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

AVIATION INVESTIGATION REPORT A14Q0155

Runway excursion

Air Canada
Airbus A330-343, C-GFAF
Montréal/Pierre Elliott Trudeau International Airport
Montréal, Quebec
07 October 2014

Canada

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The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

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Summary

On 07 October 2014, the Air Canada Airbus 330-343 (registration C-GFAF, serial number 0277), operating as flight number ACA875, left the Frankfurt-Rhein/Main International Airport in Germany, bound for Montréal/Pierre Elliott Trudeau International Airport, Quebec. During the daylight approach to Runway 24R in the presence of a thunderstorm just north of the airport, the crew was advised that the lighting on Runway 24R was out of service. This was the only runway in operation. During final approach, meteorological conditions changed from visual meteorological conditions to instrument meteorological conditions. On short final, during the approach to Runway 24R, using the instrument landing system, the aircraft entered a heavy rain shower and encountered a right crosswind exceeding 20 knots. The aircraft deviated from its path before touching down to the left of the runway centreline at 1234 Eastern Daylight Time. Following the landing, the left rear tire of the left main landing gear left the hard surface of the runway and travelled approximately 600 feet before regaining the runway. The aircraft returned to the centreline before taxiing to the terminal gate, where the passengers exited. Three runway edge lights were damaged. The aircraft was not damaged and there were no injuries.

Le présent rapport est également disponible en français.

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1.0 Factual information

1.1 History of the flight

The Air Canada Airbus 330-343 (registration C-GFAF, serial number 0277), operating as flight number ACA875, left the Frankfurt-Rhein/Main International Airport in Germany (EDDF), bound for Montréal/Pierre Elliott Trudeau International Airport, Quebec (CYUL). The pilot-in-command, seated in the left-hand seat, was the pilot monitoring (PM). The co-pilot, seated in the right-hand seat, was the pilot flying (PF). The flight was uneventful and on schedule.

At 1143,[1] preparations prior to descent and the approach briefing were completed according to the company's policies and procedures.

At 1207, at approximately 33 000 feet above sea level (asl) during descent, the crew contacted the Montréal Area Control Centre and advised that they had received information Uniform from the automatic terminal information service (ATIS). The ATIS reported visual meteorological conditions (VMC) at the airport and contained no indication of convective weather.

At 1220, at approximately 11 000 feet asl and some 30 nautical miles (nm) from CYUL, ACA875 advised Montréal Terminal that it had received information Victor. This was the first time the flight received weather information indicating the presence of cumulonimbus in the area of CYUL. The aircraft was flying in VMC. Runway 24R was the only runway in operation. No precipitation was reported; the wind was from 200° magnetic (M) at 7 knots, giving an expected 40° left crosswind for landing; there were a few clouds at 2000 feet above ground level (agl), scattered clouds at 4500 feet agl, and broken clouds at 9000 feet agl as well as at 15 000 feet agl, with cumulonimbus embedded in other cloud layers.

At 1227, when the aircraft was at approximately 5000 feet asl and 18 nm from the runway, the crew noted rather dark conditions north of the airport, consistent with the presence of heavy precipitation shown on the aircraft's weather radar. Nonetheless, the crew could see the runway and the airport clearly. The crew conducted an approach using the instrument landing system (ILS) on Runway 24R and anticipated landing in VMC with a light crosswind from the left. During the approach, the pilots monitored the poor weather conditions to the north of the runway and discussed the possibility of encountering precipitation and wind shear, but not the possibility of a go-around. The crew increased the approach speed and confirmed the flap configuration "FLAPS 3"[2] for landing.

At 1232, while the aircraft was at approximately 1900 feet asl and 5.5 nm from the runway, the airport controller advised the crew that the wind was from 280°M at 13 knots gusting to

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1 All times are eastern daylight savings time (Coordinated Universal Time minus 4 hours).

2 Flap settings and leading edge slats were at the appropriate positions for landing in the prevailing conditions.

18 knots. The controller then cleared the aircraft to land. A few seconds later, the controller advised the crew that the runway lighting was out of service. At approximately 1233, as the aircraft descended through 1000 feet agl in the landing configuration, flaps were extended to "FLAPS 3", landing gear was down, and ground spoilers were armed. At approximately 900 feet agl, the autopilot was disconnected.

At 1233:57, as the aircraft was passing through 600 feet agl in a stabilized approach,[3] a de Havilland DHC-8 that had just landed reported light wind shear below 400 feet agl. At 1234:12, at the PM's request, the controller reported that the wind was now from 300°M at 18 knots gusting to 24 knots; he also noted the presence of wind shear below 400 feet agl. The crew observed a rain shower approaching mid-runway, but could clearly see the entire length of the runway; the crew increased the approach speed by 4 knots.

At 0.4 nm from the runway threshold and at approximately 130 feet agl, the aircraft entered rain, and the PF asked that the windshield wipers be turned on at maximum speed. The aircraft then experienced a number of rolling oscillations as it crossed the runway threshold at 50 feet agl, on the centreline, and at 2 knots above the desired approach speed.

At approximately 30 feet agl, the thrust levers were placed in the idle position, and the aircraft entered the low-energy landing regime. The aircraft, which was to the left of the centreline, banked to the left and drifted quickly toward the left edge of the runway.

At this point, the rain reached its maximum intensity, visibility dropped and visual references were degraded. The PF pitched the aircraft nose-up to flare and began a roll to the right reaching an attitude slightly inclined to the right when the wheels first touched down, at 1234:51.

The rear tires[4] of the right main landing gear[5] touched the runway some 1332 feet from the threshold and approximately 57 feet to the left of the centre of the runway, with the left tire of the left landing gear 97 feet from the centre of the runway. The aircraft was at a crab angle of 8° to the right with a drift of 2° to the left.

One second later, before touching down, the rear inboard tire of the left main landing gear[6] clipped the runway edge light located 1538 feet from the threshold. Less than 200 feet further, the left outboard tire of the left landing gear[7] landed on the grass while the inboard tire of the left gear remained on the runway surface. In the moments that followed, the aircraft struck 2 more runway edge lights before returning to the runway.

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[3] In accordance with the company's stabilized approach criteria (see section 1.18.1.7 Visual references required and pull-up or go-around).

[4] No. 7 and No. 8 tires.

[5] Each main landing gear is a 4-wheel, twin tandem bogie assembly (Airbus).

[6] No. 6 tire.

[7] No. 5 tire.

The ground spoilers extended normally, the autobrake engaged, the thrust reversers were deployed then stowed and then fully deployed after the aircraft returned to the centre of the runway. At 1235:02, the nose wheel touched the ground, and the aircraft returned to the centre of the runway 3 seconds later.

Thereafter, the landing roll continued without further incident, and the aircraft taxied to its terminal gate. The crew only realized that the aircraft had veered off the runway after being advised by the maintenance crew.

The outboard tires of the left bogie travelled over the grass for 2.3 seconds, over a distance of 507 feet.

1.2 Injuries to persons

None (Table 1).

Table 1. Injuries to persons

	Crew	Passengers	Children	Infants	Total
Fatal	–	–	–	–	–
Serious	–	–	–	–	–
Minor	–	–	–	–	–
None	9	205	2	1	217
Total	9	205	2	1	217

1.3 Damage to aircraft

The aircraft was not damaged. The left main landing gear sprayed mud onto the left side of the fuselage during the runway excursion. The rear tires of the left main landing gear (No. 5 and No. 6 tires) were replaced due to lacerations incurred when they struck the runway edge lights.

1.4 Other damage

The aircraft damaged 3 Runway 24R edge lights located on the left side of the runway, between 1500 and 2300 feet from the threshold.

1.5 Pilot information

Records indicate that the pilots were certified and qualified for the flight in accordance with existing regulations (Table 2).

Table 2. Flight crew information

	Pilot-in-command	Co-pilot
Pilot licence	ATPL (airline transport pilot licence)	ATPL (airline transport pilot licence)
Medical expiry date	01 December 2014	19 March 2015
Total flying hours	17 259	8262
Flight hours on A330	427*	628**
Flight hours on Airbus-type aircraft	8524	N/A
Hours on A330 in preceding 30 days	65	37
Hours on A330 in preceding 90 days	216	121
Hours on duty prior to the occurrence	9.5	9.5
Hours off duty prior to work period	21.5	21.5

* As pilot-in-command
** As co-pilot

The 2 pilots, based in Toronto, Ontario, arrived in Montréal on 05 October at approximately 1700 for a return flight between CYUL-EDDF. During the occurrence flight, the 2 pilots took a controlled rest on the flight deck. The pilot-in-command took 2 rest periods of 25 and 30 minutes respectively, 5 hours and 2 hours before arrival. The co-pilot took a rest period of 45 minutes, 4 hours before arrival.

The sleep-wake history of the pilots was analyzed to determine whether fatigue might have diminished their performance and played a role in the incident. The following 6 factors were examined:

- acute sleep disturbance;
- chronic sleep disturbance;
- prolonged wakefulness;
- circadian rhythm effects;
- sleep disorders and medical or psychological conditions;
- illness or medication.

Analysis of these factors concluded that the pilots were not fatigued at the time of the occurrence.

1.6 *Aircraft information*

1.6.1 *General*

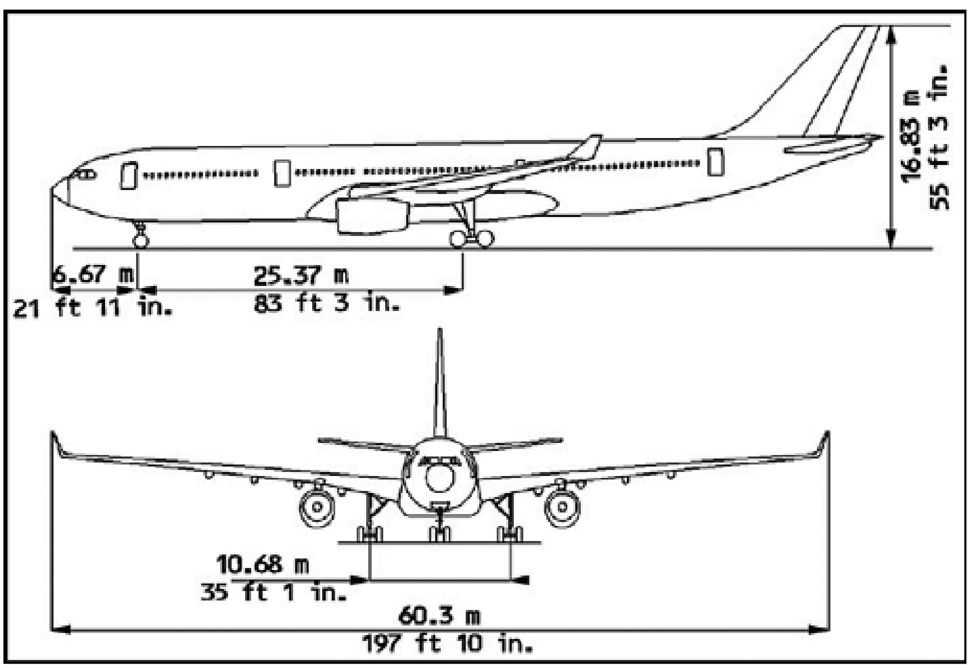
Table 3. Aircraft information

Manufacturer	Airbus Industries
Type and model*	A330-343
Year of manufacture	1999
Serial number	0277
Certificate of airworthiness	13 January 2000
Total flying hours/airframe cycles	66 423 hours/10 482 cycles
Engine type (number of)	Rolls Royce-UK, RB211 Trent 772B-60 (2)
Maximum authorized take-off weight	230 000 kg
Recommended fuel type(s)	Jet A, Jet A-1, Jet B, JP 4, JP 5, JP 8, No.3 Jet, and TS-1.
Type of fuel used	Jet A-1

* The primary reference for the type and model is the type specification; a secondary reference would be International Civil Aviation Organization Document 8643/22.

The maintenance records show that the aircraft (Table 3; Figure 1) was certified, equipped, and maintained in accordance with existing regulations and approved procedures. No messages from any system that might have contributed to the occurrence were recorded by the aircraft's central maintenance computer.

Figure 1. Dimensions of the A330 (Source: Air Canada)



1.6.2 Landing gear and tires

Figure 2. Numbering of the main landing gear tires on the A330 (Source: Ryser Urs, with TSB annotations)

The landing gear on the A330 is made up of 1 nose gear with 2 wheels, and 2 main landing gear assemblies with 4 wheels each in a double tandem configuration. In flight, the bogies are inclined such that the back tires touch the runway first. The wheels are numbered 1 to 8, from left to right, starting from the front (Figure 2).

The tires were examined and the pressure measured shortly after the incident. The condition of the tires and treads as well as the inflation pressure of the tires complied with the manufacturer's instructions.

The right front tire of the right landing gear (No. 4 tire) showed signs of devulcanization. The No. 6 tire showed surface gouges and had glass embedded.

1.6.2.1 Brake warning message

While C-GFAF was taxiing at EDDF, the electronic centralized aircraft monitor (ECAM) generated a fault message "BRAKES SYS 1 FAULT." The crew performed the appropriate procedures, and the flight continued without another brake message.

1.6.3 Weight and balance

C-GFAF landed with 5700 kg of fuel[8] and a landing weight of 166 800 kg. The weight and centre of gravity were within prescribed limits. The aircraft had sufficient fuel to proceed to the alternate airport and to hold for 30 minutes, and had an additional fuel reserve of 1800 kg, i.e. approximately 19 minutes of flight.

1.6.4 Aircraft communications, addressing and reporting system

Air Canada aircraft are equipped with an aircraft communications addressing and reporting system (ACARS) that transmits and receives messages via data link. These messages are sent by very high frequency (VHF) radio or by satellite, depending on the aircraft's location and its equipment. ATIS information can be requested from the "PRE-FLIGHT," "ENROUTE" or "REQUEST" pages of the ACARS. Various types of ATIS messages can be requested, such as departure, cruise flight or arrival messages. In the case of an arrival ATIS request, it is possible to select an additional option that provides an automatic update each time a new ATIS is issued. However, depending on the location of the aircraft, there can be a time delay before this information reaches the aircraft. The ATIS data transmitted to Air Canada crews via the ACARS is provided by a third-party supplier. During the critical phases of the flight, such as while the aircraft is on final approach, it is possible that the crew will not retrieve these messages.

1.6.5 Rain removal system

1.6.5.1 Windshield wipers

The Airbus A330 is equipped with 2 systems to assist in clearing rain from the windshield: windshield wipers and a rain repellent system. The windshield wipers have 2 settings, slow and fast.

1.6.5.2 Rain repellent system

The rain repellent system is designed for use in moderate to heavy rain. When either the pilot-in-command's or co-pilot's rain repellent button is pushed down, a measured amount of repellent is applied to that side of the windshield. The system distributes a predetermined amount of rain repellent, which is spread evenly over the external surface of the windshield.

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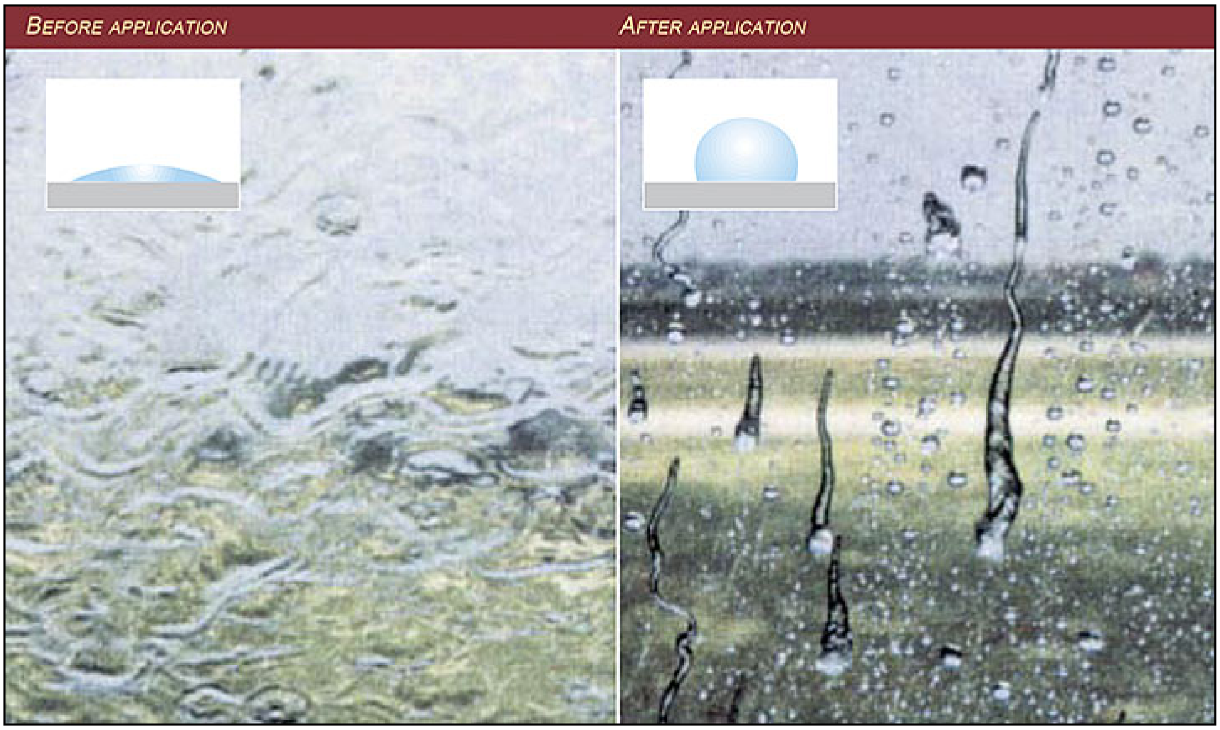
[8] Enough fuel for approximately 1 hour 4 minutes of flight at low power.

Figure 3. Illustration of the general effects of rain repellent at point of contact between drops of water and windshield. (Source: Airbus Industries Inc.)



The rain repellent acts quickly and for an extended period without leaving residue or creating distortion, and restores visibility within a few seconds. The surface tension of the windshield, which is temporarily altered, coupled with airflow, prevents drops of water from adhering to the windshield (Figure 3).

In January 1996, the production, import, and export of the original rain repellent were prohibited for environmental protection reasons. In 1998, a substitute liquid that complied with existing environmental regulations was made available to the aviation industry. Only a minor modification to existing rain repellent systems was required to allow use of the new repellent.

Air Canada had decided not to activate the rain repellent systems on its Airbus fleet.

1.6.5.3 Hydrophobic coatings

For operators who wish to leave the rain repellent system deactivated, Airbus has formally approved the use of a hydrophobic coating developed by a third-party supplier for all its aircraft types. The coating provides protection characteristics similar to those of the liquid repellent. The *Airbus Service Information Letter 30 024*, published in July 1997, provides information on the procurement and coating as well as recommendations regarding its application and maintenance. Like many other carriers, Air Canada has not equipped its aircraft with a hydrophobic coating.

1.6.6 *Wind shear alert system*

One of the functions performed by the "flight envelope" (FE) portion of the flight management and guidance system (FMGS), is to detect wind shear (reactive system). Visual and aural warnings of wind shear are generated when the aircraft encounters wind shear conditions, and when the energy level of the aircraft is expected to drop below a predetermined safe threshold based on the angle of attack.[9] The system is active when the flap lever is selected to position 1 or higher and:

- on takeoff, 3 seconds after takeoff up to 1300 feet agl;
- on landing, from 1300 feet agl to 50 feet agl.

The "Doppler" function of the weather radar is capable of detecting areas where there is a potential for wind shear (predictor system). This wind shear predictor system gives approximately 1 minute of advance warning, and generates visual and aural warnings that are different from the reactive warnings.

No wind shear warning was generated during this occurrence.

1.6.7 *Fly-by-wire flight control system*

Pilots use a side stick controller to control the longitudinal and lateral axes of the aircraft. Deflections of the side stick controller are interpreted by the flight control computer (FCC). Normally, the FCC operates according to Flight Control Normal Law. Based on the motion of the side stick controller, the FCC controls the deflections of the flight surfaces required to obtain the rate of change of attitude or bank.

Flight Control Normal Law provides roll stabilization, such that when the wings are level, if a gust results in a bank, the FCC transmits a signal to the flight surfaces to bring the wings back to level. The FCC correction time may take longer than manual corrections performed by the pilot using the side stick controller to achieve the same result.[10]

When the aircraft is on final approach near the ground, it is normal for the pilot to make immediate corrections using the side stick controller[11] without waiting for the FCC correction.

It is possible for the pilot's corrections to combine momentarily with those of the FCC, resulting in a faster rate of banking than anticipated. If the pilot shifts the side stick controller strongly in the opposite direction, a pilot-induced oscillation (PIO) may result. Furthermore, the ergonomic design of the side stick controller is such that maximum deflection can be reached easily and quickly.

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9 Angle formed between the wing and relative wind.

10 Government of the United Kingdom, Air Accidents Investigation Branch (AAIB), Bulletin No. 3/2003, Ref: EW/C2001/2/3, p. 5.

11 The side stick controller deflections are not visible to the pilot monitoring.

1.6.8 Autopilot and auto-land

The A330 is equipped with a flight guidance system that includes an auto-land mode. However, the weather conditions that prevailed did not meet the criteria set by Air Canada to perform this type of landing in a Category I operation.[12]

1.6.9 Landing performance on a contaminated runway

The total braking force on a wet runway is approximately 70% of what it would be on a dry runway.[13] However, during hydroplaning, the tires lose their grip on the runway surface. As a result, the distance required to stop the aircraft cannot be calculated precisely. It is nonetheless estimated that the increase in stopping distance can be up to 70%. Furthermore, in such conditions, a crosswind of 10 knots can cause an aircraft to veer off the runway in approximately 7 seconds.[14]

1.6.10 Go-around

The go-around mode is activated when the thrust levers are moved fully forward, at take-off and go-around (TOGA) detent.[15] The engines then take some time to spool up to go-around thrust. As a result, the pilot must be aware that during final approach, the aircraft will lose altitude during the go-around. The loss of altitude will be greater if the initial engine thrust was at idle power.[16]

The loss of altitude is approximately 10 feet when the thrust is stabilized, but can reach 40 feet when the thrust is at idle power (Figure 4). According to Airbus, it may take up to 6 seconds before a positive rate of climb is achieved. The Airbus data is consistent with information gathered during simulator tests performed by the TSB (see section 1.17.2 Simulator session).

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12 "A precision instrument approach and landing with a decision height not lower than 200 feet (60 m) and with either a visibility of not less than ½ statute mile (800 m) or a runway visual range of not less than 2600 feet (800 m)." Transport Canada, TP1490 — *Manual of All Weather Operations (CATEGORIES II AND III)*.

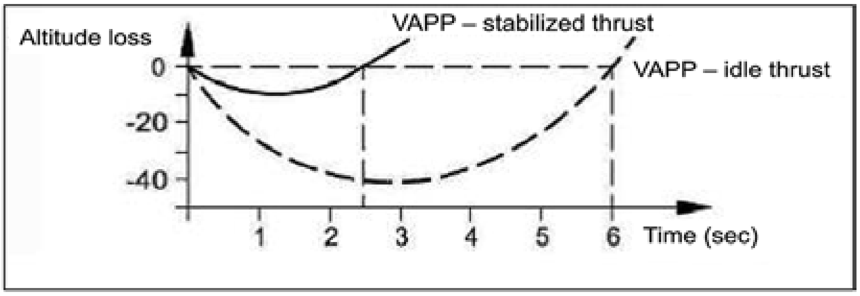
13 Air Canada, A330 Aircraft Operating Manual, Contribution of stopping forces to stopping performance, section 1.06.60, p. 2.

14 *Ibid.*, p. 1.

15 Provided the flap handle is set to 1 or higher.

16 Airbus Flight Crew Training Manual, No-180, AP/FD Go-Around Phase Activation, p. 2/4.

Figure 4. Loss of altitude following a go-around (Source: Airbus Flight Crew Training Manual No. 180)



According to Airbus, a go-around can be executed safely before the thrust reversers are deployed. If the aircraft is in low-energy landing regime at the time of the go-around, the aircraft configuration should be maintained, and the flare procedure must be continued until the acceleration of the engines is sufficient to cause the aircraft to accelerate, before the crew pitches up the aircraft based on the flight director command bars. The wheels will likely contact the runway, and any attempt to initiate a vertical climb before the engines have reached go-around thrust could lead to a stall.

1.7 Weather information

The weather conditions in the CYUL area on the day of the incident were analyzed in detail by the Meteorological Service of Canada.[17]

> [translation] A large near-stationary low-pressure system was centred over northwestern Ontario. A trough extended from the southern Ontario low-pressure system at [0200] on 07 October. At [0800], this barometric trough had already moved well to the north of Montréal. Behind the trough, a mass of slightly unstable air arrived from the southwest.

The first observation mentioning cumulonimbus embedded in other cloud layers was issued at 1200. At 1223, thunder associated with the thunderstorm was heard. At 1230, the thunderstorm, accompanied by rain, reduced predominant visibility to 2 statute miles (sm), while in the eastern and southern sectors, visibility was still approximately 8 sm. At 1236, gusts peaking at 27 knots from the west were accompanied by visibility reduced to 3 sm in the thunderstorm accompanied by rain; the temperature suddenly plunged by approximately 4°C.

1.7.1 Flight in the vicinity of thunderstorm conditions

The hazards generated by thunderstorms are well known in the aviation industry. Crews who fly near a thunderstorm can expect to encounter the following conditions: erratic wind and gusts, squalls (violent wind blasts), turbulence, extremely violent rain, low visibility, hail, and lightning. Furthermore, there is no correlation between the appearance of a thunderstorm and the intensity of its events.

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17 Environment Canada, Meteorological Service of Canada, Weather and Environmental Prediction and Services Directorate, Weather Analysis: 07 October 2014, Montréal, QC (29 October 2014).

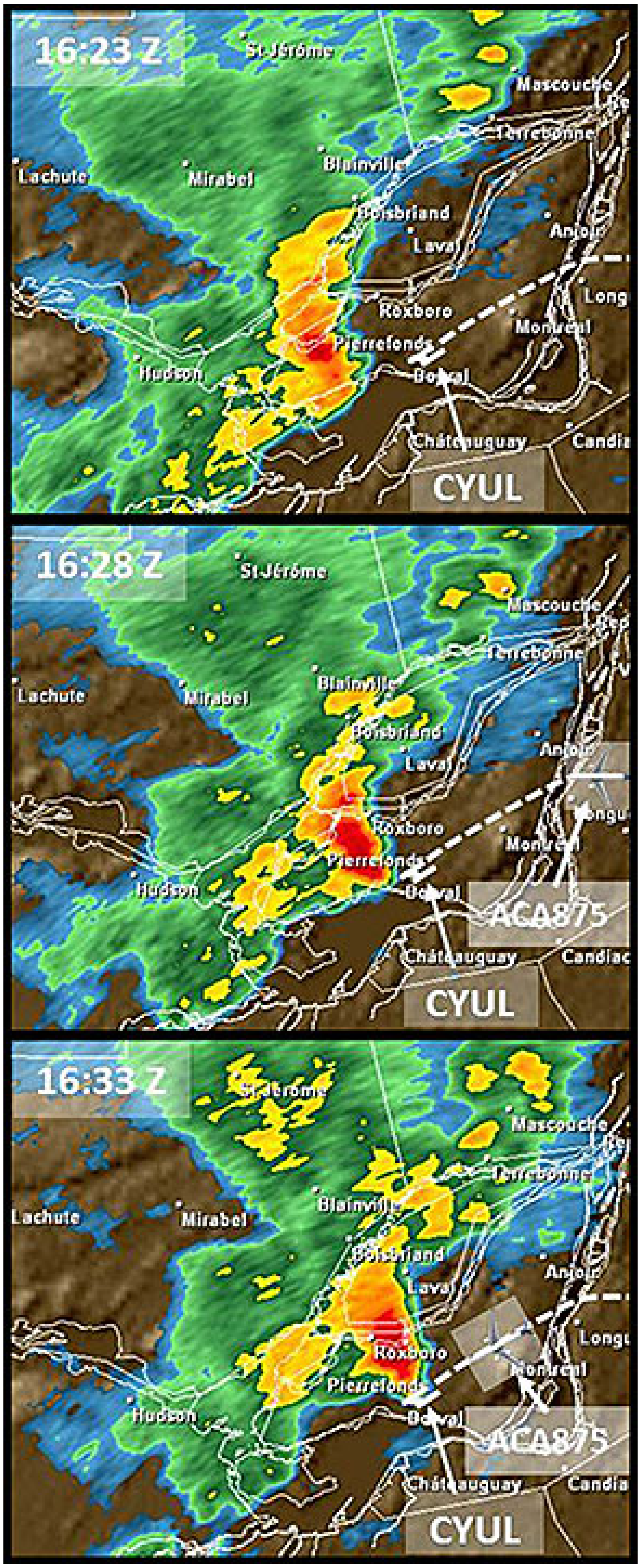
None of the flight crews that had landed earlier had refused to land on Runway 24R due to the proximity of the thunderstorm. However, 2 aircraft that followed ACA875 performed a missed approach due to the deterioration in meteorological conditions at the airport.

Analysis of the radar images and the data provided by the airport rain gauge during the few minutes of the thunderstorm passage suggest that the precipitation rate at the time of the event was nearly 10 mm per hour at the northern end of Runway 24R, causing reduced visibility.

Although the rain gauge located near the centre of the airport accumulated only 0.6 mm of rain between 1200 and 1300, McGill radar images show that at the threshold of Runway 24R, the intensity of precipitation was approximately 10 mm per hour. Furthermore, the radar image at 1234:41 showed that approximately 1 nm to the north of the runway, the intensity of precipitation reached up to 75 mm per hour (Appendix A). During the thunderstorm, visibility was reduced due to the increased intensity of precipitation north of the airport.

The strong precipitation to the north of the runway, the temporary drop in ground temperature, and the change in wind direction and strength all tend to confirm the presence of a downburst to the north of the runway at the time ACA875 was landing (Figure 5).

Figure 5. Movement of the thunderstorm shown on the Burlington Radar (Source: Environment Canada, with TSB annotations)



Based on the surface weather observations at the airports, upper air soundings, and satellite and radar images, the following may be concluded:

- A thunderstorm from the southwest of Montréal Island moved to just north of CYUL while intensifying between 1200 and 1300.
- The strong precipitation associated with the thunderstorm led to downbursts of wind that reached the ground, resulting in the strong gusts observed in the western sector.
- At 1234, the thunderstorm was located approximately 1 nm north of Runway 24R.

1.7.2 Downbursts

A downburst (Figure 6) is a "concentrated, severe downdraft which accompanies a descending column of precipitation underneath [a thunderstorm] cell."[18] A microburst is a type of downburst. Less than 4 km in diameter, it is of shorter duration, but often of greater intensity than a downburst. "A rapid drop in temperature and a sharp rise in pressure characterize this horizontal flow of gusty surface winds."[19]

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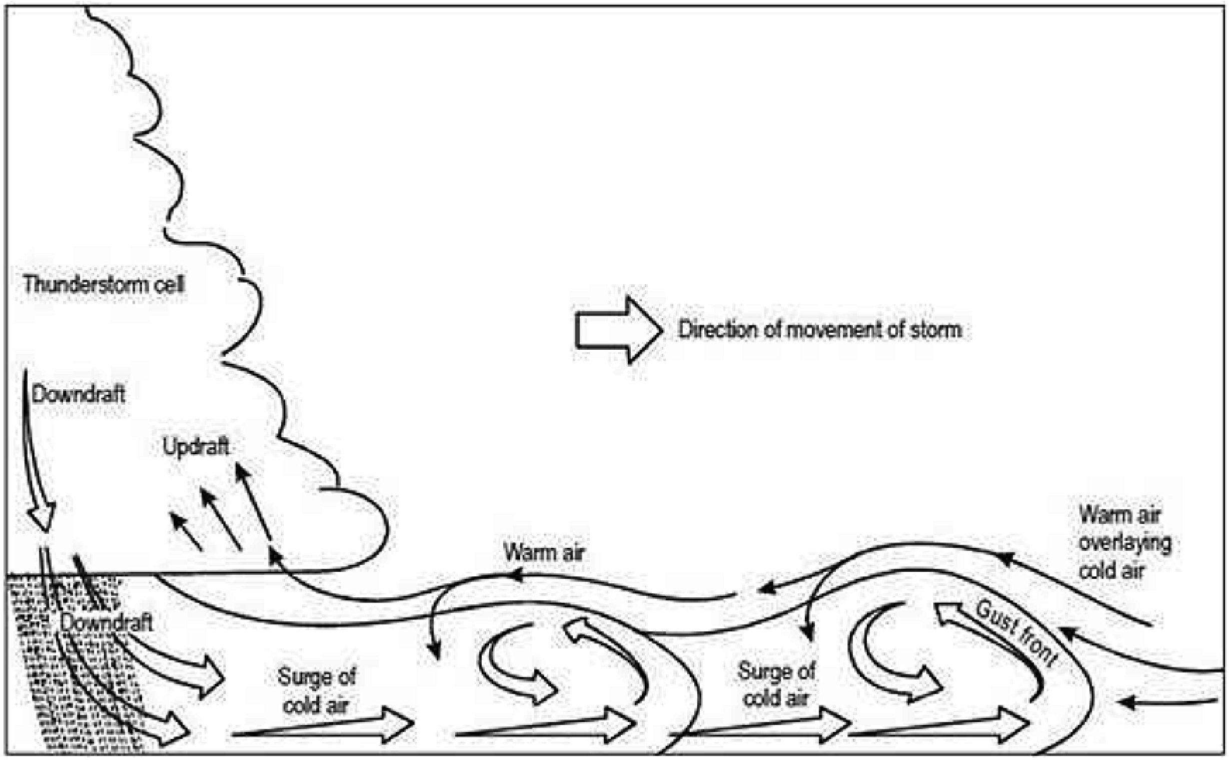
18 NAV CANADA, Chapter 2, Aviation Weather Hazards, p. 40, available at http://www.navcanada.ca/EN/media/Publications/Local%20Area%20Weather%20Manuals/LAWM-Atlantic-2-EN.pdf (last accessed on 20 March 2017).

19 *Ibid.* p. 36.

Figure 6. Downburst of wind (Source: International Civil Aviation Organization; illustration with offset tracks)



1.7.3 *Low-level wind shear*

"The downdraft, when it hits the ground, spreads out in all directions."[20] A downburst that is displaced in relation to the flight path can produce lateral wind shear strong enough to move aircraft of all sizes.

1.7.4 *Aerodrome forecasts*

The CYUL aerodrome forecast (TAF) received by the flight crew before departure from EDDF indicated VMC at the time of arrival in Montréal (Appendix B).

Subsequently, the crew obtained updated CYUL TAFs during the flight at 0550 (0438 TAF), at 0734 (0438 TAF), 0802 (0738 TAF), and 1122 (1119 TAF).

The amended 1119 TAF was the first aerodrome forecast that reported the presence of thunderstorms at CYUL. Between 1300 and 1400, i.e. approximately 30 minutes after the estimated landing time, the TAF forecast the temporary presence of the following conditions: prevailing visibility of 2 sm with thunderstorms, rain, and haze, and an overcast layer of cumulonimbus clouds at 4000 feet agl. According to the ACARS transmission log, the TAF was received at 1122, and this was the last aerodrome forecast that the crew received.

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20 *Ibid.* p. 36.

The TAF for Montréal International (Mirabel) Airport (CYMX), the flight's alternate airport, was also transmitted at 1122, and indicated instrument meteorological conditions (IMC) and thunderstorms between 1200 and 1300.

The crew did not receive the CYUL TAF issued at 1226, immediately before the aircraft landed.

1.7.5 Aviation routine weather reports

In its pre-flight weather information package, the ACA875 flight crew had received aerodrome routine meteorological reports (METAR) for CYUL. No thunderstorm activity was mentioned; VMC prevailed at CYUL during the approach.

Actual meteorological conditions in Montréal on 07 October reflected changeable conditions, and numerous aerodrome special meteorological reports (SPECI) were published in addition to hourly reports (METAR). They include the list of meteorological observations published in the hours preceding this occurrence (Appendix B).

1.7.6 Significant meteorological messages

A significant meteorological information (SIGMET) message to warn pilots of the presence of thunderstorms in the Montréal flight information region (FIR) was issued some 3 hours and 30 minutes before ACA875's arrival. SIGMET J1, valid from 0855 to 1255, indicated frequent thunderstorms located approximately 90 nm west of Montréal moving at a speed of 30 knots in a north-easterly direction while weakening. SIGMET J2, valid from 1015 to 1255, cancelled SIGMET J1.

1.7.7 Messages from the automatic terminal information service

At 1207, at approximately 33 000 feet asl while descending, the crew contacted the Montréal Area Control Centre and advised that they had received the ATIS information Uniform. At 1220, at approximately 11 000 feet asl and some 30 nm from its destination, ACA875 advised Montréal Terminal that it had received information Victor. Two more ATIS messages were issued after Victor and before the aircraft landed. The investigation could not determine whether these messages were received in the aircraft. However, as the aircraft was on final approach, the crew could observe the weather conditions directly through the front windshield. (Appendix B reports the development of the weather conditions indicated in the ATIS messages).

1.7.8 Weather conditions on the ground

Airport surveillance cameras showed the weather conditions over Runway 24R. A camera located at Gate 61 recorded part of ACA875's landing. However, the poor quality of the video recording did not allow examination of the aircraft in detail, nor was it tracking the flight at the time its wheels touched down. The video shows a heavy rain shower accompanied by wind gusts moving quickly from the northwest of the runway toward the southeast.

Figure 7 shows the weather conditions at 1232:23, i.e. 2.5 minutes before the landing; Figure 8 shows the weather conditions at 1233:56, i.e. 1 minute before the landing. The rain shower can be observed to have moved toward the threshold of the runway. Figure 9 shows the weather conditions at the time of the landing. Note that the aircraft is creating a plume of water during the landing roll.

Figure 7. Weather conditions over Runway 24R at 1232:23 (Source: Aéroports de Montréal)

Figure 8. Weather conditions over Runway 24R at 1233:56 (Source: Aéroports de Montréal)

Note that at the time of the landing, the shower was passing the threshold of Runway 24R. Also note that the aircraft tires and possibly reverse thrust are spraying a significant plume of water behind the aircraft, indicating the presence of water on the runway.

Figure 9. Weather conditions over Runway 24R (at the time of the landing; 12:35) (Source: Aéroports de Montréal with TSB annotations)

1.7.9 *Meteorological information provided by the control tower*

The control tower provided the following weather information:

Table 4. Update of weather conditions from the control tower

Time	Wind	Range	Altitude	Description
1232	280/13G18	6 nm	1900 feet agl	Cleared to land*
1234	300/18G24	1.5 nm	500 feet agl	Wind shear advisory

* First indication of wind from the right of the runway centreline.

The control tower obtains information regarding winds from the operational information display system. Only the average wind for the preceding 2 minutes is displayed. Therefore, information regarding wind issued by the air traffic control (ATC) tower is the average wind during the preceding 2 minutes.[21] The controller does not have access to real-time wind data. Furthermore, the Runway 24R windsock is not visible from the control tower.

1.8 *Flight path and update of meteorological conditions*

At 1223 and 1230 respectively, the ATIS Whiskey and ATIS X-ray messages reported a thunderstorm (these messages were not received (Figure 10).

On five occasions between 1223 and 1232, the crew commented on the poor weather conditions observed just northwest of the airport.

ATC cleared ACA875 for landing at 1232:30, and then, 27 seconds later, advised the crew that the runway lighting on Runway 24R was out of service.

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21 Transport Canada, TP14371, *Aeronautical Information Manual* (AIM), MET – METEOROLOGY, section 1.1.5 Weather Observing Systems and Procedures at Major Aerodromes, p. 122.

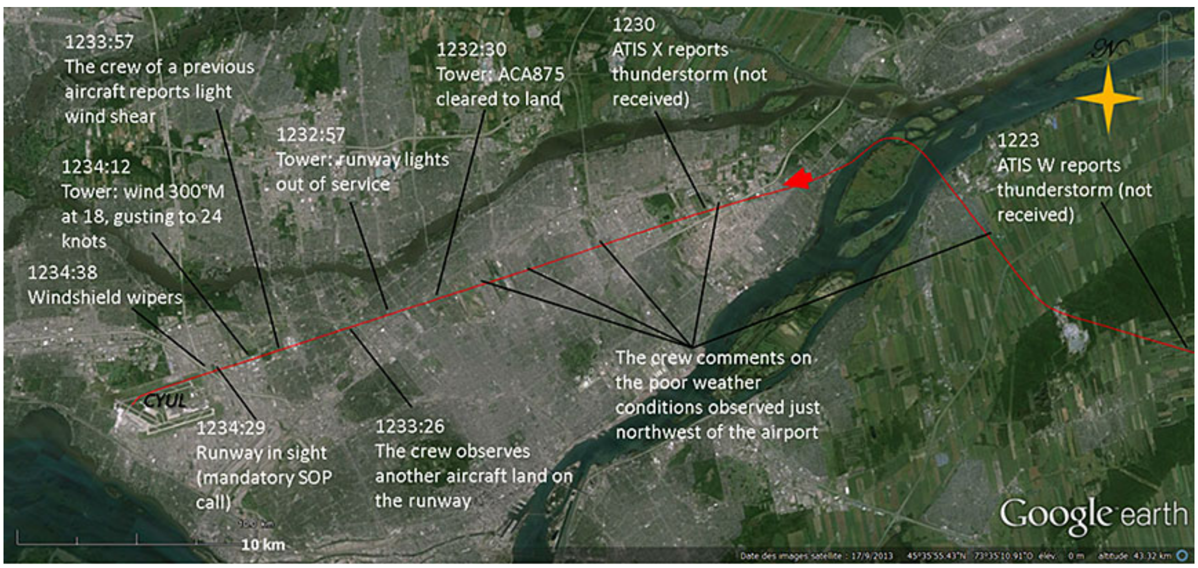
At 1233:26, the crew observed another aircraft on the runway. At 1233:57, a de Havilland DHC-8 that had just landed reported light wind shear.

At 1234:12, the controller reported that the wind was now from 300°M at 18 knots gusting to 24 knots.

At 1234:29, the aircraft called "Runway in Sight", which is a mandatory call according to the standard operating procedure (SOP).

At 1234:38, the windshield wipers were turned on.

Figure 10. Aircraft flight path on approach to Montréal/Pierre Elliot Trudeau International Airport in relation to the available weather information (Source: Google Earth, with TSB annotations)



1.9 Aids to navigation

ACA875 conducted an ILS approach to Runway 24R at CYUL, and the ILS was operating normally at the time of the approach and landing. However, due to the outage of the runway and approach lighting systems, the decision height (DH) was increased by 50 feet and minimum visibility increased by ¼ sm over the published approach minimums.

1.10 Communications

At several points during the flight, the crew communicated with the airline's dispatch centre via ACARS, and these communications indicated nothing abnormal. However, the crew did not receive the messages providing the option to change the alternate airport to Ottawa Macdonald-Cartier International Airport, Ottawa, Ontario (CYOW).

During the flight, the weather conditions in the Montréal area were deteriorating and the forecast was calling for thunderstorms. At 1119, the CYUL and CYMX TAFs were modified to include thunderstorms at the alternate airport (CYMX) between 1200 and 1300, i.e., at the flight's estimated time of landing at destination.

According to the ACARS log, the modified TAFs were sent to and received by ACA875 at 1121. Six minutes later, the flight dispatcher sent an ACARS message that contained the CYOW TAF, the preferred route, the flight time (25 minutes) and the fuel required (2300 kg) for information purposes, in case CYMX became unavailable due to the thunderstorms that were forecast.[22] However, the crew did not receive the message because of an ACARS ground-to-air data link failure. The data link was likely lost because the aircraft was flying through an area where VHF data link is not reliable. After the first failure, the request was put in a queue to be sent automatically. After 3 failed attempts, the system generated a warning message, which the flight dispatcher did not notice. The system design requires that the flight dispatcher first notice the warning message, and then manually open the message that says, "FAILED DELIVER-EXPIRY OF MESSAGE ASSURANCE TIMER" along with the aircraft number. The system does not provide any information on which message was not delivered. The flight dispatcher must then use different software to identify which message is missing.

ATC services during approach and landing were provided by NAV CANADA, in accordance with the policies and directives in the Air Traffic Control Manual of Operations (ATC MANOPS). The controller at CYUL provided wind information. He also advised the crew of the presence of wind shear, which had been reported by the flight that preceded them, and reminded them that the Runway 24R lighting was out of service. Communications recorded between the crew and ATC units indicated nothing unusual.

1.11 Aerodrome information

Aéroports de Montréal (ADM), a not-for-profit corporation, operates CYUL in accordance with the standards stipulated in Transport Canada (TC) document TP312.[23]

CYUL has 2 parallel runways (Runways 06L/24R and 06R/24L), a crossing runway (Runway 10/28), numerous taxiways, and several aprons. At the time of the occurrence, Runway 24R was the only runway in operation; the other 2 runways, i.e. Runway 06R/24L and Runway 10/28 were closed. Runway 24R is 11 000 feet long and 200 feet wide.

Runway 24L was closed due to the presence of a crane near the runway threshold. Following the occurrence, Runway 24R was closed temporarily, and Runway 24L was returned to service after the mast of the crane was lowered.

1.11.1 Runway 24R lighting and marking

Runway lighting systems enable pilots to locate the runway during landing, to touch down in the right place, to maintain the aircraft on the runway centreline, and to evaluate the distance to the end of the runway.

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22 ACA875 was carrying nearly 1000 kg more fuel than that required to divert to Ottawa.

23 Transport Canada, TP312, *Aerodrome Standards and Recommended Practices,* 4th edition (March 1993).

The runway lighting system of Runway 24R includes high-intensity approach lighting, runway threshold lights, runway edge lights, runway end lights, and centreline lights, as follows:

- The approach lights are white, arranged in a line and flash in sequence to indicate to approaching aircraft the direction of and their proximity to the runway.
- The runway threshold lights are green, recessed, and arranged in a line perpendicular to the centreline; they indicate the threshold of the runway.
- The runway centreline lights are recessed and arranged in a line; they indicate the centreline of the runway.
- The runway edge lights are above-ground, white, and arranged along the length of the runway; they indicate the runway edges.

At the time of the occurrence, 2 notices to airmen (NOTAMs) regarding the runway lighting on Runway 24R had been issued by the airport authority. The first NOTAM, regarding the runway edge lights and lights on all taxiways leading to the runway, indicated that they had been out of service since 23 September 2014. The second NOTAM indicated that the approach lighting, runway threshold lights, runway end lights, and centreline lights were out of service between 0730 and 1730. In light of these NOTAMs, a third NOTAM indicated that the approach minimums had been increased (the DH increased by 50 feet and the minimum visibility increased by ¼ mile). The crew received these NOTAM during flight planning. During final approach, the airport controller also advised ACA875 that the runway lighting was not available.

Runway 24R has white runway markings for instrument approaches. Runway 24R has the following markings:

- threshold markings – a series of vertical bars marking the threshold;
- runway designation markings, in the form of a runway number;
- touchdown zone marking, in the form of an array of repeating vertical bars on either side of the centreline, every 500 feet over the first 3000 feet of the runway;
- aiming point markings 1500 feet from the runway threshold; and
- centreline markings – a broken line indicating the centre of the runway.

1.11.2 Standards for operation and control of aerodrome lighting systems

TP312 serves as a reference for aerodrome specifications, including runway lighting. It contains the standards that have to be consistently applied by all airport operators for the safety or regularity of air navigation.

Section 8.5 of TP312[24] stipulates that aerodrome runway lighting must, among other things, be used according to the following standards:

> **8.5.1.6 Standard**.—Approach lighting shall be operated at night or in daytime IMC conditions for an arriving aircraft;

[24] *Ibid.*, Operation and Control of Aerodrome Lighting Systems.

a) for not less than 5 minutes prior to the ETA [estimated time of arrival] of the aircraft; and

b) until the aircraft has landed.

8.5.1.7 Standard.—Runway identification lights shall be operated for an arriving aircraft when;

a) the visibility is 5 miles or less; or

b) the ceiling is 1000 ft or less.

8.5.1.8 Standard.—Runway edge, runway centreline and touchdown zone lighting shall be operated at night or in daytime IMC condition for an arriving aircraft:

a) for not less than 5 minutes prior to the ETA of the aircraft; and

b) until the aircraft has taxied clear of the runway.

1.11.3 Air Traffic Control Manual of Operations

The directives published in subpart 370 of the ATC MANOPS[25] comply with the standards published in TP312.

NAV CANADA's ATC MANOPS[26] states that airports equipped with approach lighting with a variable-intensity setting shall set the approach lights to intensity setting 4 during daylight hours when visibility is less than 3 sm.

In compliance with the directives published in section 322.1 of the ATC MANOPS, the airport controller informed ACA875 approximately 3 minutes before the landing that the lighting system on Runway 24R was non-operational.

Section 316.3 of the ATC MANOPS instructs controllers not use an airport or any part of an airport that is closed by the airport operator. The note for section 316.3 of the ATC MANOPS reminds that "The Airport Operator is responsible for closing an airport or any part of an airport's infrastructure or manoeuvring area."[27]

1.11.4 Operating agreement between Aéroports de Montréal and NAV CANADA

ADM and NAV CANADA signed an agreement to "define the procedures and the coordination concerning operations between the Montreal control Tower (NAV CANADA) and Aéroports de Montréal (ADM)."[28] In particular, Appendix B of this agreement (Table 5) indicates the mitigation measures to be taken when the equipment required during low-visibility or reduced-visibility operation is unavailable.

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25 NAV CANADA, *Air Traffic Control Manual of Operations* (ATC MANOPS), subpart 370 – Airport Lighting (03 April 2014).

26 *Ibid*., section 379.1.

27 *Ibid*., section 316.3.

28 Agreement between NAV CANADA and Aéroports de Montréal, effective 26 February 2014.

Table 5. Aéroports de Montréal mitigation measures in the event of equipment failure during operations in reduced and low visibility conditions[29]

Missing element	All runways	Runway 06L
	Reduced visibility (1200≤RVR*<2600)	Low visibility (600≤RVR< 1200)
High intensity runway edge lights	Suspension of night operations	Suspension of operations
Runway centerline lights	No impact	Suspension of operations
Circuit design	Suspension of night operations	Suspension of operations
Standby power	No impact	Suspension of operations
RGL [runway guard lights]	Only 1 aircraft at the time on the manoeuvring area for all runways except 06L if stop bars are operational	No impact
Stop bars	No impact	Only 1 aircraft at the time on the manoeuvring area
Taxiway centrelines	No impact	Only 1 aircraft at the time on the manoeuvring area
Illumination of signs	Suspension of night operations	Suspension of operations
Stop bars automatic control	No impact	Only 1 aircraft at the time on the manoeuvring area

* Runway visual range in feet

In IMC conditions,[30] ADM does not suspend daytime operation of Runway 24R when the runway lighting is out of service.

The weather conditions did not allow use of the runway given that standard 8.5.1.8 of TP312 states, in part, that

> Runway edge, runway centreline and touchdown zone lighting shall be operated at night or in daytime IMC condition for an arriving aircraft [...]

1.11.4.1 Red alert

ADM has a procedure to protect ground personnel from the hazards associated with lightning activity. When lightning detectors record a predetermined number of lightning strikes within a specific radius of the airport, ADM issues a red alert. Operators can, on an individual basis and at their discretion, react to a red alert by ceasing their ground activities. ADM issued a red alert at 1229, approximately 6 minutes before the ACA875's arrival. The red alert, which is not an airport closure, was lifted at 1254.

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29 *Ibid.*, Appendix B

30 When the ceiling is less than 1000 feet agl and the visibility is below 3 statute miles at CYUL.

1.11.4.2 Airport closure

The decision to close an airport or part of its infrastructure or its manoeuvring area is the responsibility of the airport operator. ADM has well-established procedures for closure of a runway in specified conditions including freezing rain, snow, and nil braking. In addition, ADM closes runways that are obstructed by any known obstacle. ADM does not close runways or the airport for reasons related to summer weather conditions, such as wind, rain, or lightning.

Pilots may be under the impression that airports could be closed if weather conditions are too severe to allow approaches and landings to be conducted safely. In this respect, ATC is only responsible for ensuring that the runway to be used by a departing or arriving aircraft is free, or will be free, of any known obstacles, be they vehicles, equipment, or personnel, before the departing aircraft commences takeoff or the landing aircraft crosses the runway threshold. ATC may restrict the flow of air traffic into a particular airport due to weather conditions, but the ultimate decision to conduct an approach or landing rests with the pilot.

1.11.4.3 Low level wind shear alert system

The low level wind shear alert system (LLWAS) measures average surface wind speed and direction using a network of remote detection stations, located near runways and along the approach or departure corridor. The LLWAS is recognized as a factor that can affect situational awareness of wind shear and the ability to avoid it.[31]

Terminal Doppler weather radar is an enhanced system that uses a narrow three-dimensional beam to detect wind shear conditions.

CYUL airport has no LLWAS, and regulations do not require one.

1.11.4.4 Aéroports de Montréal response after the incident

ADM is responsible for taking action following an accident or incident at CYUL. ADM uses the emergency response plan (ERP) as an emergency management tool to establish guidelines, directives, and procedures, and to define the roles and responsibilities of the lead responding agencies.

An ADM employee observed ACA875's landing. In the minutes that followed, an ADM representative informed NAV CANADA that Runway 24R was closed due to the runway excursion. ADM fire service and runway maintenance crews were dispatched to the site. Since the occurrence was limited to a few damaged runway edge lights and mud on the manoeuvring surface, ADM deemed that the Emergency Coordination Centre (ECC) did not have to be opened. ADM partially documented the evidence from the site. Subsequently,

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31 Airbus, *Flight Operations Briefing Notes* (FOBN): *Adverse Weather Operations*, "Windshear Awareness, Factors Affecting Windshear Awareness", p. 11. (FOBN reference: FLT_OPS – ADV_WX – SEQ 02 – REV 03 – OCT. 2007)

ADM personnel repaired the lights and cleaned the runway with a jet of water and mechanical sweepers. At 1330, the runway was reopened.

At 1345, ADM asked NAV CANADA to report the runway excursion to the TSB. The TSB was only informed of the incident approximately 1 hour and 30 minutes after it occurred. When the TSB investigators arrived on site at approximately 1419, debris had already been moved, and some pieces of evidence had disappeared. The parties involved indicated that they were unsure of the necessity to protect the occurrence site and to preserve evidence following an incident of that nature.

According to the ERP manual in use at the time of the occurrence, an "aircraft accident or incident involves any event that might cause death or personal injuries and/or damages to an aircraft. This also includes aircraft crash, on board fire and ground collision."[32] Apart from this definition, the ERP makes no mention of aviation incidents that must be reported, as listed in the *Transportation Safety Board Regulations,* and in particular of incidents likely to occur at an airport, such as situations where an aircraft fails to remain within the intended landing area.

ADM published directives regarding the protection of sites after an accident or incident. These directives are aimed at the various groups of responders. In this regard, the ERP states that nobody "can move or manipulate remains or other elements of proof from the aircraft or its wreck or its contents, or interfere with, or move anything on location without the presence or the consent of an investigator from the Transportation Safety Board of Canada."[33] Directives to the ECC Director specify "authorize the removal of debris, wreck of the aircraft or other elements of proof once the TSB has completed its investigation."[34]

According to subsection 8(1) of the *Transportation Safety Board Regulations* (TSB Regulations), "Every person having possession of or control over evidence relating to a transportation occurrence must keep and preserve the evidence unless the Board provides otherwise."[35]

1.12 Flight recorders

The aircraft was equipped with a Honeywell semiconductor cockpit voice recorder (CVR) (model No. 980-6022-001, serial No. 0591) and a Honeywell digital flight data recorder (DFDR) (model No. 980-4700-042, serial No. SSFDR-09590). The 2 recorders were removed from the aircraft and sent to the TSB Laboratory, where the data they contained was recovered and analyzed.

The CVR contained 2 hours 5 minutes of recordings.

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32 Aéroports de Montréal, Montreal-Trudeau Airport, Restricted Emergency Plan, On-site Aircraft Accident/Incident, ch. 2, section 1.1.

33 *Ibid.*, section 3.1.

34 *Ibid.*, p. 3.

35 *Transportation Safety Board Regulations,* DORS 2014-37, subsection 8(1).

The DFDR contained 53 hours of flight data, i.e., those for the occurrence flight plus 6 previous flights. The DFDR data were validated and augmented with data from airport surface detection equipment (ASDE) and NAV CANADA auxiliary radar display system (NARDS). Subsequently, the DFDR data were synchronized with the CVR recordings, the ATC communication recordings, and measurements of marks on the runway from field data to create an animation of the approach and landing.

Analysis of these data made it possible to establish the exact path of the aircraft, the exact point where the rear wheels of the bogie of each main landing gear touched down, the moment when the weight of the aircraft rested on all of the wheels of each bogie, the use of flight controls by the PM, as well the activation of the various manual and automatic systems.

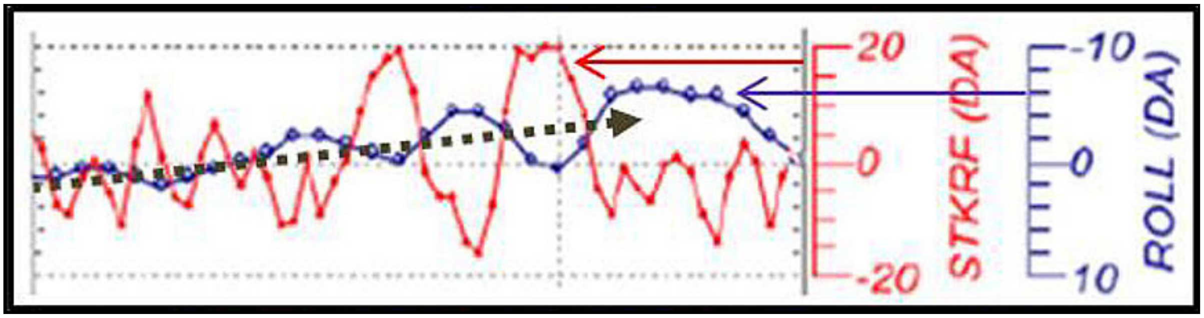
Plots of the flight parameters were produced to allow analysis of the approach and landing. These plots allowed comparison of the characteristics of the occurrence landing with previous landings and also determined that

- the auto-throttle was engaged up to the moment of flare;
- the autopilot was disconnected at approximately 980 feet agl;
- a veering wind was present during descent that, on average, below 100 feet agl, was from 291°M at 18 knots (average crosswind from the right of 15 knots);
- the speed fluctuations combined with the increase in vertical accelerations indicated heightened turbulence while descending during the approach;
- the approach met all of the company's stabilized approach criteria;
- the aircraft crossed over the runway threshold at 50 feet agl on the glide path, on centreline and at the selected speed (V_{APP});
- several deflections of the side stick controller, including 2 maximum deflections, occurred at less than 100 feet agl;
- thrust was reduced to idle at approximately 30 feet agl while the aircraft was banked 6.3° to the left;
- the increase of lateral negative "G" (to the left) after compression of the main landing gear tended to confirm that the aircraft was not subjected to hydroplaning after landing.

1.12.1 Pilot-induced oscillation

Analysis of the DFDR plots shows that at approximately 120 feet agl, the aircraft experienced 3 rolling oscillations, the amplitudes of which expanded progressively from 2° to 6° (Figure 11). At the same time, pronounced sideways movement of the co-pilot's side stick controller was observed, twice reaching the maximum deflection, and out of phase 90° with the rolling movement of the aircraft. These oscillations accompanied by the opposing deflections by the co-pilot indicate the presence of pilot-induced oscillation.

Figure 11. Data from the digital flight data recorder indicating the presence of pilot-induced oscillation



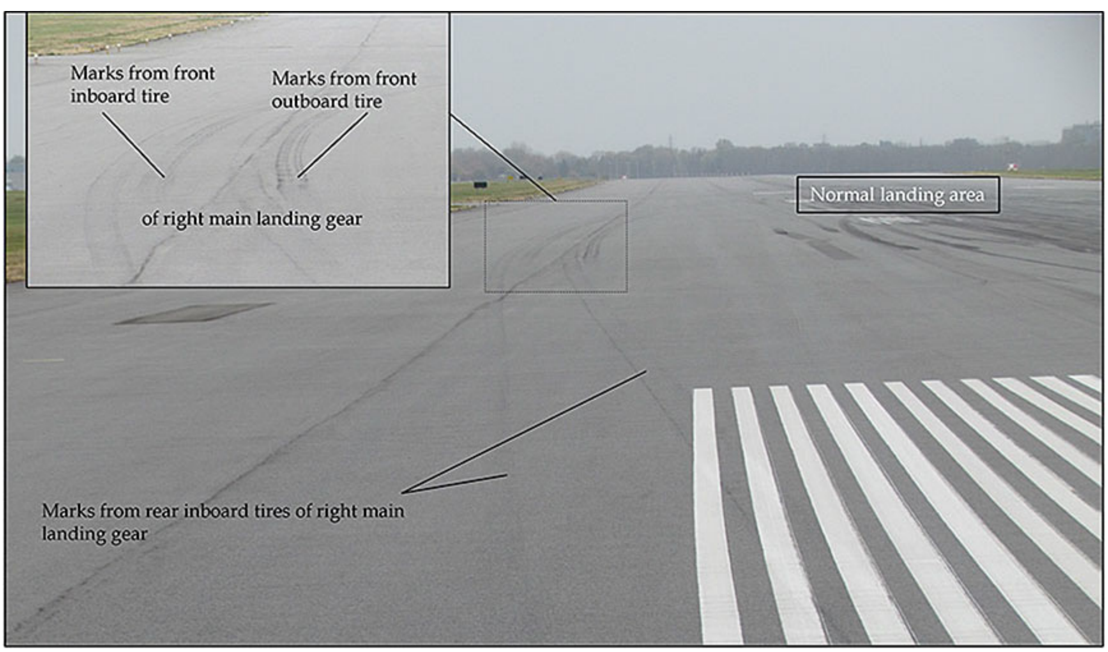
By definition, pilot-induced oscillation occurs only when the pilot performs actions with the side stick controller that have the effect of maintaining these oscillations. Since the pilot's actions are the source of these oscillations, generally halting all movement or letting go of the side stick controller is sufficient to stop pilot-induced oscillation.

1.13 Damage and impact information

1.13.1 Tire marks on the runway and grass

Tire marks from the main landing gear were visible on the runway (Figure 12). Before compression of the main gear, the rear wheels of the right gear (No. 7 tire and No. 8 tire) left marks that began 1332 feet from the runway threshold and 57 feet to the left of the centre of the runway. At that time, the left rear tire (No. 5 tire) of the left bogie was 97 feet from the centre of the runway and approximately 4 inches from the ground. The trajectory of these marks was shifted 2° to the left in relation to the runway centreline.

Figure 12. Tire marks on the runway



Before touching down, the right rear tire of the left main gear (No. 6 tire) struck a first runway edge light 1538 feet from the threshold. The first tire marks from No. 5 tire appeared on the grass 1708 feet from the threshold and 107 feet to the left of the centre of the runway. Subsequently, No. 6 tire struck another runway edge light and passed beside the next light, located 200 feet beyond.

Compression of the right main gear (Nos. 3, 4, 7, and 8 tires) occurred 1734 feet from the threshold and 68 feet to the left of the centre of the runway. Darker tire marks indicated a trajectory that clearly veered toward the right of the runway centreline. These marks suggest good adherence of the tires on the runway surface. No indication of hydroplaning on the runway was observed. At that time, the aircraft was banked approximately 0.5° to the right.

At 2130 feet from the threshold and approximately 107 feet to the left of the centre of the runway, an expansion of the marks was observed on the grass, corresponding to compression of the left main gear (Figure 13). At the same time, the right front tire of the left bogie (No. 2 tire) struck the runway edge light.

Figure 13. Tire marks on the grass

The last marks on the grass were 2215 feet from the threshold and 105 feet from the centre of the runway. The total length of the marks on the grass was 507 feet. The runway excursion covered a total distance of 677 feet (Appendix D).

1.14 Medical and pathological information

There was no indication that incapacitation or physiological factors affected the crew's performance.

1.15 Fire

Not applicable.

1.16 Survival aspects

Not applicable.

1.17 Tests and research

1.17.1 Highlights

Data from the CVR were synchronized with those from the DFDR and data collected on the runway. The table in Appendix E summarizes the highlights.

1.17.2 Simulator session

A session of simulator tests was conducted to support the investigation into this incident. The simulator used for the tests was the training simulator for Air Canada A330/340 crews,[36] and not a technical simulator. The equipment was a CAE full-flight simulator certified by TC[37] at level D, the most sophisticated level. All flight controls are authorized in this simulator.

The test session was undertaken to determine the length of time between when a "Go Around" call is made and when the aircraft achieves a positive rate of climb. The tests also gave a general idea of how the aircraft behaves and the piloting technique used in accordance with Air Canada's standard operating procedures. An Air Canada A330 flight instructor/check pilot occupied the left-hand seat and an A330 pilot the right-hand seat. Nineteen approaches to CYUL were performed from a starting point 5 nm in final approach from the end of Runway 24R up to landing. The weather and runway conditions at the time of the incident were reproduced as closely as the modelling limits of the simulator allowed. The simulator's level of fidelity did not allow exact reproduction of the effects of the rain and light conditions on visual perception at the time of the occurrence.

The tests involved go-arounds below 50 feet agl, with a number of them below 30 feet agl, after selecting "Idle" on the thrust levers. The simulator session yielded the following results:

- A significant reduction in the visual perception of the runway limits versus its environment when conditions shifted from VMC to IMC.
- The importance of runway lights to clearly demarcate the runway edges.
- Elapse of 6 to 7 seconds between a "Go Around" call and achieving a positive rate of climb.

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36 Air Canada 330/340 FFS, year 2002, serial No. 2RJ8-404.

37 Transport Canada identification No. 472/473.

- Go-arounds in a low-energy landing regime result in the wheels touching down approximately 4 seconds before achieving a positive rate of climb.

The delays before a positive rate of climb was achieved that were observed during the simulator session is consistent with the Airbus data in Figure 4 of section 1.6.10 Go-around.

1.17.3 TSB laboratory reports

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

- LP205/2014 – DFDR [digital flight data recorder] Download & Analysis
- LP228/2014 – Site Survey

1.18 Organizational and management information

1.18.1 Air Canada – Policies and procedures

Air Canada holds a TC-issued operator's certificate. The company has, among others, a Flight Operations Division and a Flight Safety Department. The Air Canada Operations Manual states the company's policies and procedures.

1.18.1.1 Flight watch system

The flight watch system is an integral part of the operational control process. It includes the communications, monitoring, analysis, consulting, and decision making required to validate, execute and change the operational flight plan. Flight watch begins with the approval of the operational flight plan by the flight dispatcher, and continues until the end of the flight.[38]

Among other things, flight watch includes continuous monitoring of the state of the aircraft and of all variables associated with the operational flight plan, with a particular focus on weather conditions, aerodrome conditions, minimum equipment list defects, fuel specifications, fuel remaining on board, weight and balance, aircraft performance, and NOTAMs.

1.18.1.2 Operational control

Operational control is carried out jointly by the flight dispatcher and the pilot-in-command until the latter accepts the operational flight plan. Thereafter, flight watch is the shared responsibility of the pilot-in-command and the flight dispatcher.[39]

1.18.1.3 Alternate airport selection

The selection of an alternate airport must be made in compliance with existing regulations, on the one hand and, on the other, according to 3 basic risk assessment and risk management

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38 Air Canada, Flight Operations Manual, Flight Watch, section 8.1.3, p. 2.

39 Air Canada, Flight Operations Manual, Operational Control, section 8.1.3.3, p. 3.

principles established by the company.[40] Based on these directives and the weather forecast, CYMX, which is located approximately 17 nm to the north of the destination airport, was selected as the alternate airport for ACA875.

1.18.1.4 Preparation for arrival and approach briefing

The preparation for landing published in the Air Canada Operations Manual includes all elements related to descent, approach and landing: considerations regarding the weather, the type of approach, the runway, the aircraft as well those of a business nature (passengers).[41] Furthermore, instructions specific to the type of aircraft are detailed in the A330 Aircraft Operating Manual (AOM).[42]

As per company policies and procedures, following preparation for arrival, the crew conducted an arrival and approach briefing to enhance their situational awareness and to clarify expectations. It was at this time that the crew assessed the threats to the flight and developed an action plan to mitigate the associated risks.

1.18.1.5 Stabilized approach criteria

The Air Canada stabilized approach policy is based on the principle of arrival gates, where the approach can be continued provided the criteria required for each gate is fulfilled. All approaches involve 2 arrival gates: the first is the final approach fix (FAF) (or its equivalent); the second is at 500 feet agl (or at 100 feet above the minimums, whichever is higher). Therefore, a go-around is mandatory if the criteria are not fulfilled for each of the arrival gates.[43]

1.18.1.6 Approaches in low-visibility conditions and approach and runway lighting

Air Canada's policy regarding approaches in low-visibility conditions (other than Category II and Category III)[44, 45] applies essentially when visibility is below the published visibility for approach or less than ¾ sm (runway visual range [RVR] of 4000 feet). The company has established a number of essential environmental criteria to continue the approach after the FAF. In particular, Air Canada has established standards regarding approach and runway lighting required for approaches under such conditions. Furthermore, the company has not set any requirements regarding approach or runway lighting when daytime visibility is greater than ¾ sm (RVR of 4000 feet).

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40 *Ibid*., Alternate Selection Process, section 8.1.8.4, p. 18.

41 *Ibid*., Arrival Preparation and Approach Briefings, section 8.9.10, p. 69.

42 Air Canada, A330 Aircraft Operating Manual, vol. 1, Descent Preparation, section 1.04.09, p. 7.

43 Air Canada, Flight Operations Manual, Stabilized Approach Criteria, section 8.11.6, p. 78 at the time of the event.

44 The Category II and Category III instrument landing systems enable pilots to execute instrument approaches up to weather minima lower than the usual minima using special procedures and specialized equipment, both aboard the aircraft and at the airport.

45 Air Canada, Flight Operations Manual, Air Canada's Low Visibility Approach Policy, section 8.11.13.1, p. 85.

1.18.1.7 Visual references required and pull-up or go-around

According to company policy[46]

> The required visual reference to continue the approach and landing and shall include at least one of the following references distinctly visible and identifiable for the intended runway:
>
> a) The runway or runway markings; or
>
> b) The runway threshold or threshold markings; or
>
> c) The touchdown zone or touchdown zone markings; or
>
> d) The approach lights; or
>
> e) The approach slope indicator system (VASI [visual approach slope indicator] or PAPI [precision approach path indicator]); or
>
> f) The runway identification lights; or
>
> g) The threshold and runway end lights; or
>
> h) The touchdown zone lights; or
>
> i) The parallel runway edge lights; or
>
> j) The runway centerline lights.

Furthermore, according to the Flight Operations Manual, a go-around must be initiated in the following cases:

> 1. The aircraft has reached the DH/DA [decision height / decision altitude] or MDA [minimum descent altitude] and the required visual reference is not established or is lost after descending below DH, DA, or MDA; or
> 2. If a safe landing cannot be accomplished within the touchdown zone and the aircraft stopped on the runway[47]

> At minimum, the PM shall monitor auto call-outs or call "Minimum" and for other than CAT II or III approaches shall call "Runway in Sight," "Lights Only," […] The PF shall respond to the call with either "Landing" or "Go-Around Flap."[48]

46 Air Canada, Flight Operations Manual, Approach – Definitions, section 8.11.1, p. 77.

47 *Ibid*., Go-Around, section 8.11.9.2, p. 81-82.

48 *Ibid*., Approach Minimum, section 8.11.8, p. 81.

1.18.1.8 Risks associated with approaches in low-visibility conditions

Air Canada recognizes that the risk of losing visual references is greater during an approach in low-visibility conditions[49] and in the absence of runway touchdown zone lighting and runway centreline lighting. The company reminds its pilots that a go-around must be initiated immediately if adequate visual references are lost once the aircraft has descended below the DH, the decision altitude DA, or the MDA.[50]

1.18.1.9 Approach in the presence of thunderstorms

Basically, the operations policy in the presence of convective activity calls for avoidance as the method to deal with thunderstorm-related hazards.[51] The company reminds crews that the weather radar should be used to avoid thunderstorm areas and to avoid entering them.

The FOM recommends avoiding red zones representing areas of heavy precipitation on the weather radar by a distance of 10 nm when the temperature is below the freezing point (0°C) and 20 nm when the temperature is above 0°C. For its part, the AOM suggests avoiding red or magenta zones, areas of turbulence, by at least 20 nm above flight level (FL) 230 and by 5 to 10 nm below FL230.[52]

Furthermore, other than the prohibition to take off and land when microbursts or downbursts are detected or reported, Air Canada has not established a formal policy regarding operations in the presence of thunderstorms during approaches and landings. Like many other airlines, Air Canada relies on the aviation skill, experience and judgement of its crews to ensure the safety of takeoffs and landings during thunderstorms.

1.18.1.10 Low-level wind shear

Low-level wind shear (LLWS) can reach an intensity that exceeds aircraft performance. Thus, in the presence of thunderstorms, the possibility of low-level wind shear must be anticipated, and this phenomenon can cause significant losses of speed and thereby losses of performance. The presence of low-level wind shear below 500 feet agl, a height at which

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49 The definition of reduced visibility in Air Canada's policy differs from the definitions used by Transport Canada (TC). In the TC context, low or reduced visibility operations are said to occur when the visibility is below ½ sm (RVR of 2600 feet) but greater than or equal to ¼ sm (RVR of 1200 feet), while low visibility is understood to be visibility below ¼ sm (RVR 1200 feet). Source: Transport Canada, Reduced/Low Visibility Operations Frequently Asked Questions (FAQs), online https://www.tc.gc.ca/eng/civilaviation/opssvs/managementservices-referencecentre-acs-300-faq_302-006-473.htm (last accessed on 20 March 2017).

50 Air Canada, Flight Operations Manual, Risk Associated with Low Visibility Approaches, section 8.11.13.4, p. 87.

51 *Ibid.*, Flight Procedures, section 8.18.3.2, p. 106.

52 Air Canada, A330 Aircraft Operating Manual, vol. 1, Red and magenta areas: thunderstorm, tornado, hail, section 1.03.34, p. 44.

inadvertent contact with the ground is possible, must be considered an emergency situation requiring the taking of immediate emergency procedures.[53]

A number of phenomena can create lateral wind shear or wind shear with a lateral component that can move an aircraft laterally from the runway centreline, and that could be destabilizing in conditions of limited visibility.[54]

1.18.1.11 *Ground operations in the presence of convective activity*

> Anytime an active electrical thunderstorm in within three to five statute miles of an airport, the operation will be placed on "Standby Alert" (Amber Alert). If an active electrical thunderstorm approaches to within three statute miles of an airport, a determination will be made to declare an "Operations Shut-Down" (Red Alert). A Red Alert signifies the probability of a lightning strike in the area. In this case, all employees and third parties shall vacate the ramp for safety reasons.[55]

1.18.1.12 *Landing distance and crosswind limits*

According to the AOM:

> Landing Distances should be calculated anytime:
>
> - The Aircraft is over MLW [maximum landing weight].
> - Landing with a tail wind.
> - The landing runway is shorter than 8000 feet.
> - The landing runway is contaminated.
> - There is an abnormality affecting the Landing Performance of the
> - aircraft.[56]

Landing distances are found in the "Performance" section of the Quick Reference Handbook (QRH),[57] and crosswind limits are in the "Limitations" section of the AOM.[58]

1.18.1.13 *Landing techniques in crosswind conditions*

According to the Air Canada Standard Operating Procedures for the A330:

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53 Air Canada, Flight Operations Manual, Low Level Windshear (LLWS) – General, section 8.18.4., p. 108.

54 *Ibid*., LLWS During Landing, section 8.18.4.2, para. 4c), p. 110.

55 *Ibid*., Ground Operations During Convective Activity – Ground Procedures, section 8.18.3.1, p. 106.

56 Air Canada, A330 Aircraft Operating Manual, vol. 1, Standard Operating Procedures, Descent Preparation, section 1.04.09, p. 8.

57 Air Canada QRH, In-Flight Performance, sections 4.02 to 4.04.

58 Air Canada, A330 Aircraft Operating Manual, vol. 1, Limitations, section 1.01.90, p. 2.

> Either the forward slip or the decrab technique may be used or a combination of both. The preferred technique is to use rudder to align the aircraft with the runway heading during the flare while using lateral control to maintain the aircraft on the runway centerline.[59]

The recommendations of Airbus for landing in crosswind conditions make the distinction between a weak crosswind (typically, up to 15 to 20 knots) and a stronger wind.

Airbus recommendations in weak crosswind conditions:

> During the flare, rudder should be applied as required to align the aircraft with the runway heading. Any tendency to roll downwind should be counteracted by an appropriate input on the side stick.[60]

However, with a higher crosswind (above 15 to 20 knots), Airbus advises that a safe crosswind landing requires

- a crabbed angle approach; and
- a partial decrab before touchdown, using a combination of bank angle and crab angle (achieved by applying cross-controls).

On most Airbus models, this requires touching down with a maximum 5° of crab angle and maximum 5° of bank angle.[61]

In an article about preventing lateral runway excursions, Airbus informs operators that should drift occur close to the ground, the safe practice is to go around as long as the reversers are not selected.[62]

1.18.1.14 *Low-energy landing regime*

> The low-energy landing regime is defined as:
>
> - aircraft is in descent,
> - thrust is at or near idle,
> - airspeed is decreasing,
> - aircraft height is 50 ft or less above the runway elevation.[63]

"The decision to place an aircraft into the low-energy landing regime is a decision to land."[64] Go-around during a low-energy landing regime is an interrupted landing and could lead to

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59 *Ibid*., Standard Operating Procedures, Crosswind Landings, section 1.04.13, p. 1.

60 Airbus Industries, *Safety First: The Airbus Safety Magazine,* "Lateral runway excursions upon landing", July 2015, No. 20, p. 24.

61 Airbus Industries, *Airbus Flight Operations Briefing Notes*, "Landing Techniques, Crosswind Landings", SEQ 05-REV 03, p. 7 (March 2008).

62 Airbus Industries, *Safety First: The Airbus Safety Magazine,* "Lateral runway excursions upon landing", July 2015, No. 20, p. 24.

63 Air Canada, A330 Aircraft Operating Manual, vol. 1, Red and magenta areas: thunderstorm, tornado, hail, section 1.02.10, p. 15.

contact with the ground. Nonetheless, according to Airbus, a go-around is still possible as long as the thrust reversers have not been deployed.

1.18.2 Air Canada – Training

1.18.2.1 General

Air Canada has its own certified training structure for issuing type ratings. The training program is approved by TC, whose representatives participate in a number of simulator sessions.

Simulator training provides pilots with an opportunity to practise manoeuvres that are not normally performed during actual flying operations. By providing pilots with the opportunity to practise these manoeuvres in a controlled environment, pilots can gain confidence in their ability to handle a similar situation should it arise during actual flight operations.

1.18.2.2 A330 training

When pilots are assigned to the A330, the aircraft qualification program (AQP) requires that they complete a qualification curriculum that includes ground and simulator training, a proficiency check on a simulator, online training (flight), route and aerodrome qualifications, and a line check (flight).

Subsequently, pilots must take training continually to maintain their qualifications, including simulator training and evaluation every 6 or 8 months, a line check (flight) every 12 months, as well as annual recurrent training (ART).

1.18.2.3 Threat and error management training

The threat and error management (TEM) model is a structural element of the Air Canada pilot training program. Pilots are trained based on the premise that every flight presents hazards they must deal with. These hazards increase the risks in flight and are designated as "threats." Threats include such things as weather conditions, traffic, aircraft serviceability issues, and unfamiliar airports.

If the crew is able to manage the threat effectively, the situation will have a favourable outcome, without adverse consequences. However, mismanagement of the threat can result in crew error, which the crew must also manage. Mismanagement of crew error may lead to an undesired aircraft state, which can lead to an accident. At any point, effective management of the situation by the crew can mitigate the risk, and the situation may have no consequence.

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64 *Ibid*., Abnormals, Low-Energy Go-Around, section 1.02.10, p. 15.

Furthermore, Air Canada trains and assesses its pilots according to the principles of crew resource management (CRM), which can be defined as the effective use of resources by the crew to ensure the safety of the flight. In summary, the aim of the components of Air Canada's training program is to train pilots to manage risks in the cockpit through effective crew resource management.

1.19 Additional information

1.19.1 Approach-and-landing accidents

In order to avoid approach-and-landing accidents, pilots must calculate the landing distance necessary. To ensure the accuracy of their calculations, they must have accurate and up-to-date information about the state of the runway surface, such as the presence of snow, rain, or ice that could affect the landing distance.

1.19.2 Previous TSB recommendations

On 02 August 2005, an Air France Airbus A340-313 aircraft (registration F-GLZQ) departed Paris, France, at 1153 Coordinated Universal Time (UTC) as Air France Flight 358 on a scheduled flight to Toronto, Ontario, with 297 passengers and 12 crew members on board. Before departure, the flight crew obtained the arrival weather forecast, which included a risk of thunderstorms. On final approach, they were advised that the crew of an aircraft landing ahead of them had reported poor braking action. Air France Flight 358's aircraft weather radar was displaying heavy precipitation encroaching on the runway from the northwest. At approximately 200 feet above the runway threshold, while on the ILS approach to Runway 24L with autopilot and autothrust disconnected, the aircraft deviated above the glideslope, and the groundspeed began to increase. The aircraft crossed the runway threshold approximately 40 feet above the glideslope.

During the flare, the aircraft travelled through an area of heavy rain, and visual contact with the runway was significantly reduced. The aircraft touched down approximately 3800 feet past the threshold of the 9000-foot runway. The aircraft was unable to stop and departed the end of the runway at a groundspeed of approximately 80 knots. The aircraft stopped in a ravine at 2002 UTC (1602 Eastern Daylight Time) and caught fire. All passengers and crew members were able to evacuate the aircraft before the fire reached the escape routes. A total of 2 crew members and 10 passengers were seriously injured during the crash and the ensuing evacuation.

The Board concluded its investigation; Aviation Investigation Report A05H0002 was officially released on 12 December 2007.

Recommendation A07-01 (December 2007)

Aircraft penetration of thunderstorms on approach occurs throughout the industry and has contributed to a number of accidents worldwide. Many operators do not provide their crews with specific criteria, such as distance-based guidelines, to avoid convective weather during final approach and landing. Environment Canada advises that thunderstorms can pose significant risks to the safe operation of an aircraft.

Therefore, there is a need for clear standards to avoid convective weather during approach and landing. This will reduce the ambiguity involved in decision making when faced with a rapidly changing weather phenomenon, and the likelihood that factors such as operational pressures, stress, or fatigue will adversely affect a crew's decision to conduct an approach. Consequently, the Board recommended that

> The Department of Transport establish clear standards limiting approaches and landings in convective weather for all air transport operators at Canadian airports.
>
> **TSB Recommendation A07-01**

Transport Canada response to Recommendation A07-01 (February 2008)

> In its response, Transport Canada (TC) states that it will consider this recommendation in consultation with other international aviation authorities with a view to harmonizing any regulatory initiatives that may result from this recommendation. In addition, TC is preparing an Issue Paper on this subject, to be presented at the next International Civil Aviation Organization (ICAO) Standard and Recommended Procedures working group meeting in Montréal, scheduled for summer 2008.
>
> In the short term, TC will consider issuing an Advisory Circular (AC) that will discuss the hazards associated with flight operations in or near convective weather conditions. This AC would recommend that Canadian air operators include specific procedures in their company operations manual that would guide flight crewmembers in alerting the crew of the current weather and associated hazards, as well as to provide guidance in decision-making when faced with flight through or landing in such weather conditions.

Board reassessment of the response to Recommendation A07-01 (July 2008)

> Although TC does not specifically state that it fully supports this recommendation, it intends to conduct consultations with international authorities to harmonize an action plan. In addition, it is preparing an Issue Paper, to be presented at the upcoming ICAO Standard and Recommended Procedures working group meeting. TC is also considering issuing an Advisory Circular (AC) to Canadian air operators that will discuss the hazards associated with flight operations in or near convective weather conditions.
>
> This response is a positive indication that TC believes that more needs to be done, both internationally as well as domestically, to reduce the risk identified in this recommendation. However, the Board believes that in the short term, and until more stringent standards are established, the risk will remain.

Therefore, the Board assessed TC's response as Satisfactory Intent.

Transport Canada response to Recommendation A07-01 (February 2010)

> TC's response states that it published Advisory Circular 705-005 entitled Approach and Landing During Convective Weather Conditions on 5 March 2009. It indicates that the target audience is 705 air operators.
>
> Additionally, the 3/2009 issue of TC's Aviation Safety Letter contained an article entitled Flight in the Vicinity of Convective Weather. The response indicates that it was a general information article targeted at both the industry as a whole and general aviation.

Board reassessment of the response to Recommendation A07-01 (July 2010)

> The issue of landing accidents and runway overruns is on the Board's Watchlist. TC's response indicates it has taken positive steps to raise awareness amongst Canadian operators and pilots with respect to the subject of approaches and landings in convective weather. However, its current response does not provide any evidence of consultations with other regulatory authorities or any follow through on the commitment to raise the issue at the 2009 ICAO Standard and Recommended Procedures working group meeting. The Board is concerned that until TC establishes clear standards to mitigate the risks identified in Recommendation A07-01, the risk will remain.
>
> TC's action taken to date will not substantially reduce or eliminate the safety deficiency.

Therefore, the Board assessed TC's response as Satisfactory in Part.

Transport Canada response to Recommendation A07-01 (January 2011)

> TC's response states that an Issue Paper was presented by TC to the ICAO Operations Panel meeting of the working group in Montreal on November 3, 2010.
>
> Panel members emphasized that while the issue of convective weather was of importance, the move to a "limit" for all aircraft operations at Canadian airports would have significant implications on safety beyond the borders of Canada. It was agreed that the issue was worthy of consideration by ICAO but Canada should not act alone in developing a strategy to address the issue.
>
> It was agreed that the ICAO Secretariat would place the issue on its work plan to be dealt with at a future date. However, given the volume of work currently being undertaken by the Panel, any revisit of this issue could be two years or more away.

Board reassessment of the response to Recommendation A07-01 (March 2011)

> The previous action by TC to raise the awareness of Canadian operators regarding flight in convective weather partially addressed the safety deficiency highlighted by the Recommendation A07-01. TC has initiated international discussion on the issue, but the time schedule in dealing with the issue through the ICAO Operations Panel will delay the mitigation of the safety deficiency.

Therefore, the Board assessed TC's response as Satisfactory in Part.

Transport Canada response to Recommendation A07-01 (December 2012)

> TSB Recommendation A07-01 will not be addressed by the development of a contemporary CRM training standard.
>
> In response to Rec. A07-01, TCCA [Transport Canada Civil Aviation] presented an issue paper to ICAO in November 2010, 1) it was agreed that Canada should not act alone in developing a strategy to address the issue, 2) the ICAO Secretariat agreed to place the issue on the work plan to be dealt with at a future date. TCCA will support ICAO in this initiative as a long term plan; however, we do not expect activity to begin within the next 2 years.
>
> TC has initiated contact with international counterparts to explore opportunities for harmonization and participate internationally in the advancement of these standards
>
> In the short term, TC will consider issuing an Advisory Circular (AC) that will discuss the hazards associated with flight operations in or near convective weather conditions.

Board assessment of the response to Recommendation A07-01 (March 2013)

> The Board again highlights the slow progress in establishing standards to mitigate the risks identified in Recommendation A07-01. On 21 January 2011, TC had indicated that, given the volume of work currently being undertaken by the ICAO Operations Panel, any revisit of this issue could be 2 years or more away. On 04 December 2012, 22 months later, TC reiterates that it will support ICAO in this initiative as a long-term plan; however, it does not expect activity to begin within the next 2 years. While TC did present an issue paper to the ICAO Operations Panel in November 2010, and has indicated that it will support ICAO in developing a strategy to address the issue, to this date it appears that no clear timeline has been established for this project. Until improved standards are in place, the risks will remain.

The Board assessed the response as Satisfactory in Part.

Transport Canada response to Recommendation A07-01 (November 2013)

> In 2009, Transport Canada published Advisory Circular 705-005: Approach and Landing in Convective Weather Conditions, which provides information about limitations for approaches and landings in adverse weather conditions. The Department will continue to evaluate the content of Advisory Circular 705-005 as new information becomes available.
>
> No additional regulatory or advisory material is planned at this time.

Board reassessment of the response to Recommendation A07-01 (April 2014)

> Transport Canada's previous action of publishing Advisory Circular 705-005 only partially addressed TSB Recommendation A07-01. The TSB is disappointed that no further action is planned by TC, and that without

> improved standards, the risks identified in Recommendation A07-01 will remain.

The Board assessed the response as Satisfactory in Part[65].

Recommendation A07-03 (December 2007)

Based on cues perceived or understood, cockpit decisions can be described as having 2 components: assessment of the situation and selection of a course of action. Cues, or information about the situation, can range from clear to ambiguous. Clear cues allow for an easy decision-making process. Ambiguous cues are much more difficult to grasp, understand, and assimilate. Therefore, the more ambiguous or complex a cue, the greater the likelihood of a decision that is less than ideal.

Much has been written on the issue of pilot decision-making processes when landing. Nevertheless, the accident of 02 August 2005[66] and others clearly indicate that there are still risks associated with this task. The Board believes that the ability to capture and interpret cues that are essential in the decision-to-land process is inadequate, especially when the cues are ambiguous or not immediately compelling. Consequently, pilots will continue to land in deteriorating weather once the landing decision has been made, despite cues indicating that a go-around or balked approach should be executed. Consequently, the Board recommended that

> The Department of Transport mandate training for all pilots involved in Canadian air transport operations to better enable them to make landing decisions in deteriorating weather.
>
> **TSB Recommendation A07-03**

Transport Canada's response to Recommendation A07-03 (January 2015)

> Transport Canada agrees with the intent of the recommendation.
>
> Work continues on the development of Standards and Guidance material for crew resource management (CRM) and updated Pilot Decision Making (PDM) to be incorporated in the CRM modules. Public consultation on proposed amendments to the standards is underway, and the standards are expected to come into effect in late 2015.

Board assessment of the response to Recommendation A07-03 (March 2015)

> The Board is concerned about the slow pace of action by TC to address the deficiency identified in Recommendation A07-03. Until all regulatory changes

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65 The assessment determines that there is a residual risk, but no further action is planned to be taken, and continued re-assessment will not likely yield further results. Dormant recommendations will not be re-assessed on a regular basis. However, occasional reviews will be conducted to see if any dormant recommendations should be reactivated and/or reassessed. The Board may also reassess a dormant recommendation at any time if actions have been taken which significantly reduce the residual risk.

66 TSB Aviation Investigation Report A05H0002.

> proposed by TC are enacted, the deficiency identified in Recommendation A07-03 will continue to exist. However, the proposed regulatory changes, if fully implemented, will substantially reduce or eliminate the risks associated with the safety deficiency identified in Recommendation A07-03.

The Board assessed the response as Satisfactory Intent.

1.19.3 Threat and error management

The TEM is a conceptual framework that focuses on the interrelationship between aviation safety and human performance from an operational standpoint. "There are three basic components in the TEM model, from the perspective of flight crews: threats, errors and undesired aircraft states."[67]

"Threats are defined as 'events or errors that occur beyond the influence of the flight crew, increase operational complexity, and which must be managed to maintain the margins of safety.'" [68]

Errors are defined as follows:

> Errors are defined "actions or inactions by the flight crew that lead to deviations from organizational or flight crew intentions or expectations." Unmanaged and/or mismanaged errors frequently lead to undesired aircraft states. Errors in the operational context thus tend to reduce the margins of safety and increase the probability of adverse events.[69]

An undesired aircraft state occurs when an aircraft finds itself in a situation that increases the risk to safety. The notion of undesired aircraft state includes, among other things, deviations in path or altitude, low fuel level, unstable approaches, and incorrect landings.

TEM advocates the careful analysis of potential hazards and taking appropriate steps to avoid, trap, or mitigate threats and errors before they lead to an undesired aircraft state. In other words, TEM stresses anticipation, recognition, and correction as its key principles.[70]

Flight crews must, within their flight operations, use countermeasures so that threats, errors and undesired aircraft states do not reduce the margins of safety of flight operations. Checklists, briefings, references and standard operating procedures, as well as personal and tactical strategies, are examples of countermeasures. Flight crews devote much time and energy to applying countermeasures to maintain the applicable margins of safety of flight

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67 Dan Maurino, *Threat and Error Management (TEM)*, Canadian Aviation Safety Seminar (CASS), 18–20 April 2005, p. 2.

68 *Ibid.*

69 *Ibid.*, p. 3.

70 Ashleigh Merritt and James Klinect, *Defensive Flying for Pilots: An Introduction to Threat and Error Management*, The University of Texas Human Factors Research Project: The LOSA Collaborative, Austin, Texas (12 December 2006), p. 16.

operations. Empirical observations obtained during training and verification suggest that up to 70% of flight crew activities may be related to the use of countermeasures.[71]

1.19.4 Decision making in a dynamic environment

Pilots make decisions in changing conditions where the information available reflects the dynamic environment in which the aircraft is operated. Studies have established that the decision-making process is a loop made up of 3 sequential steps: situational awareness, decision making, and observation of the performance resulting from the decision. The crew must be aware of the actual situation to make an appropriate decision. In a cockpit, counterchecks and effective communication between flight crew members mitigate perception errors.

Situational awareness involves perceiving the elements of the actual situation, understanding of this situation, and projecting the situation in time. Among other things, the training, knowledge, experience and preconceived notions of pilots are individual factors that influence their understanding of the situation.[72]

Mental workload affects the decision-making process. It can be defined as the quantity of information to be analyzed at a given time. Mental workload increases depending on the quantity and complexity of the information received. In abnormal or urgent situations, pilots must analyze complex and potentially conflicting information before arriving at an exact understanding of the situation, which is essential for implementing a suitable plan. Information overload can contribute to inaccurate situational awareness.

When pilots experience information overload, they tend to concentrate on one part of the information to the detriment of the overall situation. Channelling information this way is beneficial only if the pilot has chosen the relevant information.

Effective decision making involves an accurate understanding of the situation, appreciation of the implications of that situation, formulation of an action plan or plans and contingencies, followed by the implementation of the best course of action. Equally important is the flight crew's ability to recognize changes in their situation and to reinitiate the decision-making process to ensure that changes are accounted for and plans modified accordingly. Inadequate consideration of the potential implications of a situation increases the risk that a decision will produce an adverse outcome that may result in an undesired aircraft state.[73, 74]

1.20 Useful or effective investigation techniques

Not applicable.

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71 D. Maurino, Threat and Error Management, Paper presented at the Canadian Aviation Safety Summit (CASS), Vancouver, British Columbia (18-20 April 2005).

72 TSB Aviation Investigation Report A08Q0051.

73 TSB Aviation Investigation Report A09A0016.

74 TSB Aviation Investigation Report A11H0002.

2.0 Analysis

The aircraft was operating normally during the flight and during the incident. The crew was qualified for the flight in accordance with existing regulations, and each crew member had received the training required by Transport Canada (TC). According to the investigation, the pilots were not fatigued, and there was no indication that incapacitation or physiological factors affected their performance.

The analysis will focus on protecting occurrence sites and the preservation of evidence, operational factors that played a role in the occurrence, options available to the crew during the landing, managing the threats the crew faced, and landing during thunderstorms.

2.1 Protecting occurrence sites and preserving evidence

The marks left by the aircraft on the runway and in the grass constituted perishable clues that could be lost or altered by environmental conditions and by human activity. Despite the *Transportation Safety Board Regulations* (TSB Regulations)[75] and its own guidelines, Aéroports de Montréal (ADM) personnel cleaned the runway and repaired the damaged lights without first consulting TSB investigators. The purpose of the regulations is to ensure that all evidence and clues are preserved and documented to assist in determining what occurred. Cleaning the runway using jets of water and mechanical brooms erased marks on the runway, thereby depriving investigators of information about the runway excursion. Furthermore, since the quality and quantity of clues lost or altered could not be determined, it was not possible to assess the significance of this information. Nonetheless, collecting and recording evidence are essential steps in an investigation, since the determination of contributing factors depends on the quality of the analysis of all data collected. To comply with the TSB Regulations, ADM had published specific directives in its emergency response plan (ERP) regarding the handling of evidence. To that end, the ERP stresses that any response following an accident or incident has to be authorized by the TSB. However, in its directives, ADM defined an incident as any occurrence that might cause death or personal injuries and/or damages to an aircraft, without listing the incidents, such as runway excursions, that must be reported according to the TSB Regulations.

Since the occurrence caused no damage to the aircraft and no injuries, ADM operational staff did not believe it was necessary to inform the TSB before returning the runway to service. It is likely that the personnel operated out of concern for efficiency since the other 2 runways were closed. The ADM responders may have been unaware of the importance of preserving evidence following an incident due to the absence of significant consequences. Either they were unfamiliar with the ERP directives in the event of an incident, or they misinterpreted the scope of application of the directive.
Since incidents that must be reported are not listed in the ERP, this may create ambiguity regarding the requirement to preserve the occurrence site until the TSB has released it. As a

75 *Transportation Safety Board Regulations, DORS/2014-37*, subsection 8(1).

result, due to the ADM response, evidence was lost or altered. If occurrence sites are not preserved, there is a risk that evidence essential to identifying factors that contributed to an occurrence will be lost.

2.2 Operational factors

2.2.1 Thunderstorms

Among other things, the crew's decision making was shaped by situational awareness and threat management. To this end, the pilots had to prepare a landing plan and implement it before arrival. Situational awareness is achieved through perception, understanding, and projecting the situation in time. The information available within a very narrow timeframe influenced understanding of the situation. Furthermore, workload affects the analysis of this information and, as a result, the decision-making process.

The weather information available at the time of departure from Frankfurt-Rhein/Main (EDDF), Germany, was up-to-date, and did not suggest any difficulty in landing. The weather information was updated during the flight via the aircraft communications addressing and reporting system (ACARS).

At 1143, the crew prepared for the descent according to the company's directives, based on the aerodrome forecast (TAF) issued at 1119 and the routine weather report (METAR) of 1100. Since the TAF matched the METAR in effect, the crew could reasonably assume that the TAF was reliable. As a result, the thunderstorms forecast for 30 minutes after the time of landing at Montréal/Pierre Elliott Trudeau International Airport, Quebec (CYUL) did not constitute a threat in the pilots' view. Under these conditions, it was reasonable for the crew to expect to land at CYUL without any particular difficulties in visual meteorological conditions (VMC) with a visibility exceeding 6 statute miles (sm) and a ceiling of 7000 feet above ground level (agl).

As they approached CYUL, the crew checked the automatic terminal information service (ATIS) issued by ACARS. When they contacted Arrival, the crew confirmed having ATIS information Victor. Two more ATIS messages were issued after Victor and before the aircraft landed. The investigation could not determine whether these messages were received in the aircraft. However, as the aircraft was on final approach, the crew could observe the weather conditions directly through the front windshield. Furthermore, the weather radar on board the aircraft provided the pilots with a graphic representation of the weather conditions at the airport.

As a result, when the crew was confronted with the presence of a thunderstorm north of the airport as they were intercepting the final approach path, the workload associated with the approach and the time available did not allow an in-depth analysis of the possible effects of the thunderstorm on the landing. Furthermore, the preceding aircraft appeared to operate normally during its approach while the runway was still fully visible.

Air traffic control (ATC) then provided some information regarding wind and wind shear reported by the flight that preceded ACA875. When ATC advised ACA875 of the presence of wind shear, the pilots mitigated the threat by increasing the approach speed by 4 knots. Furthermore, given that the report of wind shear had not been quantified, the crew was unaware of whether this represented a decrease or an increase in speed. In the absence of this information, the crew protected against the risk of a decrease in speed upon landing.

The crew was able to observe the changing weather conditions at CYUL; however the wind and wind shear information provided by ATC was not in real time. Although the wind information at CYUL was transmitted to the flight in a timely manner, the information provided did not enable the crew to be fully aware of the rapidly changing weather conditions in the area of the runway. As a result, it can be concluded that the crew did not have the information necessary to make an informed decision whether to continue the approach and landing.

The 1223 and 1236 METARs show a drop in temperature of 4°C, with wind from the southwest at 9 knots veering to the northwest at 18 knots, gusting to 27 knots. On this basis, it can be concluded that the drop in temperature and shift in wind direction and increased wind speed confirm the presence of a downburst associated with the thunderstorm located immediately to the north of the runway.

Thunderstorms are the source of several hazardous phenomena and constitute a significant threat to aircraft flying in their vicinity. The heavy precipitations associated with the thunderstorm led to a downburst of wind that reached the ground, leading to violent gusts in the western sector. Since the thunderstorm passed immediately to the north of the runway on a trajectory more-or-less parallel to the runway, the strong and unstable wind shifted from the west to the north, resulting in lateral shear.

The digital flight data recorder (DFDR) data indicate that a sudden increase occurred in the aircraft's drift approximately 2° to the left during the flare. This change in drift coincided with a significant increase in rain showers. On this basis, it can be concluded that the aircraft experienced the effect of a downburst associated with the rain generated by the thunderstorm. A lateral wind shear generated by a downburst to the north of the runway suddenly increased the aircraft's drift to the left during the flare.

Canadian airports have no low-level wind shear alert system (LLWAS), and are not required to have one. However, LLWAS is recognized as a source of information that provides awareness of the wind shear situation and assists in avoiding it.[76] If airports are not equipped with a LLWAS, crews landing there may not be aware of the presence of downbursts or microbursts, and therefore may be exposed to the risk of approach-and-landing accidents.

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76 Airbus, *Flight Operations Briefing Notes* (FOBN): *Adverse Weather Operations*, "Windshear Awareness, Factors Affecting Windshear Awareness", p. 11. (Reference FOBN: FLT_OPS – ADV_WX – SEQ 02 – REV 03 – OCT. 2007).

2.2.2 *Runway condition and landing performance*

To reduce the risks of approach-and-landing accidents it is necessary to calculate the landing distance on contaminated runways. For this purpose, pilots must have precise, up-to-date information on the condition of the runway surface. During the preparation for descent, no precipitation was expected at the estimated time of arrival. It was only once they were on approach that the pilots observed rain at the airport. Since the crew could see the entire runway, they were expecting a low-intensity rain shower and assumed the runway was not contaminated. However, at approximately 130 feet agl, the rain intensified such that the windshield wipers functioning at maximum speed were unable to remove all rain from the windshield. Given this increase in precipitation, it is likely that the runway was covered with water. Subsequent weather analysis indicated that the precipitation rate north of the threshold of Runway 24R could have reached 75 mm/hour.

The marks on the runway (which occurred after the full weight of the aircraft settled on its landing gear) indicate good adherence of the tires on the runway surface at the moment of compression of the right landing gear and a rapid change in trajectory. Since No. 4 tire (right front tire of right main landing gear) touched down at this precise moment, it is reasonable to believe that the slight rubber burn was caused by the rapid change in trajectory. As a result, it can be concluded that hydroplaning did not contribute to the incident.

The rapid change in weather conditions while the aircraft was on short final did not allow the crew to determine whether the heavy rain changed the crosswind limits, or to assess performance upon landing on a water-covered runway. Since the crew did not have quantitative data regarding the precipitation rate, they were unable to assess the impact of the rain on landing performance in crosswind conditions. If a crew is unable to verify landing performance in heavy rain conditions involving a risk of hydroplaning, there is an increased risk of runway excursion.

2.2.3 *Reduction in visibility*

2.2.3.1 *Rain shower*

The crew could see the entire runway until the aircraft entered the rain shower. When the aircraft was at 0.4 nautical miles (nm) from the runway threshold and at 130 feet agl, the rain reduced in-flight visibility, which required the windshield wipers to be turned on. At the pilot flying's (PF) request, the windshield wipers were turned on at maximum speed. Activation of the windshield wipers suggests that visibility dropped quickly, since the aircraft passed in a very short time from good visibility conditions to a condition requiring the use of windshield wipers at maximum speed.

The sudden increase in the intensity of precipitation would have reduced visual references and made it difficult to discern the horizon through the front windshield. As well, the lateral confines of the runway would have blended into the grass and been difficult to distinguish. However the crew could see the runway sufficiently to determine the offset position of the aircraft to the left, since both the pilot monitoring (PM) and the PF reacted to the situation.

Once the aircraft crossed the runway threshold, the intensity of the precipitation increased suddenly, such that the PF had reduced visual references. Under these conditions, the PF did not detect the lateral movement of the aircraft in time to correct the drift before the outboard tires of the left bogie landed in the grass.

2.2.3.2 *Windshield wipers and rain repellent system*

Airbus equipped its aircraft with windshield wipers and a rain repellent system to reduce the effects of rain on forward visibility. The rain repellent system is a recognized system that acts quickly to restore visibility within a few seconds. However, the rain repellent system of C-GFAF had not been restored to service after it was deactivated. The system had originally been deactivated due to the hazard it posed to the environment. Since that time, a substitute fluid that is acceptable from an environmental standpoint is available to operators. However, during the approach, the windshield wiper system operating at maximum speed was inadequate to eliminate the abundant water on the windshield. Because the windshield was heavily contaminated, the PF had little visual contrast to be able to detect the lateral movement of the aircraft above the runway.

It was not possible to establish with certainty whether the combined use of the rain repellent system and windshield wipers would have enabled the PF to maintain acceptable visibility through the windshield and keep the aircraft on the runway centreline. Nevertheless, the rain repellent system is known to be effective in reducing the effects of rain on forward visibility. Since vision is the primary source of information for pilots, if the rain repellent system is unavailable or not used, there is an increased risk, in heavy rain conditions, that crews will lose the visual references necessary to avoid a runway excursion.

2.2.3.3 *Approach and runway lighting*

Given that during the approach briefing the crew increased the approach minimums as reported by the NOTAMs in effect, it can be concluded that the pilots were aware of the fact that the runway lighting on Runway 24R was out of service. Nonetheless, the crew did not identify this condition as a threat since the landing was to be conducted in daylight in VMC, which, in their view, posed no risk of loss of required visual references for approach and landing.

Because of the thunderstorm, the crew found themselves in fading light conditions during the approach and landing. Furthermore, due to the absence of runway lighting and visibility reduced by heavy rain, the grey surface of the runway presented little contrast with its surroundings and offered few visual cues. It can be concluded that the environmental context made it difficult for the PF to keep the aircraft on the runway centreline and to detect lateral movement of the aircraft above the runway. Given the absence of runway lighting in reduced visibility conditions, it was difficult for the PF to detect the lateral movement of the aircraft over the runway and therefore to prevent the runway excursion.

The lights that make up the runway lighting system enable pilots to locate the runway during landing, to touch down in the right place, to stay in the centre of the runway, and to evaluate the distance to the end of the runway. For these reasons, approach lighting is required in low-light conditions, both at night and in instrument meteorological conditions (IMC).[77]

The information contained in the special weather report (SPECI) issued at 1230 indicated that IMC prevailed at CYUL. As a result, according to the certification standards for Runway 24R, runway lighting was required. In fact, according to TC, the existing weather conditions prohibited the use of this runway. But ATC cleared ACA875 for landing at 1232:30, and then 27 seconds later advised the crew that the runway lighting on Runway 24R was out of service. Although Air Canada has imposed an operational restriction regarding runway lighting in order to conduct an approach using the Category I instrument landing system (ILS CAT I) if visibility is less than ¾ sm (runway visual range [RVR] of 4000), it has not set any requirement regarding runway lighting when visibility is ¾ sm or higher.

Lastly, existing regulations do not stipulate any requirements for pilots regarding runway lighting in these conditions. As a result, the crew could reasonably believe that the runway complied with the airport certification standard and that all risk mitigation measures were in place when ACA875 was cleared to land on Runway 24R.

2.2.4 Runway Closure

Normally, closing an airport infrastructure is the responsibility of ADM. ADM signed an agreement to this effect with the Montréal Control Tower defining the conditions for closure of a runway in the event of inoperative components of the runway lighting. Since the agreement did not specify any conditions for the closure of Runway 24R during the day in the event of a failure of the lighting system, the controller did not suspend operations on the runway.

As already discussed, runway lighting was required for the operation of Runway 24R when the conditions changed from VMC to IMC. In such circumstances, ADM should have stopped operating Runway 24R and opened Runway 24L, on which the runway lighting was operating normally. However, ADM appears not to have realized that runway lighting was required both day and night for operation of a runway in IMC. Runway 24R was not closed in IMC, even though the runway lighting was not working. As a result, the runway was not equipped with the lights required to enable crews to clearly distinguish the lateral confines of the runway.

2.3 Options during landing

2.3.1 Preparation for go-around

Preparation for go-around is an important defence against approach-and-landing accidents. In this context, when the PM makes the "minimum" call and the PF responds "Landing," it is

[77] Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, fourth edition (March 1993), section 8.5 Operation and control of aerodrome lighting systems.

possible that the call creates an expectation that the landing is assured, even if circumstances change before touchdown.

In dynamic weather conditions, such an expectation could reduce preparedness for a go-around, particularly if it would be subject to a change of decision and need to be executed at very low altitude or in a low-energy landing regime. As a result, if the “landing” response to the “minimum” calls reinforces the notion that landing is assured, there is a possibility that preparation for, and the decision to, go-around could be affected, increasing the risk of a landing incident or accident.

2.3.2 Continuing the approach

It was only once approach minimums had been reached, after the aircraft entered the area of thunderstorm activity, that the associated hazards had a concrete impact on the flight.

In the seconds that followed, the aircraft was subjected to 3 rolling oscillations, with amplitudes expanding progressively from 2° to 6°. At that time, pronounced sideways movement of the PF’s side stick controller were observed, twice reaching maximum deflection, and out of phase with the bank of the aircraft. The increased amplitude of oscillation and the significant deflections of the side stick controller recorded by the DFDR tend to indicate the presence of pilot-induced oscillation (PIO).

The phenomenon of PIO occurred when the aircraft was located just south of the thunderstorm, in turbulent conditions as the heavy precipitation intensified. In this context, it is reasonable to conclude that the effects of the thunderstorm contributed to the PIO.

Despite the presence of PIO during the approach to the runway, the aircraft was well positioned above the runway threshold, and the drift was eliminated to place the aircraft on a trajectory along the runway centreline. The approach was therefore continued. At that point, the crew’s actions complied with the company’s operating procedures, and the crew could expect to land more or less on the runway centreline.

The cyclical deflections of the side stick controller from left to right ceased near ground level while the aircraft had a bank of 6° to the left some 40 feet above the runway and the PIO ceased at that moment. Thereafter, the deflections to the right of the side stick controller were insufficient to return the wings to level, and the bank to the left lasted nearly 3 seconds. The sustained left bank combined with a right crosswind and a lateral wind shear due to the downburst from the thunderstorm just north of the runway, resulted in a rapid drift to the left.

During an approach in the presence of a thunderstorm, PIO led to the aircraft being in a left bank as it crossed the runway threshold which, combined with a strong right crosswind, resulted in a rapid drift to the left very close to the ground.

2.3.3 Options and the decision to land

It was only once the aircraft was over the runway, immediately before the flare, that the situation originally anticipated by the crew changed. At that precise moment, amid heavy rain and with very poor visibility, the PF had 2 options to avoid a runway excursion:

1. Stop the descent long enough to return the aircraft to the runway centreline before landing; or
2. Go around.

Given the proximity of the ground, either of these 2 manoeuvres would require immediate reaction from the crew, since the aircraft was only 3 seconds from the wheels touching down.

Even in good visibility conditions, the first option would require a great deal of dexterity to halt the descent of a heavy aircraft and perform a highly precise lateral movement to return the aircraft to the centre of the runway very close to the ground in crosswind conditions with gusts at 27 knots. In this occurrence, the PF would have faced even greater difficulties in controlling the aircraft given the poor visibility. As a result, this manoeuvre was not advisable under the existing conditions.

2.3.4 Low-energy go-around

Since placing the aircraft in a low-energy state constitutes in and of itself a decision to land and there is no time to analyze new factors, this decision should constitute a trigger point and be dealt with in a manner similar to the take-off decision speed.[78] Since there is no time for analysis during takeoff, the decision speed is treated as the limit up to which the takeoff is interrupted in case of a breakdown and beyond which continuing the takeoff is recommended.

In this context, the point when the thrust is reduced could be used as the irrevocable decision point to land. Thus, crews might be more disposed to perform a go-around up to the decision point.

Despite the drift, the PF felt that it was still possible to land on the runway surface and began the reduction to idle thrust at approximately 30 feet agl. An immediate go-around at that precise moment was the last point when it would still have been possible to avoid contact with the ground and, consequently, the runway excursion. Therefore, when the PF reduced thrust, the aircraft entered into low-energy landing regime and, although a go-around remained possible, contact with the ground was inevitable.

The reduction in thrust placed the aircraft in low-energy landing regime and constituted a critical point to avoid the runway excursion. It is clear that at that precise moment, the PF did not have sufficient time to reassess the effect of the changing conditions since he was in a

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[78] The term "decision speed" means the maximum speed of an aircraft below which the pilot can decide to interrupt the take-off.

high workload situation, concentrating on controlling the trajectory and executing the flare and landing. If the aircraft is drifting near the ground and pilots place the aircraft in low-energy landing regime, there is an increased risk of runway excursion.

When the wheels first touched down, the aircraft was slightly banked to the right with a crab angle of approximately 8° to the right. Since the PF did not perform a manoeuvre to reduce the crab angle, but rather maintained it, it can be concluded that, being aware of the position of the aircraft in relation to the runway centreline, the PF was attempting to correct the trajectory of the aircraft. The runway excursion was not the result of a premature crab angle reduction manoeuvre, which is often associated with landing incidents in crosswind conditions.

2.3.5 Retaking of the controls by the captain

The captain, as PM, provides an additional defence to prevent landing-related incidents by monitoring the progress of the landing and making calls if a deviation occurs. As a last resort, the captain can retake the flight controls to ensure the safety of the flight.

When the reduction in visibility occurred, the PM had to recognize the lateral drift, observe the actions of the PF, and determine whether they were sufficient to keep the aircraft on the runway. The wings were returned to level, the thrust was reduced to idle, and the rain shower intensified. Two seconds later, the PM realized that the aircraft was offset to the left; 1 second after this realization, the PM ordered the PF to correct the aircraft to the right. This is when the No. 6 tire struck the first runway light, while the PF had begun a significant correction to the right.

The aircraft struck the first light just as the pilot-in-command ordered a correction to the right, even though he had been closely monitoring the progress of the flight. Once the aircraft began its deviation, the time constraints did not allow the pilot-in-command to intervene and take the controls in time to make a correction to avoid the runway excursion.

The incident shows that the PM did not have the time to make a call before the tire struck the runway edge light. As a result, it is reasonable to conclude that the risks of a landing incident increase when an aircraft lands near a thunderstorm, since the associated hazards can arise in less time than is required to take the necessary measures.

Furthermore, Air Canada does not provide pilots-in-command specific training on retaking the controls during the landing flare. It seems that such situations are rare. Furthermore, the pilots met during the investigation had never had to retake the controls at such an advanced stage of a flight. This being said, the possibility of an event requiring the other pilot to retake the controls cannot be dismissed. If crews are not trained to retake the controls at very low altitudes or during the low-energy landing regime, there is a risk that, in the event of a problem, the PM will not have time to identify the problem and take appropriate measures.

2.4 Threat and error management

The concept of threat and error management includes the preparation and adaptation of crew action plans following identification of current threats in order to reduce the risks. During the flight, team members followed the threat and error management (TEM) process based on their experience, the training provided by the company, and the information available at that time.

During the preparation before descent, the only threat known to the crew, i.e. the momentary fault with the No. 1 brake system reported by the electronic centralized aircraft monitor (ECAM) at EDDF, was identified and managed by the crew. After noting the presence of thunderstorms, the crew mitigated the threat of turbulence and wind shear by progressively increasing the approach speed.

Due to the normal approach and landing of the DHC-8 that preceded them and the fact that the entire runway was clearly visible from the cockpit, the pilots of the occurrence flight may have thought that no other risk associated with the thunderstorm threatened the landing.

Furthermore, the brief interval of time separating the reports of wind and shear, and the imminent landing, made it difficult for the crew to identify the risk of lateral wind shear caused by the downburst of wind to the north of the runway. As a result, the possibility of a go-around in the event of failure to keep to the runway centreline was not anticipated.

Although the crew had been tracking the motion of the rain shower over the runway, the possibility of losing visual references in a heavy rain shower was neither discussed nor anticipated. The crew did not experience any negative weather effects until the aircraft was on very short final, at approximately 130 feet agl, when the aircraft was passing approximately 1 nm from the thunderstorm to its right. Therefore, the consequences of a landing in poor visibility without runway lighting had not been properly assessed. As a result, the crew continued with the plan formulated before the approach, and decided to land.

Since the approach was conducted in daylight in good visibility conditions, the absence of runway lighting was not identified as a threat. Furthermore, under such conditions, neither Air Canada nor ADM require runway lighting. Consequently, the crew had not anticipated that the risk of losing sight of the runway due to reduced visibility through the windshield in the rain would be exacerbated by the absence of runway lighting.

The sudden and unexpected effects of the thunderstorm combined with the absence of runway lighting, during a heavy workload period, deprived the PF of the ability to effectively and consistently use the visual references normally available to correct the drift before the runway excursion. Therefore, if a crew does not consider the consequences of multiple threats, there is a risk that pilots will continue a landing under conditions that are not favourable.

In the event of diversion, the flight was to land at Montréal International (Mirabel) Airport (CYMX), located approximately 17 nm north of CYUL. The choice of alternate landing site was appropriate since, at the time the flight was planned, the weather forecasts and fuel reserves carried complied with existing regulations.

However, during the flight, weather forecasts varied greatly at the destination airport and alternate landing site. At 1128, due to the presence of thunderstorms in the Montréal area, Air Canada dispatch transmitted an ACARS message for informational purposes to ACA875 containing the information necessary to offer Ottawa Macdonald-Cartier International Airport, Ottawa, Ontario (CYOW) as a possible alternate airport. However, due to the communication protocol in the event of transmission failure, ACA875 did not receive this message, unbeknownst to the dispatcher. Consequently, the flight dispatcher and crew did not have the same situational awareness regarding threats associated with the thunderstorms in the Montréal area and the possibility of using CYOW as an alternate airport. Therefore, if dispatch is not aware of an ACARS transmission failure, there is an increased risk that critical flight information is not received by the crew.

Furthermore, the thunderstorms expected at CYMX at the time of arrival could have constituted a threat to the flight if a diversion proved necessary. Nonetheless, the information at their disposal allowed the crew to anticipate a landing at their destination. Under these circumstances, the crew did not identify the convective weather at the alternate landing site as a threat, and did not formulate any specific plan taking into account weather conditions in the event of a diversion. In general, information received during the flight did not change the crew's perception of the situation that they had formed since the start of the flight. Based on the foregoing, it appears that the crew were convinced they could safely land at their destination.

It can be concluded that, taking into account information at their disposal at the time of descent, approach planning, and landing, the crew did not take into account all the risks associated with the thunderstorms expected at the alternate airport.

In summary:

- Thunderstorms are dynamic and their effects emerge quickly.
- Wind data are not provided by the tower in real time; the data provided are therefore out-of-date under downburst conditions, which evolve rapidly.
- The crew did not have time to reassess all of the risks they encountered less than 30 seconds before landing.
- The pilots underestimated the combined effects of the thunderstorm, i.e. turbulence, lateral wind shear, and the sudden reduction in visibility.
- The crew, surprised by the sudden reduction in visibility so close to the ground, continued with the landing plan, despite significant lateral movement of the aircraft.

The incident serves as a reminder that the effects of a thunderstorm during approach represent a greater risk as the aircraft draws closer to the ground. Also, convective weather generates insidious threats, even more so if the thunderstorm is offset in relation to the aircraft's trajectory, as was the case for ACA875. In this context, preparation for go-around was the only remaining defence to counter unforeseen circumstances.

2.5 *Landing in the presence of thunderstorms*

2.5.1 *TSB recommendation A07-01*

Thunderstorms present a range of threats to aviation and the flight conditions in the vicinity of a thunderstorm can change dramatically and abruptly. The key to effectively managing these threats lies in a crew's ability to detect and avoid them.

As part of its investigation into the runway overrun involving AFR358 in Toronto in 2005, the Board identified previous accidents and research indicating that there was a significant risk associated with flight crews flying in close proximity to convective weather in the terminal environment. As a result, the TSB issued Recommendation A07-01 calling on TC to establish clear standards limiting approaches and landings in convective weather for all air transport operators at Canadian airports.

At the time, it was believed that the nature of convective weather, involving multiple hazards that can increase precipitously, meant that standards providing crews clear guidance with respect to avoiding convective weather in the terminal environment were warranted. It was also believed that strategies aimed at raising awareness to improve crew judgment would not be adequate to mitigate the multiple, unpredictable hazards associated with a thunderstorm.

TC committed to considering this recommendation in consultation with other international aviation authorities with a view to harmonizing any regulatory initiatives. In the 10 years since this recommendation was issued, TC has taken some action. Specifically:

- TC issued AC 705-005: Approach and Landing in Convective Weather Conditions. This document advised air operators that they: "should ensure that information is available to flight crew members and dispatchers regarding the hazards of flight operations in the vicinity of convective weather activity, as well as review this information during initial and recurrent training."[79] The AC provided a suggested list of topics to be included in this guidance and training.
- TC also raised this issue internationally, presenting an issue paper to ICAO in November 2010. The result of these discussions was general agreement that any standard related to flight near convective weather in the terminal environment would require international collaboration given the potential operational impact of such a standard. Further, given other priorities it was communicated that work on such a standard would not be undertaken for several years.

These actions and the response to them clearly indicate that TC and the international community recognize that clear guidance in the form of a standard for avoiding convective weather in the terminal environment would be worthwhile but that developing such a

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79 Transport Canada, Advisory Circular 705-005: Approach and Landing During Convective Weather Conditions (05 March 2009), available at https://www.tc.gc.ca/eng/civilaviation/opssvs/managementservices-referencecentre-acs-700-705-005-509.htm (last accessed 16 March 2017).

standard would be difficult and take time. As a result, the response to recommendation A07-01 is currently assessed as "Satisfactory in Part" and "Dormant".

This occurrence clearly demonstrates the potential for crews, who are well aware of the hazards associated with convective weather, to be surprised by the sudden onset and intensity of their effect during a critical phase of flight. As in previous accidents, the crew of ACA875 were aware of the presence of convective weather near the approach and landing area and had taken steps to mitigate the most significant anticipated threats associated with convective weather on approach. However, the crew encountered a change in wind direction combined with a significant reduction in visibility at a critical phase in flight as the aircraft was entering the landing flare.

If TC does not take action to develop the clear standards on avoiding thunderstorms during approach and landing called for in Recommendation A07-01, approaches in the presence of convective weather will continue, exposing aircraft to the multiple, unpredictable hazards associated with thunderstorms.

2.5.2 Continuing the approach in the presence of thunderstorms

Throughout the approach, in a stabilized condition with no evident danger and no established standards regarding the presence of a thunderstorm in the vicinity of an airport, no existing condition justified interrupting the landing. Therefore, the crew's decision to continue the approach despite a thunderstorm just north of the runway was in line with industry practices. The option of performing a go-around represents the final measure to mitigate the sudden onset of a dangerous condition. However, as AC875 drew closer to the thunderstorm, the hazardous effects associated with convective weather affected the flight and led to the runway excursion despite the crew's extensive experience and training.

Air Canada provides its crews with explicit guidelines for circumnavigating thunderstorms en route. During the en route phase of flight, the operating procedures are unambiguous about the distances aircraft must maintain from a thunderstorm. However, like the majority of operators, the company has not developed clear procedures for circumnavigating thunderstorms during approach or landing nor is it required. Thus, pilots have a larger safety margin to avoid bad weather while en route than during approach and landing. Since Air Canada relies on the experience of its crews to determine the trajectory of the flight in the presence of thunderstorms in the vicinity of airports, the margin of safety varies from flight to flight, depending on the crew. Furthermore, under these conditions, the crew may in part base their decision to continue or interrupt the approach on the decisions of the crews that preceded them. Consequently, based on their experience, a crew might tend to follow other aircraft that landed, unaware of the dynamic and unpredictable nature of the prevailing convective weather. In this occurrence, ACA875 was the last flight to land before aircraft that followed interrupted their approach due to the proximity of the thunderstorm.

Furthermore, in the absence of predetermined triggering factors to execute a go-around, the crew continued the approach to land. During the approach, the crew estimated they had a safe lateral clearance from the runway centreline, and nothing indicated potential difficulty landing on the runway, which was clearly visible despite the rain; therefore, no alternate landing plan at CYUL was considered. It is reasonable to believe that predetermined triggering factors for the execution of a go-around would increase crews' state of preparedness.

As seen, the effects of the thunderstorm were a causal factor to the runway excursion. This occurrence is an excellent example of the sudden and simultaneous appearance of hazards associated with thunderstorms at a critical point during landing. This occurrence highlights the unpredictability of thunderstorms and the necessity to maintain a safe distance during the critical stages of flight.

The PF experienced a considerable reduction in visibility, but could still see the runway, with varying visual acuity, with the motion of the windshield wipers. According to his interpretation of the information, it was still possible to land on the runway surface. Given the outcome, it is evident that the PF did not detect the drift in time. Nonetheless, it is likely that, in the same circumstances, other pilots would react the same way and continue the landing.

This incident shows that, despite specialized training, having a detailed landing plan in place, and threat management performed in accordance with existing concepts, an experienced crew was unable to counter the factors that suddenly combined at a critical moment in the flight in order to prevent the runway excursion. This demonstrates that landings in the presence of thunderstorms near the runway present an ongoing risk to aviation safety.

3.0 Findings

3.1 Findings as to causes and contributing factors

1. During an approach in the presence of a thunderstorm, pilot-induced oscillation led to the aircraft being in a left bank as it crossed the runway threshold which, combined with a strong right crosswind, resulted in a rapid drift to the left very close to the ground.

2. Once the aircraft crossed the runway threshold, the intensity of the precipitation increased suddenly, such that the pilot flying (PF) had reduced visual references. Under these conditions, the PF did not detect the lateral movement of the aircraft in time to correct the drift before the outboard tires of the left bogie landed in the grass.

3. Given the absence of runway lighting in reduced visibility conditions, it was difficult for the pilot flying to detect the lateral movement of the aircraft over the runway and therefore to prevent the runway excursion.

4. A lateral wind shear generated by a downburst to the north of the runway suddenly increased the aircraft's drift to the left during the landing flare.

5. Runway 24R was not closed in instrument meteorological conditions, even though the runway lighting was not working. As a result, the runway was not equipped with the lights required to enable crews to clearly distinguish the lateral confines of the runway.

3.2 Findings as to risk

1. If airports are not equipped with a low-level wind shear alert system, crews landing there may not be aware of the presence of downbursts or microbursts, and therefore may be exposed to the risk of approach-and-landing accidents.

2. If a crew is unable to verify landing performance in heavy rain conditions involving a risk of hydroplaning, there is an increased risk of runway excursion.

3. If the "landing" response to the "minimum" calls reinforces the notion that landing is assured, there is a possibility that preparation for, and the decision to, go-around could be affected, increasing the risk of a landing incident or accident.

4. If the rain repellent system is unavailable or not used, there is an increased risk, in heavy rain conditions, that crews will lose the visual references necessary to avoid a runway excursion.

5. If a crew does not consider the consequences of multiple threats, there is a risk that pilots will continue a landing under conditions that are not favourable.

6. If the aircraft is drifting near the ground and pilots place the aircraft in low-energy landing regime, there is an increased risk of runway excursion.

7. If crews are not trained to retake the controls at very low altitudes or during the low-energy landing regime, there is a risk that, in the event of a problem, the pilot monitoring will not have time to identify the problem and take the appropriate measures.

8. If TC does not take action to develop the clear standards on avoiding thunderstorms during approach and landing called for in Recommendation A07-01, approaches in the presence of convective weather will continue, exposing aircraft to the multiple, unpredictable hazards associated with thunderstorms.

9. If occurrence sites are not preserved, there is a risk that evidence essential to identifying factors that contributed to an occurrence will be lost.

10. If dispatch is not aware of an aircraft communications, addressing and reporting system transmission failure, there is an increased risk that critical flight information is not received by the crew.

3.3 Other findings

1. Although the wind information at Montréal/Pierre Elliott Trudeau International Airport was transmitted to the flight by air traffic control in a timely manner, the information provided did not enable the crew to be fully aware of the rapidly changing weather conditions in the area of the runway.

2. The runway excursion was not the result of a premature crab angle reduction manoeuvre, which is often associated with landing incidents in crosswind conditions.

4.0 Safety actions

4.1 Safety Action Taken

4.1.1 Aéroports de Montréal

Aéroports de Montréal (ADM), in consultation with NAV CANADA, reviewed their operating agreement regarding approach and runway lighting, particularly with respect to conditions for closing a runway.

ADM amended its directives and procedures to provide more specific instructions to staff, particularly with respect to the types of accidents and incidents that are required to be reported to the TSB. It should be noted that the emergency response plan (ERP) is one of several documents (operational plans, directives, procedures, etc.) that outlines the actions required by ADM staff in particular.

4.1.2 Air Canada

Safety actions taken by Air Canada since October 2014, and applicable to the circumstances of this event, include the following items:

- Threat-based briefings have been developed for all departure and arrival procedures at Air Canada. This change was precipitated by AC's safety processes, supported by its latest line operations safety audit (LOSA) results and reflects best industry practice. This new approach to preparing for the departure and arrival focuses the crew on the threats and potential hazards associated with the current flight. Having identified appropriate threats and their risk, the crew is then able to discuss their expectations and any required mitigations to properly and proactively address the threats identified.
- A safety awareness article, published in the Airbus *Safety first* magazine, was sent to all pilots with regard to lateral excursions.
- Air Canada has examined existing policies and developed and offered new guidance to pilots regarding approach visibility requirements, through the Flight Operations Manual (FOM). More specifically, these enhancements include the following:

    - FOM 8.11.9.3 has been refined to ensure clarity on the requirement to go around if landing is not assured in the touchdown zone, both longitudinally and laterally;
    - FOM 8.11.9.3 item 2 has been redrafted and now requires pilots commence a go around if the required visual reference "is lost after descending below DH, DA, or MDA"; and
    - FOM 8.11.14.2 has been amended and now gives direction to pilots regarding lowest usable visibility relative to charted visibility. Air Canada elects to use visibility values similar to those permitted by the FAA, which not only address visibility but also include the standard of runway and approach lighting in

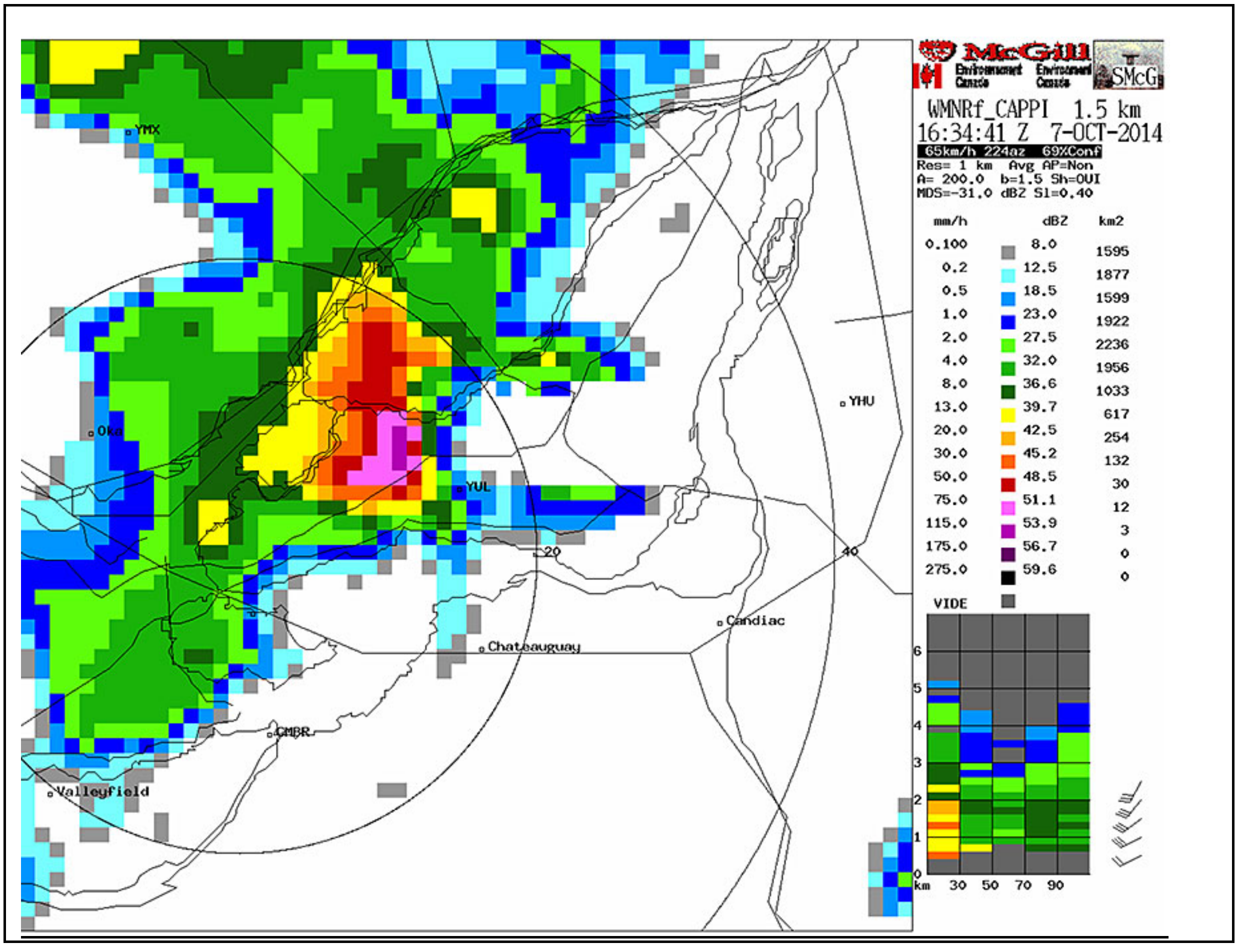
determining the minimum visibility standard. This new standard is more restrictive than the Canadian regulatory minimum.

This report concludes the Transportation Safety Board's investigation into this occurrence. The Board authorized the release of this report on 07 March 2017. It was officially released on 28 March 2017.

Visit the Transportation Safety Board'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 transportation safety issues that pose the greatest risk to Canadians. 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 – Radar image and precipitation rate



Source: Environment Canada

Appendix B – Weather conditions

Weather forecasts

The text that follows is the plain-language version of the aerodrome forecast (TAF) for Montréal/Pierre Elliott Trudeau International Airport, Quebec (CYUL) that the flight crew received from Air Canada dispatch before leaving Frankfurt-Rhein/Main (EDDF), Germany:

> [translation] Issued at 0143 and valid between 0200 and 0200 (07 October); surface wind 150°T [true] at 15 knots; visibility greater than 6 sm [statute miles] in light rain showers; broken cloud layer at 5000 feet agl [above ground level] and overcast at 12 000 feet agl; temporarily between 0500 and 1200, visibility 6 sm in light rain showers and mist; cloud layer at 2000 feet agl and overcast at 5000 feet agl; from 1200, surface wind 160°T at 12 knots gusting to 22 knots; visibility greater than 6 sm; broken-cloud layer at 5000 feet agl; between 1700 and 1900, winds will blow from 160°T at 10 knots; the next forecast will be made available by 0500.

The TAF for Montréal International (Mirabel) Airport (CYMX), their alternate airport, was also transmitted at 1122. It contained the following information:

> [translation] Issued at 1119 and valid between 1100 and 0800 (07 October); surface wind 150°T at 8 knots; visibility greater than 6 sm in light rain showers; broken cloud layer at 3000 feet agl and overcast at 6000 feet agl; temporarily between 1200 and 1300, variable wind at 15 knots gusting to 25 knots, visibility 2 sm in thunderstorms, rain and mist; cloud layer at 1000 feet agl and overcast at 3000 feet agl; from 1300, surface wind 200°T at 10 knots gusting to 20 knots, visibility greater than 6 sm, scattered cloud at 4000 feet agl; temporarily between 1300 and 1400, visibility greater than 6 sm in light rain showers, broken cloud layer to 4000 feet agl; becoming between 1800 and 1900, surface wind 170°T at 7 knots; from 0200 (07 October), surface wind 060°T at 7 knots, visibility greater than 6 sm, broken cloud layer at 6000 feet agl and overcast at 12 000 feet agl; from 0400 (07 October), surface wind 140°T at 10 knots, visibility greater than 6 sm in light rain showers and mist, broken cloud layer at 1200 feet agl and overcast at 3000 feet agl; the next forecast will be made available by 1400.

The TAF from CYUL was issued immediately prior to the landing of the aircraft, but was not received by the crew:

> [translation] Issued at 1226 and valid between 1200 and 0800 (October 07); surface wind 200°T at 12 knots gusting to 22 knots, visibility greater than 6 sm in light rain showers, a few clouds at 4000 feet agl; overcast layer at 7000 feet agl; temporarily between 1200 and 1400, prevailing visibility of 2 sm due to thunderstorms, rain and mist; broken cloud layer at 2000 feet agl and overcast at 4000 feet agl with cumulonimbus; from 1400, surface wind 160°T at 12 knots and gusts to 22 knots; visibility greater than 6 sm; a few clouds at 5000 feet agl; temporarily between 1400 and 1500, visibility greater than 6 sm with light rain showers, broken cloud layer at 5000 feet agl; between 1700 and 1900, surface wind 160°T at 10 knots, visibility above 6 sm, broken cloud layer at 6000 feet agl and overcast at 12 000 feet agl; from 0400 (07 October), surface

wind 140°T at 12 knots, visibility greater than 6 sm in light rain showers and mist, broken cloud layer at 1500 feet agl and overcast at 3000 feet agl; the next forecast will be made available by 1400.

List of weather reports for Montréal/Pierre Elliott Trudeau International Airport

Aviation routine weather report (METAR) of 1100: [translation] wind 180°T at 10 knots, visibility 12 sm, a few clouds at 4500 feet agl, scattered clouds at 6500 feet agl, overcast at 9000 feet agl, temperature 15°C, dew point 13°C, altimeter 29.87 in. Hg.; comments: 2 oktas[80] stratocumulus, 2 oktas stratocumulus, 4 oktas altocumulus, sea level pressure 115, density altitude 400 feet.

METAR of 1200: [translation] wind 180°T at 7 knots, visibility 12 sm, a few clouds at 2000 feet agl, broken cloud at 9000 and 15 000 feet agl, temperature 18°C, dew point 14°C, altimeter 29.87 in. Hg.; comments: 1 okta cumulus, 2 oktas stratocumulus, 3 oktas altocumulus, 1 okta altocumulus, cumulonimbus embedded in other cloud layers, sea level pressure 115, density altitude 400 feet.

Special report (SPECI) of 1223: [translation] wind 200°T at 9 knots, visibility 10 sm, a few clouds at 3000 feet agl with cumulonimbus, scattered cloud at 5000 feet agl, broken cloud at 7000 and 12 000 feet agl, temperature 18°C, dew point 12°C, altimeter 29.88 in. Hg.; comments: 2 oktas cumulonimbus, 1 okta stratocumulus, 3 oktas altocumulus, 1 okta altocumulus, cumulonimbus embedded in other cloud layers. Stratus fractus, sea level pressure 117, density altitude 400 feet.

SPECI of 1230: [translation] wind 240°T at 6 knots, visibility 2 sm in light thunderstorms and rain, a few clouds at 1000 feet agl, broken cloud at 2500 and thunderstorm, overcast at 5000 feet agl, temperature 17°C, dew point 12°C, altimeter 29.87 in. Hg.; comments: 2 oktas cumulonimbus, 1 okta stratocumulus, 3 oktas altocumulus, 1 okta stratus fractus, 5 oktas cumulonimbus, 2 oktas stratocumulus, mean sea level pressure 114, density altitude 400 feet.

SPECI of 1236: [translation] wind 270°T at 18 knots gusting to 27 knots, variable wind 200 to 280°T, visibility 3 sm in weak thunderstorms and rain, a few clouds at 1200 feet agl, broken cloud at 2500 and thunderstorm, overcast at 4800 feet agl, temperature 14°C, dew point 10°C, altimeter 29.89 in. Hg.; comments: 1 okta stratus fractus, 4 oktas cumulonimbus, 3 oktas stratocumulus, visibility 15 sm south, mean sea level pressure 122.

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80 The layer amounts are reported in eighths (oktas) of sky coverage.

Evolution of weather conditions from the Automatic Terminal Information Service (ATIS)

ATIS Uniform information issued at 1100: [translation] wind at 10 knots at 200° magnetic (M), visibility 12 sm, in light rain, a few clouds at 4500 feet agl, 12 000 feet agl overcast, temperature 15°C, dew point 13°C and altimeter 29.87 in. Hg.

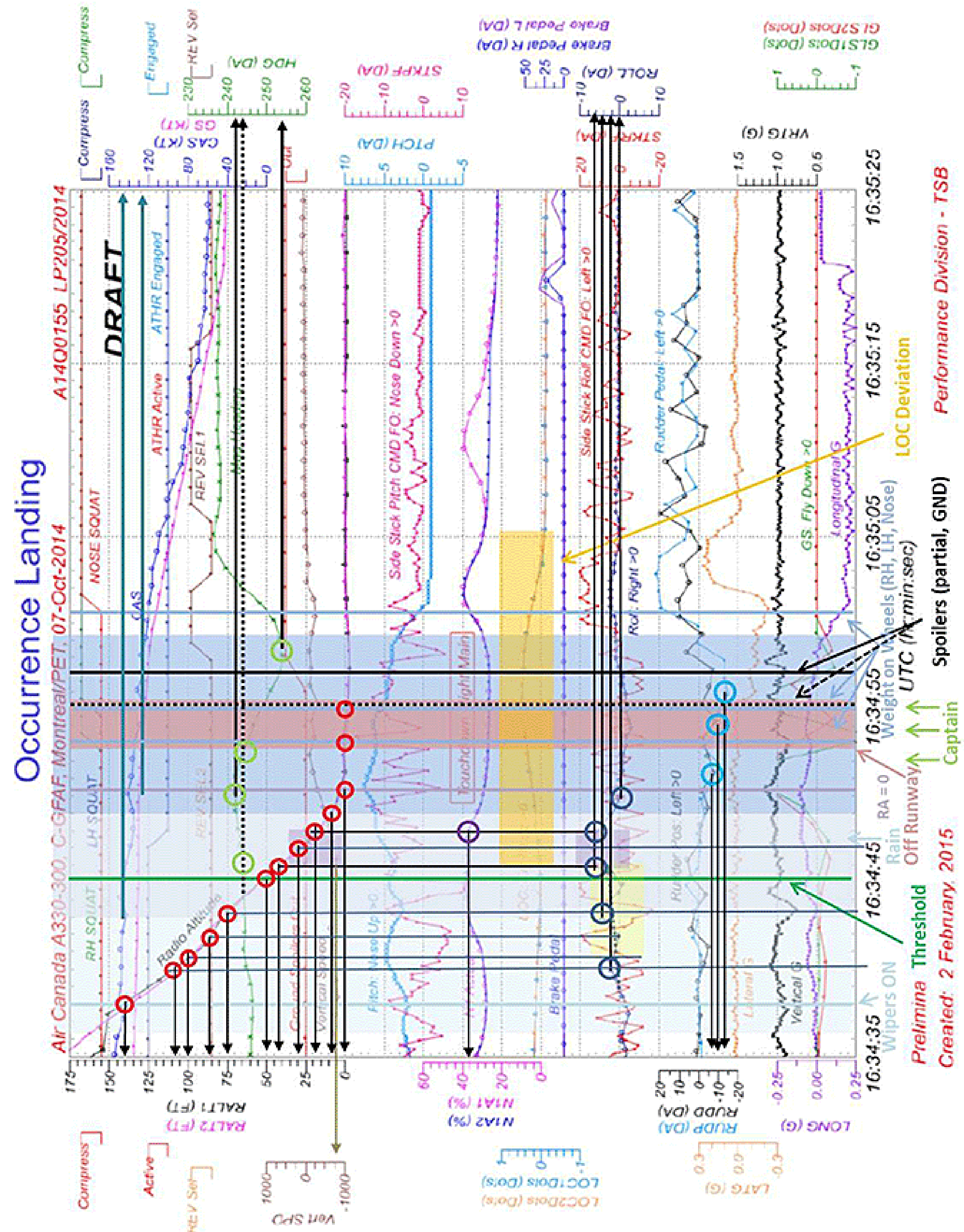
ATIS Victor information issued at 1200: [translation] wind 7 knots at 200°M, visibility 12 sm, a few clouds at 2000 feet agl, 4500 feet agl scattered, 9000 feet agl broken, 15 000 feet agl broken, temperature 18°C, dew point 14°C and altimeter 29.87 in. Hg, cumulonimbus embedded in other cloud layers.

ATIS Whiskey information issued at 1223: [translation] wind 9 knots at 220°M, visibility 10 sm, thunderstorm, a few clouds at 3000 feet agl, cumulonimbus 5000 feet agl scattered, 7000 feet agl scattered, 12 000 feet agl broken, temperature 18°C, dew point 12°C and altimeter 29.88 in. Hg.

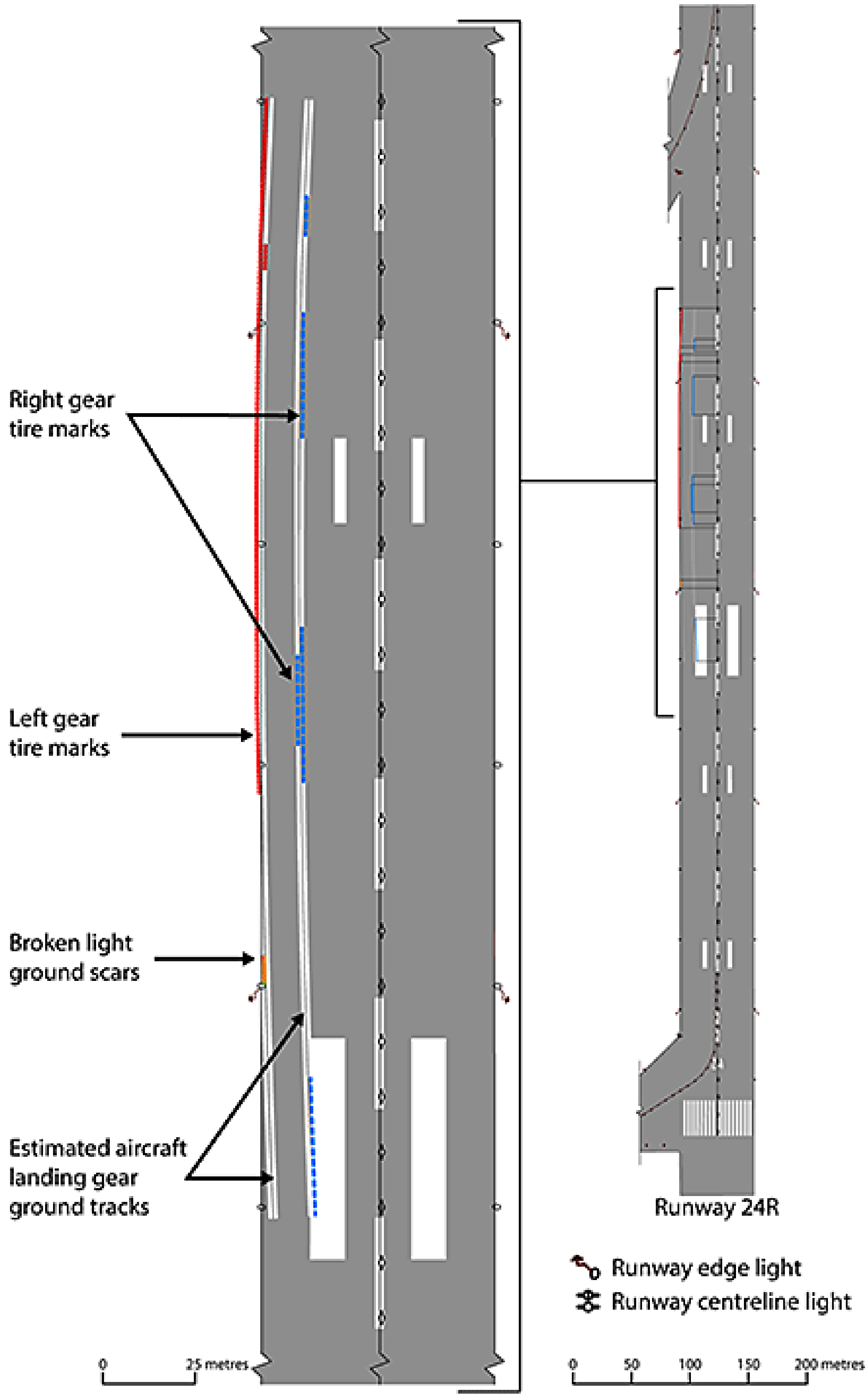
ATIS X-Ray information issued at 1230: [translation] wind 6 knots at 260°M, visibility 2 sm, thunderstorm, light rain, a few cloud at 1000 feet agl, cloud layer at 2500 feet agl broken, cumulonimbus 5000 feet agl overcast, temperature 17°C, dew point 12°C and altimeter 29.87 in. Hg.

ATIS Yankee information issued at 1236: [translation] wind 18 knots gusting to 27 knots at 290°M, variable between 200°M and 280°M, visibility 3 sm, thunderstorm, light rain, a few clouds at 1200 feet agl, cloud layer at 2500 feet agl broken, cumulonimbus, 4800 feet agl overcast, temperature 14°C, dew point 10°C and altimeter 29.89 in. Hg.

Appendix C – Flight data recorder plot



Appendix D – Site survey



Appendix E – Highlights of occurrence

Time	Event	Radar altitude (feet agl)	Distance from threshold (feet)	Airspeed (knots)	Bank (°)	Heading (°M)	Drift (°)
1232:29.5	Authorization to land						
1234:12.0	Tower informs flight: wind 300°M at 18 to 24 knots	600	-9369				
1234:38.0	Windshield wipers operating	130	-1810	149		246	-7
1234:40.0	Start of pilot-induced oscillation (PIO)	115	-1337		-2.0		
1234:42.1	Auto call-out 100 feet agl	85	-790	147	0.0	245	-5.6
1234:43.0	Increase in wind intensity	75	-570	144	-4.0	245	-5.7
1234:45.4	Crosses threshold at 50 feet agl	50	0	142	0.0	243	-6.2
1234:46.0	Start of deviation from runway centreline	40	150	143	-6.0	244	-6
1234:47.0	Auto call-out 30 feet agl	30	380	136	-6.0	242	-6.5
1234:48.3	Power lever at idle	18	658	135	-5.5	243	-6.4
1234:49.0	Maximum rain shower intensity	9	800		-2.0		-6.5
1234:49.6	Auto call-out "RETARD"	3	934	138	0.0	242	-6.6
1234:50.5	Radar altimeter at 0 feet	0	1134	140	-0.5	242	-7.1
1234:51.2	PM notes aircraft's drift			135	-0.5	244	-8.8
1234:51.4	Tires of right bogie on ground		1332	137	-0.5	242	-7.8
1234:52.4	**No. 4 tire strikes first runway edge light**		1538	136	-0.5	244	-8.5
	Tires of left bogie on ground		1561		-0.5		
1234:52.8	PM orders turn to right		1619		1.0		
1234:53.2	First tire mark on grass		1708	134		245	-9.1
1234:53.3	Runway edge light struck		1718		2.0		-9.1
1234:53.3	Compression of right bogie		1734	134		246	-9.1
1234:55.1	PM orders turn to right		2113	126		249	
1234:55.2	Runway edge light struck		2130	125		249	
1234:55.2	Compression of left bogie						
1234:55.5	**Last tire mark on grass**		2215	126		250	
1234:57.7	Sound of rain stops		2653	126		254	
1235:02.1	Compression of nosewheel		3515	117		244	
1235:05.5	Aircraft returns to runway centreline		4097	107		237	

Legend

Start, height, and end of rain shower (light blue)

Deviation from and return to runway centreline (orange)

Aircraft wheel touchdown sequence (green)

Start and finish of runway excursion