification

WestJet produces a document known as a route and aerodrome qualification for each aerodrome at which it operates. The document provides flight crews with general information pertinent to their destination. WestJet's Route & Aerodrome Qualification for TNCM provides crews with aerodrome-specific guidance that includes cautions, weather-related approach and departure minima, and procedures pertaining to enroute flight, approach and landing, and departure. The arrival procedure described therein states, in part:

> RNAV 10 MAP located 2NM prior to threshold – ensure the autopilot is disengage [*sic*] and the FD cycled or disengaged prior to this point or aircraft will turn in LNAV [lateral navigation] at ONBED and thrust will increase. Be prepared for the thrust to annunciate "**ARM**" at this point and closely monitor speed. **Manual manipulation of thrust or selecting "speed" is required.**[38]

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34 Boeing, *737 Flight Crew Operations Manual* (15 September 2016), p. MAN 1.5.

35 Honeywell International Inc., *Mark V and Mark VII EGPWS Pilot's Guide*, Revision H (08 August 2011), p. 55.

36 Ibid.

37 Transport Canada, *Commercial Air Service Standards*, subsection 725.137(6).

38 WestJet, *Route & Aerodrome Qualification*, Princess Juliana International, Sint Maarten, Netherlands Antilles, TNCM/SXM (09 November 2015), p. 2.

1.18 Additional information

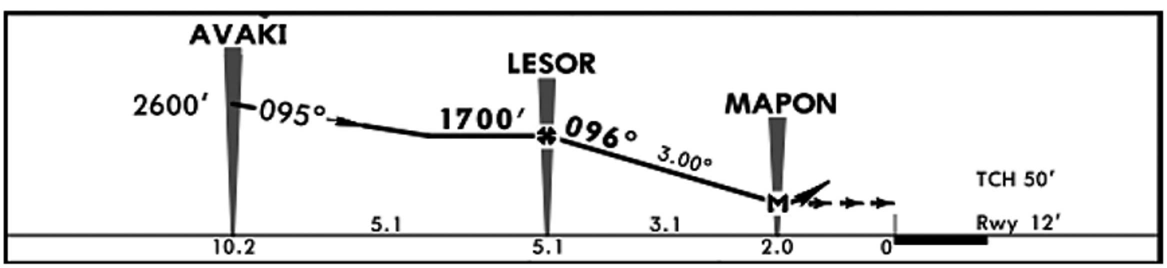
1.18.1 Instrument approaches at Princess Juliana International Airport

There are 2 approaches at TNCM: VOR Rwy 10 and RNAV (GNSS) Rwy 10. During the occurrence, the crew were conducting the RNAV (GNSS) Rwy 10 approach.

The RNAV approach provides flight crews with lateral navigation information (LNAV) for the approach, starting at an initial approach waypoint fix and ending at the MAP. The vertical flight path management for this approach is assured by the crew.

In this occurrence, the FMS provided the crew with vertical guidance to the MAP during the inbound final approach course. Because there is a mountain close to the runway, the MAP is situated 2 nm (3704 m) before the runway threshold, and the MDA is at 700 feet ASL (688 feet AGL), to meet the PANS-OPS[39] criteria for obstacle clearance in the event of a go-around. Therefore, there is a long visual flight segment following the MAP where the crew is required to manage the descent to the runway threshold in order to complete the landing (Figure 4). It is not common for WestJet pilots to fly long visual segments of an IFR approach such as that of the RNAV (GNSS) Rwy 10 at TNCM. Even less common are long visual segments over water and with the type of weather encountered during the occurrence approach.

Figure 4. Descent profile for the RNAV (GNSS) Rwy 10 approach to Princess Juliana International Airport (Source: Jeppesen Sanderson Inc., approach chart)



1.18.1.1 Minimum visibility to conduct an approach to Princess Juliana International Airport

When operating abroad, Canadian air operators must follow the laws, regulations, and procedures of both Canada and the foreign state in which they are operating.[40] Under the *Sint Maarten Civil Aviation Regulations*, the minimum visibility requirements to conduct an approach are more restrictive than those in the CARs.[41] The *Sint Maarten Civil Aviation*

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39 International Civil Aviation Organization (ICAO), Doc 8168, Procedures for Air Navigation Services: Aircraft Operations (PANS-OPS), Volume II, *Construction of Visual and Instrument Flight Procedures*, Sixth edition (2014).

40 Government of Canada, R.S.C., 1985, c. A-2, *Aeronautics Act*, sections 4 and 4.1.

41 Transport Canada, SOR/96-433, *Canadian Aviation Regulations*, section 705.48.

Regulations stipulate that an aircraft may not continue with an approach past the FAF unless visibility is "equal to or more than the minimums prescribed for that procedure."[42]

For WJA2652's aircraft category, the minimum visibility for the RNAV (GNSS) Rwy 10 approach to TNCM is 3600 metres. Visibility must therefore be at least 3600 m for an aircraft to continue an approach beyond the FAF (LESOR).

1.18.2 Required visual references

Under the CARs, a required visual reference

> in respect of an aircraft on an approach to a runway, means that portion of the approach area of the runway or those visual aids that, when viewed by the pilot of the aircraft, enable the pilot to make an assessment of the aircraft position and rate of change of position, in order to continue the approach and complete a landing.[43]

The *Canada Air Pilot* (CAP) states:

> The visual references required by the pilot to continue the approach to a safe landing should include at least one of the following references for the intended runway and should be distinctly visible and identifiable to the pilot.
>
> a. the runway or runway markings;
> b. the runway threshold or threshold markings;
> c. the touchdown zone or touchdown zone markings;
> d. the approach lights;
> e. the approach slope indicator system;
> f. the runway identification lights;
> g. the threshold and runway end lights;
> h. the touchdown zone light;
> i. the parallel runway edge lights; or
> j. the runway centreline lights.[44]

At TNCM, the RNAV (GNSS) Rwy 10 inbound final approach course is situated over ocean and includes a visual segment of 2 nm from the MAP to the threshold, which is adjacent to the shore (Figure 5). The visual references available for the RNAV (GNSS) Rwy 10 approach include

- the runway and runway markings,
- the runway threshold and threshold markings,
- the touchdown zone and touchdown zone markings,

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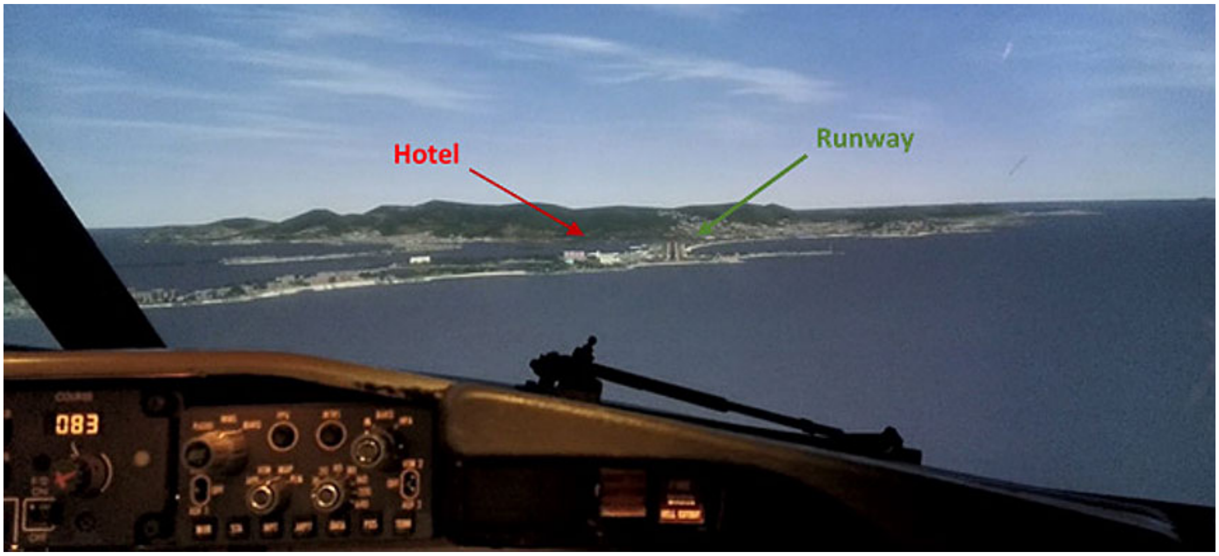
42 Sint Maarten Civil Aviation Authority, *Sint Maarten Civil Aviation Regulations*, Part 8: Operations, section 8.8.4.13.

43 Transport Canada, SOR/96-433, *Canadian Aviation Regulations*, subsection 100.01 (1).

44 NAV CANADA, *Canada Air Pilot* – Instrument Procedures – General Pages (CAP GEN) (effective 02 March 2017 to 27 April 2017), p. 11.

- the approach slope indicator system,
- the threshold and runway end lights, and
- the parallel runway edge lights.

Figure 5. Approach to Runway 10 at TNCM on a clear day, viewed in a flight simulator



1.18.3 Situational awareness

1.18.3.1 General

Situational awareness is the product of the

> continuous extraction of environmental information, integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception and anticipating future events.[45]

The processing of information by pilots at each of these 3 stages—perception, comprehension, and projection—must be unerring if accurate situational awareness is to be achieved and maintained. During an approach and landing, for example, a flight crew must perceive the visual references relevant to the approach, must understand what those references mean in the context of conducting an approach, and must predict the effect that information will have on the approach profile. If there is an error in the pilot's initial perception of critical elements in the environment, a pilot may misunderstand the context and any associated hazards.

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[45] C. Dominguez, "Can SA be defined?", in: M. Vidulich, E. Vogel, et al., AL/CF-TR-1994-0085, *Situation awareness: Papers and annotated bibliography* (Armstrong Laboratory, 1994), Section I.

1.18.3.2 *Errors in acquiring a visual reference*

Cognitive conspicuity refers to the degree of importance and relevance that an element of information has to an individual's own context.[46] For example, when conducting a visual approach, pilots visually scan the horizon for any reference that looks like the runway or threshold cues that they must acquire before proceeding. If there are visual elements that, when partially presented, appear similar to the cues they are searching for, these may be mistakenly acquired instead of the actual runway or threshold.

Expectation bias may also play a role in such errors. Pilots expect to see runway or threshold cues in the area where they anticipate the runway or threshold to be. When individuals receive information that fulfills their expectations, they tend to react automatically, and immediately initiate the sequence of actions associated with that information.

Unknowingly acquiring an incorrect visual reference illustrates an error at the first stage of development of situational awareness (perception). An unresolved error at this stage leads to errors in the subsequent 2 stages (comprehension and projection)—in this case, in the pilot's ability to accurately assess the aircraft's vertical position and rate of change relative to the runway environment. The consequences, according to the Flight Safety Foundation (FSF), may include "unconscious modification of the aircraft trajectory to maintain constant perception of the visual references"[47] or a "natural tendency to descend below the glideslope or the initial glide path."[48] The need for pilots to resist a tendency to pitch down or descend prematurely because of incorrect height perception is referred to by the FSF as "the greatest challenge during the visual segment of the approach."[49]

1.18.3.3 *Sensory conspicuity*

The sensory conspicuity of an object of visual reference refers to the degree to which its characteristics are likely to capture a pilot's attention when the pilot performs a visual scan. Visual references that are sensorially conspicuous may include concentrations of lights, objects that contrast greatly with their backgrounds in terms of brightness, colour, or texture, and prominently large objects.[50]

When set at the appropriate intensity, runway lights and PAPI lights can fulfil the level of sensory conspicuity required to serve as visual references. In poor visibility and with light

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46 P. A. Hancock, G. Wulf, D. Thom and P. Fassnacht, "Driver workload during differing driving maneuvers," *Accident Analysis & Prevention*, Vol. 22, No. 3 (1990), pp. 281–290.

47 Flight Safety Foundation, "FSF ALAR Briefing Note 5.3 – Visual Illusions," in: *Flight Safety Digest* (August–November 2000), page 107.

48 Ibid.

49 Ibid.

50 P. L. Olson, R. Dewar, and E. Farber, "Vision, audition, vibration and processing of information," in: *Forensic Aspects of Driver Perception and Response*, Third Edition (Tucson, Arizona: Lawyers & Judges Publishing Company, 2010).

intensity set too low to contrast with the runway environment, they may not be sufficiently conspicuous, particularly if other features in the environment are more visually prominent.

During the aircraft's approach, the runway lighting intensity was low, and under conditions of precipitation during daylight hours, rain further diminished the intensity of the approach lighting system,[51] reducing the conspicuity of the flight crew's visual references. Conversely, the hotel that was located to the left of the runway environment was large, rectangular, and bright white, which was in significant contrast to its background.

1.18.3.4 Validation cues

External cues in a pilot's forward and peripheral vision serve to alert the pilot to an aircraft's speed and height. Such cues may include cloud layers or features of the terrain (e.g., trees, buildings, or mountains) that stream in the pilot's peripheral vision. During flight over water, at night, or in atmospheric conditions such as rain, such cues may be absent or nonvisible, and "there is a lack of visual texture and other visual cues that would provide a reliable perception of height".[52]

1.18.3.5 Workload and anticipation

High levels of workload can have an adverse impact on a pilot's ability to perceive and evaluate cues in the environment.

Although a comfortable and alert pilot may be able to easily detect objects in the corner of the eye, the imposition of a moderate workload, fatigue, or stress induces tunnel vision. In aviation, cockpit workload is likely to be the most common cause of visual field narrowing.[53]

When individuals are focused on a central task, such as specific cue detection or talking, it is more difficult for them to detect peripheral stimuli.[54] Flying a visual approach in poor visibility represents a central task involving a high perceptual workload.

Further, pilots may intentionally or unintentionally focus attention on an area where they expect an event, or a change in an event, to occur. This anticipation may exacerbate the narrowing of the pilot's visual field.

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51 Flight Safety Foundation, "FSF ALAR Briefing Note 5.3 – Visual Illusions," in: *Flight Safety Digest* (August–November 2000), p. 105.

52 Ibid., p. 287.

53 Australian Transport Safety Bureau (ATSB), Alan Hobbs, *Limitations of the See-and-Avoid Principle*, ATSB Transport Safety Report (April 1991), Chapter 2.6.

54 H. W. Lebowitz and S. Apelle, "The Effect of a Central Task on Luminance Thresholds for Peripherally Presented Stimuli," *Human Factors*, Vol. 11 (1969), pp. 387–392, in: Australian Transport Safety Bureau, *Limitations of the See-and-Avoid Principle*, ATSB Transport Safety Report (April 1991), Chapter 2.6.

1.18.4 *Flight path monitoring*

According to the FSF, the most frequently cited causal factors in approach-and-landing accidents include:

- Inadequate reference to instruments to support the visual segment;
- Failure to detect the deterioration of visual references; and
- Failure to monitor the instruments and the flight path because both pilots are involved in the identification of visual references.[55]

In November 2014, following a study to determine the factors that lead to inadequate flight path monitoring, the FSF issued 20 recommendations in *A Practical Guide for Improving Flight Path Monitoring*. Among the barriers to effective flight path monitoring described in the guide are human limitations:

> alternating periods of high-workload, multitasking demands and low-workload, sustained-vigilance demands collide with a human brain that has difficulty accomplishing either type. What we need is a system of policies, procedures, automated systems design and pilot training that better supports the way the brain processes information and helps pilots monitor effectively in all phases of flight. Implementing recommendations contained in this guide should help meet that need.[56]

To mitigate the probability of visual errors and optimize situational awareness, according to the guide, flight crews must maintain effective monitoring and coordination by, in part,

> following SOPs consistently; clearly communicating deviations to other crewmembers; aggressively managing distractions; remaining vigilant; […] [and] methodically regaining flight path situational awareness (SA) after completing non-flight-related tasks […].[57]

In particular, the PM should continuously scan instruments, such as the instantaneous vertical speed indicator and altimeter, and cross-check their indications against outside references. Altitude calls and excessive parameter-deviation calls should be the same for instrument and visual approaches.

1.18.5 *Threat and error management*

The threat and error management (TEM) model is a conceptual framework that

- is employed to describe how flight crews manage the situations they encounter that increase the risks associated with flight.

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55 Flight Safety Foundation, "FSF ALAR Briefing Note 5.3 – Visual Illusions," in: *Flight Safety Digest* (August–November 2000), p. 107.

56 Flight Safety Foundation, A Practical Guide for Improving Flight Path Monitoring: Final report of the Active Pilot Monitoring Working Group (November 2014), p. 13.

57 Ibid., p. 4.

- is used as a tool to analyze the development of situations that culminated in an occurrence.
- examines the key elements of threats, errors, and undesired aircraft states.
- outlines countermeasures that have been shown to be effective in managing those elements.[58]

Threats are conditions beyond the control of a flight crew that increase the risk of an incident or accident. They may include environmental threats, such as adverse weather or runway contamination, or operational threats, such as air traffic control clearances that present challenges and they may lead to crew error and to undesired aircraft states, wherein an aircraft is placed under a condition of increased risk. However, if threats are identified and actively managed, they can be of little consequence.

Errors include actions or inactions by crew that lead to deviations from organizational or crew expectations, and may include

- aircraft-handling errors, such as incorrect use of automation;
- procedural errors, such as completion of checklists from memory or omission of briefings; or
- communication errors, such as missed callouts or incorrect air traffic control readbacks.

Errors may result from mismanagement of a threat or may occur spontaneously. Effective error management involves both detection and action.

The key principles of TEM are anticipation of, recognition of, and recovery from threats and errors.[59] It advocates carefully analyzing potential hazards and taking appropriate steps to avoid, trap, or mitigate threats and errors before they lead to an undesired aircraft state.

1.18.5.1 Threat and error management training

In 2007, the TSB conducted an investigation[60] into a collision with terrain in Sandy Bay, Saskatchewan. The investigation determined that ineffective CRM had contributed to the accident. The investigation concluded that some operators are unlikely to provide CRM training in the absence of a regulatory requirement to do so, and that some commercial pilots may consequently be unprepared to avoid, trap, or mitigate crew errors encountered during

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58 D. Maurino, "Threat and Error Management," presented at the Canadian Aviation Safety Summit, Vancouver, British Columbia (18 to 20 April 2005).

59 A. Merritt and J. Klinect, "Defensive Flying for Pilots: An Introduction to Threat and Error Management," The University of Texas Human Factors Research Project: The LOSA Collaborative (Austin, TX: 2006), p. 16.

60 TSB Aviation Investigation Report A07C0001.

flight. Given the risks associated with the absence of recent CRM training for CARs subparts 703 (Air Taxi) and 704 (Commuter) crews, the Board recommended that

> the Department of Transport require commercial air operators to provide contemporary crew resource management (CRM) training for *Canadian Aviation Regulations* (CARs) subpart 703 air taxi and CARs subpart 704 commuter pilots.
>
> **TSB Recommendation A09-02**

TC defines contemporary CRM as a method that

> integrates technical skill development with communications and crew coordination training and operational risk management by applying threat and error management (TEM) concept.[61]

In 2011, the TSB conducted an investigation[62] into a controlled flight into terrain in Resolute Bay, Nunavut, involving a Boeing 737. It was determined that during the final approach, the crew's CRM was ineffective. During that investigation, a focus group consisting of TC and industry representatives had already begun work to address TSB Recommendation A09-02. The focus group called for TC to develop regulations and standards for contemporary CRM training[63] for CARs subparts 702 (Aerial Work), 703 (Air Taxi), 704 (Commuter), and 705 (Airline) operators. TC accepted the group's recommendation, but as the details of the updated regulations and standards for CRM training were not yet known at the time of the report's release, the Board issued the following safety concern:

> [T]he Board is concerned that, without a comprehensive and integrated approach to CRM by TC and aviation operators, flight crews may not routinely practise effective CRM.

In its December 2017 response to Recommendation A09-02, TC indicated that new CRM standards would come into effect on 31 January 2019, under subparts 722, 723, 724, and 725 of the *Commercial Air Service Standards* (CASS), and apply to CARs subparts 702 (Aerial Work), 703 (Air Taxi), 704 (Commuter), and 705 (Airline). Under these new standards, air operators are required to provide contemporary CRM training to flight crews, flight attendants, dispatchers/flight followers, ground crew and maintenance personnel, on an initial and annual basis.

These new standards will integrate contemporary CRM by applying threat and error management (TEM) concepts for commercial air operators. In order to validate CRM skills, the new standards also require an assessment for non-technical skills, such as cooperation; leadership and managerial skills; situational awareness; and decision making. The training will provide knowledge and skills that can assist flight crews in recognizing risks, such as those associated with conducting approaches in deteriorating weather conditions.

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61 Transport Canada, Advisory Circular (AC) 700-042, Crew Resources Management (CRM).

62 TSB Aviation Investigation Report A11H0002.

63 Transport Canada, Advisory Circular (AC) 700-042, Crew Resources Management (CRM), (01 January 2019).

The new CRM standards have been published on the Canadian Aviation Regulation Advisory Council (CARAC) Activity Reporting System website. Additionally, TC published Advisory Circular 700-042, which provides guidance to the industry for compliance with the new standards, as well as an article in its Aviation Safety Letter, Issue 4/2017 regarding the need for commercial air operators to prepare for the new CRM standards.

The Board believes that the actions taken by TC will substantially reduce the risk associated with the safety deficiency identified in Recommendation A09-02, once the new CRM standards come into effect.

Therefore, the response to Recommendation A09-02 was assessed as **Fully Satisfactory**.

A review of WestJet's training confirmed that its CRM training syllabus includes the CRM content currently required under CASS subsection 725.124(39). Although WestJet uses the concept of TEM in its simulator training, the theory of TEM provided in the ground training syllabus is limited to a general overview.

1.19 Useful or effective investigation techniques

Not applicable.

2.0 Analysis

2.1 Introduction

The aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures, and no mechanical defects that could have contributed to the occurrence were found. The flight crew were certified and qualified for the flight in accordance with existing regulations, and there were no indications that their performance was in any way degraded as a result of physiological factors, such as fatigue.

In an effort to understand why the aircraft descended too low on the visual approach after MAPON missed approach point (MAP) before conducting a go-around, this analysis will focus on the weather information available and visibility, visual references, aircraft handling, airport lighting systems, and human factors.

On 15 September 2017, the island of St. Martin was severely damaged by Hurricane Irma and communication with the Sint Maarten Civil Aviation Authority (SMCAA) was lost. As a result, some local air traffic control information was not available to the investigation.

2.2 Visibility

Before WestJet flight 2652 (WJA2652) began its descent toward Princess Juliana International Airport (TNCM), the visibility in the vicinity was reported to be unlimited. However, when the aircraft was approximately 15 nautical miles (nm) from the threshold of the runway, the visibility at the airport deteriorated significantly, becoming 2000 m in moderate to heavy rain showers. Automatic terminal information system (ATIS) November had been issued approximately 3 minutes before the crew were cleared for the approach. During this phase of flight, crews are not aware when there is a change of ATIS unless advised of it by the controller.

The minimum visibility required to continue an approach to TNCM beyond the final approach fix is 3600 m. The air traffic controller cleared the flight crew for the RNAV Runway 10 approach when the aircraft was approximately 13 nm from the runway. Just after issuing the approach clearance, the controller advised the crew of the presence of moderate to heavy rain showers at the airport, but did not inform them of the updated visibility. Unaware that the visibility was below that required to conduct the approach, the crew continued the approach toward the runway.

Significant changes in visibility were not communicated to the crew, which allowed them to continue the approach when the visibility was below the minimum required to do so.

2.3 Deviation from approach profile

On final approach, the aircraft was stabilized on a 3° angle of descent and configured for landing. Approximately 0.5 nm before the MAP, the flight crew decided that, given that they had the shoreline in sight and expected to see the runway shortly afterward, they would continue the approach visually. At that point, the aircraft was descending at approximately 820 feet per minute (fpm) and at 159 knots indicated airspeed, with an N_1 of approximately 62%.

The pilot flying (PF) then disconnected the autopilot as per WestJet's approach procedures for landing at TNCM. Shortly afterward, the PF reduced the pitch from 0.5° nose up to 1.2° nose down, which initiated an increase in airspeed. In response to the airspeed increase, the autothrottle command reduced the engine thrust from 62% to 52% N_1 to maintain the 160-knot speed previously set in the flight management computer (FMC). Following the reduction in thrust, the aircraft began to deviate below the 3° angle of descent, at a descent rate of between 1000 and 1150 fpm. Shortly after, the PF cycled the flight directors and started to manually manipulate the thrust as per WestJet's approach procedures for landing at TNCM.

The reduction in the pitch attitude led to an increase in airspeed, which resulted in a reduction in engine thrust and a higher rate of descent than that required by the 3° angle of descent.

2.4 *Acquiring visual references*

During the approach phase of flight, pilots may be prone to visual errors as they switch from scanning the instrument panel within the cockpit to scanning outside the aircraft to acquire visual references. The alternation of attention from one to the other increases their cognitive workload, the demand on their perceptual faculties, and the complexity of their flight-path monitoring tasks, particularly in conditions of reduced visibility. Conditions such as expectation bias and anticipation may also contribute to visual errors.

In this occurrence, the crew of an aircraft that had landed just ahead of WJA2652 had reported seeing the runway upon reaching minima. The crew of WJA2652 were expecting to see the runway shortly after crossing MAPON. The occurrence of a moderate to heavy rain shower, after the aircraft crossed MAPON, led to a significant reduction in visibility. The low-intensity setting of the runway lights and precision approach path indicator (PAPI) lights limited the visual references that were available to the crew to properly identify the runway.

Among the visual references that remained available, the features of a hotel located to the left of the runway, such as its colour, shape, and location, made it more conspicuous than the runway environment and led the crew to misidentify it as the runway. As the crew crossed MAPON, the PF advised that he had the runway in sight. He began to roll the aircraft to the left to align it with what he thought was the runway but what was actually the hotel.

The hotel located to the left of the runway appeared from a distance to be wider at its base and narrower on top than it actually was, causing it to appear similar to a runway. However, as the aircraft approached, it became more apparent that the shape was in fact a building. Those changing geometrics would have differed from what the pilot expected of an actual runway's appearance on approach. Further, rain may have distorted visual references such as the hotel and made the changing geometric shape more difficult to interpret.

The reduced visibility and conspicuity of the runway environment diminished the crew's ability to detect that they had misidentified the runway.

2.4.1 *Airport lighting management*

On the day of the occurrence, the runway lights at TNCM were off and the PAPI lights were at 30%. Realizing that visibility was declining due to moderate to heavy rain showers, the controller turned the runway lights on to an automatic setting for night use. That setting illuminated the runway edge lights to 3%, but reduced the intensity of the PAPI lights to 10%. The low intensity of the runway lights and PAPI lights reduced their effectiveness as a visual reference and limited the likelihood that they would capture the attention of the flight crew in the crew's visual scan.

According to the International Civil Aviation Organization (ICAO) *Procedures for Air Navigation Services: Air Traffic Management* (PANS-ATM), air traffic controllers should be provided with guidance on the adjustment of airport lighting settings to suit prevailing conditions. At TNCM, no guidance is provided for the operation of lighting systems, and the control of light intensity for all conditions is therefore at the controller's discretion.

If the ICAO PANS-ATM are not implemented in the management of aerodrome light intensity, there is a risk that the optimal light intensity settings for prevailing weather conditions will not be selected.

2.5 *Flight path monitoring*

A high visual workload can lead pilots to narrow their visual attention and focus only on those stimuli that they perceive to be most important. This narrowing of attention may influence the way they visually scan their flight instruments, such that critical items may be dropped from their scan. Pilots may also intensify their focus on a specific area where they anticipate a change, which prevents them from fully monitoring all relevant flight instruments and degrades their situational awareness.

The Flight Safety Foundation (FSF) has found inadequate flight path monitoring to be a frequent underlying causal factor in approach-and-landing occurrences, and provides 20 recommendations for improving flight-path monitoring performance in its 2014 publication, *A Practical Guide for Improving Flight Path Monitoring*. The guide states, however, that "regardless of any action taken by any operator, […] elevating the monitoring role on the flight deck is a significant and worthwhile operational challenge."[64]

WestJet provides its crews with guidance on flight path monitoring during all phases of flight and in adverse weather. However, review of WestJet training and operational procedures indicated that only some of the FSF's recommendations are in place.

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64 Flight Safety Foundation, "Failure to Mitigate," *Aero Safety World*, Volume 8, Issue 1 (February 2013), p. viii.

In this occurrence, when the aircraft was on final approach prior to MAPON, a moderate to heavy rain shower ahead and to their left obscured the flight crew's view of the airport environment and reduced their ability to identify the runway. After crossing MAPON, the crew encountered a greater reduction in forward visibility than they had anticipated when the aircraft entered the shower. The resulting increase in the crew's visual workload led them to focus their attention on monitoring for external visual references and prevented them from adequately monitoring the aircraft's altitude.

An increase in visual workload led to inadequate altitude monitoring, which reduced the crew's situational awareness. As a result, the crew did not notice that the aircraft had descended below the normal 3° angle of descent to the runway threshold. The lack of visual texture and other visual cues available over water contributed to the crew's inability to detect the aircraft's reduced height above the water.

2.6 Threat and error management

The practice of threat and error management (TEM) includes preparing and adapting crew action plans following identification of current threats, in order to reduce the risks associated with those threats.

During the visual segment of the aircraft's final approach over the water, the rain reduced the visibility by a greater degree than the crew had anticipated, given that the prior segments of the approach had been conducted in daylight and under conditions of good visibility. The low intensity of the runway edge lights and PAPI lights and the lack of visual cues over water were not identified as threats. Consequently, the crew did not consider the consequences of such threats or take action to mitigate them.

If crews do not identify and manage threats, there is an increased risk of crew errors, which could lead to undesired aircraft states.

2.6.1 Threat and error management training

As detailed in a 2011 TSB investigation report,[65] *Canadian Aviation Regulations* (CARs) Subpart 705 operators are currently required to conduct crew resource management (CRM) training, but the regulations have not kept pace with advances in CRM theory and application, and are now outdated.

Since the Board's issuance of TSB Recommendation A09-02, which calls for provision of contemporary CRM training, and its 2011 safety concern regarding the necessity for a comprehensive and integrated approach to CRM by TC and aviation operators, Transport Canada (TC) has taken steps to address the gaps in the existing regulations. A new Commercial Air Service Standard (CASS), set to replace the current CASS subsection 725.124(39) in January 2019, will require operators under subparts 703 (Air

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65 TSB Aviation Investigation Report A11H0002.

Taxi), 704 (Commuter), and 705 (Airline) to provide contemporary CRM training, which includes training in TEM.

2.7 *Enhanced ground proximity warning system*

Enhanced ground proximity warning systems (EGPWSs) are designed to improve safety by providing alerts to flight crews when the aircraft is in a dangerous situation and corrective action is required. Some alerts require a change in aircraft configuration, while others require a change of flight path.

2.7.1 *Alert response procedures*

The EGPWS alert response procedures of both the aircraft manufacturer and the operator instruct pilots to ensure positive visual verification in the event of an EGPWS alert of "TOO LOW, TERRAIN" during flight under daylight visual meteorological conditions (VMC). This step is intended to limit the number of unnecessary go-arounds resulting from nuisance alerts. However, current EGPWS technology has reduced the incidence of nuisance alerts such that they are now rare and almost always predictable. As a result, the positive visual verification step within the response procedure may no longer be necessary. Further, it is not consistent with the EGPWS manufacturer's procedures, which state that climbing is the only recommended response when receiving an EGPWS alert.

2.7.2 *Alert recovery reaction time*

At 63 feet above ground level (AGL), the flight crew unexpectedly received an EGPWS aural alert of "TOO LOW, TERRAIN," which caused them to readjust their degraded situational awareness. On receipt of the aural alert, the crew carried out a "positive visual verification that no obstacle or terrain hazard exists" (as per both the aircraft manufacturer's and operator's recommendations for EGPWS alert response in daylight VMC), before deciding on a course of action. The PF increased the pitch to 4° nose up; however, as the aircraft continued descending, the crew received a second EGPWS alert when the aircraft was between 54 and 49 feet AGL.

While carrying out the positive visual verification, the crew's ability to evaluate their height above the water was made more challenging by a lack of texture and other visual cues in the external environment, and it took them several seconds to understand that they were indeed too low. They initiated a go-around 9 seconds after the first EGPWS alert, by which time the aircraft had descended to 40 feet above the water. The alert response procedure recommended by the aircraft manufacturer and the operator led to a delayed response to the first EGPWS alert and resulted in the aircraft's descent from 63 to 40 feet AGL before corrective action was taken.

3.0 *Findings*

3.1 *Findings as to causes and contributing factors*

1. Significant changes in visibility were not communicated to the crew, which allowed them to continue the approach when the visibility was below the minimum required to do so.

2. The reduction in the pitch attitude led to an increase in airspeed, which resulted in a reduction in engine thrust and a higher rate of descent than that required by the 3° angle of descent.

3. The occurrence of a moderate to heavy rain shower, after the aircraft crossed the missed approach point, led to a significant reduction in visibility. The low-intensity setting of the runway lights and precision approach path indicator lights limited the visual references that were available to the crew to properly identify the runway.

4. The features of a hotel located to the left of the runway, such as its colour, shape, and location, made it more conspicuous than the runway environment and led the crew to misidentify it as the runway.

5. The reduced visibility and conspicuity of the runway environment diminished the crew's ability to detect that they had misidentified the runway.

6. The lack of visual texture and other visual cues available over water contributed to the crew's inability to detect the aircraft's height above the water.

7. An increase in visual workload led to inadequate altitude monitoring, which reduced the crew's situational awareness. As a result, the crew did not notice that the aircraft had descended below the normal 3° angle of descent to the runway threshold.

3.2 *Findings as to risk*

1. If the International Civil Aviation Organization *Procedures for Air Navigation Services: Air Traffic Management* are not implemented in the management of aerodrome light intensity, there is a risk that the optimal light intensity settings for prevailing weather conditions will not be selected.

2. If crews do not identify and manage threats, there is an increased risk of crew errors, which could lead to undesired aircraft states.

3.3 *Other findings*

1. Because the occurrence was originally assessed by WestJet as a non-reportable event, the cockpit voice recorder and the digital flight data recorder data were overwritten and were not available to the investigation.

2. The enhanced ground proximity warning system (EGPWS) alert response procedures of the aircraft manufacturer and the operator differ from those in the guidance material of the EGPWS manufacturer.

3. The alert response procedure recommended by the aircraft manufacturer and the operator led to a delayed response to the first EGPWS alert and resulted in the aircraft's descent from 63 to 40 feet above ground level before corrective action was taken.

4.0 Safety action

4.1 Safety action taken

4.1.1 WestJet

Following the occurrence, WestJet conducted a company investigation and developed a corrective action plan. The plan included

- a safety communication letter (*Flight Safety Flash*), sent to all pilots, explaining the incident and providing information regarding possible challenges and threats at the Princess Juliana International Airport (TNCM),
- revision of the route and aerodrome qualification document for TNCM,
- provision of a flight safety briefing on the incident to all crews at the annual ground school, and
- design of a new instrument approach at TNCM.

The revised route and aerodrome qualification document for TNCM contained the following additional information:

> - **Extra diligence required in reduced visibility operations.** Build-up of land and buildings North of the runway can cause illusion of false runway, leading to lower approach angle.
>
>   Cross check your visual track against our FMC [flight management computer] to ensure you are lined up with the actual runway.
> - Due to difficulty in acquiring visual confirmation of runway in reduced visibility conditions, it is recommended to consider abandoning the approach if you do not identify the runway ¼ mile back from the MAP [missed approach point].[66]

4.1.1.1 WestJet initiative to design new approach

Following the occurrence, WestJet designed a new area navigation (required navigation performance) (RNAV (RNP)) instrument approach procedure for TNCM that would provide vertical guidance to the threshold of the runway.

The airline submitted its design to the Sint Maarten Civil Aviation Authority (SMCAA) for approval; however, because the island of Saint Martin was severely damaged by Hurricane Irma on 15 September 2017 and communication with the SMCAA was lost, the process is deemed to be on hold for an undetermined period.

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66 WestJet, *Route & Aerodrome Qualification*, Princess Juliana International, Sint Maarten, Netherlands Antilles, TNCM/SXM (03 May 2017), Cautions, p. 1.

4.1.2 *Guidance on airport lighting system management at Princess Juliana International Airport*

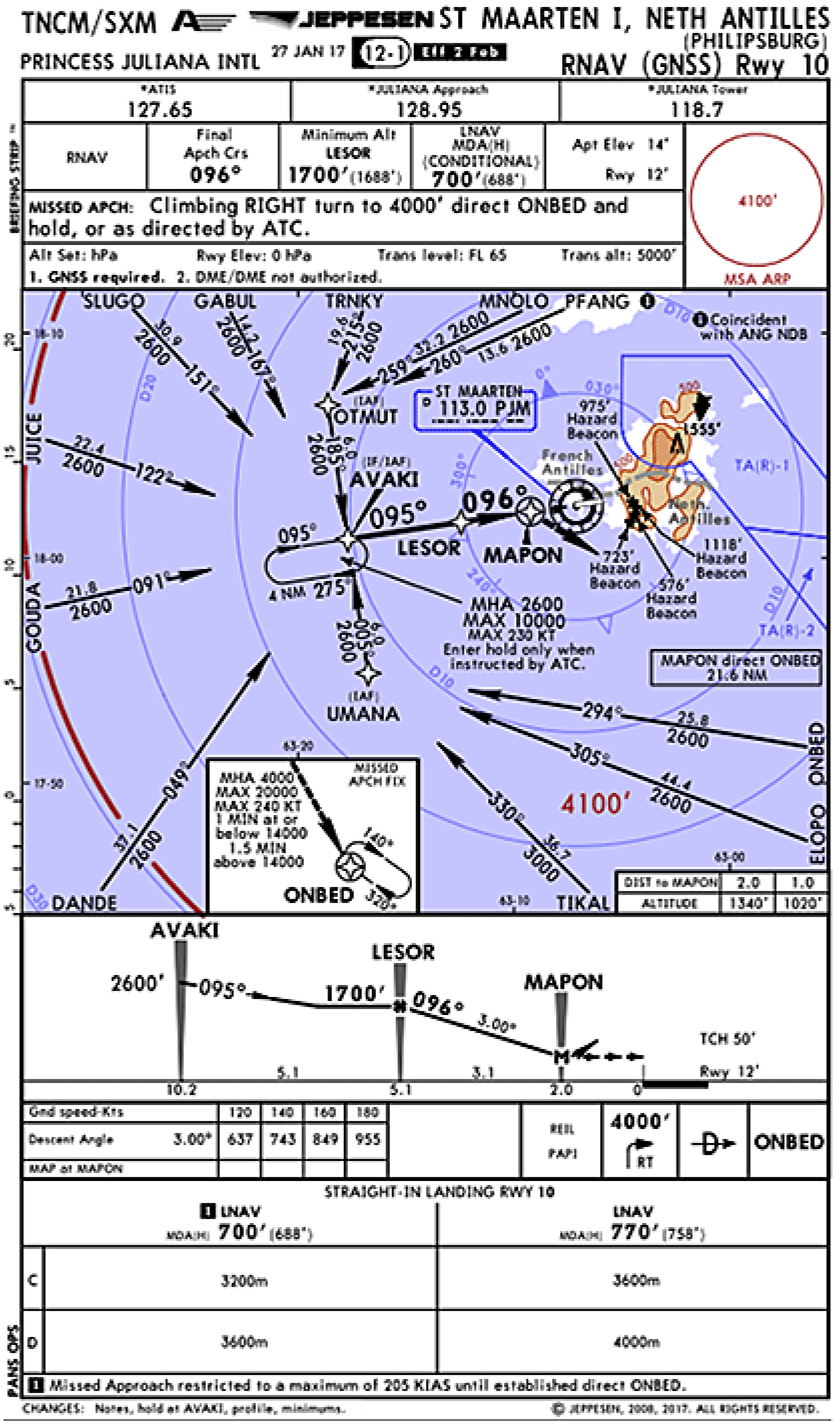
Following the occurrence, the SMCAA instructed the Sint Maarten Air Traffic Services department to include guidance on airport lighting system management in its operations manual. This guidance on airport lighting system management is expected to be added to the operations manual by September 2018.

This report concludes the Transportation Safety Board of Canada's investigation into this occurrence. The Board authorized the release of this report on 25 April 2018. It was officially released on 04 June 2018.

Visit the Transportation Safety Board of Canada's website (www.tsb.gc.ca) for information about the TSB and its products and services. You will also find the Watchlist, which identifies the key safety issues that need to be addressed to make Canada's transportation system even safer. In each case, the TSB has found that actions taken to date are inadequate, and that industry and regulators need to take additional concrete measures to eliminate the risks.

Appendices

Appendix A – Approach chart for Princess Juliana International Airport, Sint Maarten



Source: Jeppesen Sanderson, Inc. Not for navigational use.