Transportation
Safety Board
of Canada

Bureau de la sécurité
des transports
du Canada

AIR TRANSPORTATION SAFETY INVESTIGATION REPORT A18A0085

RUNWAY OVERRUN

Sky Lease Cargo
Boeing 747-412F, N908AR
Halifax/Stanfield International Airport, Nova Scotia
07 November 2018

Canada

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Citation

Transportation Safety Board of Canada, *Air Transportation Safety Investigation Report* A18A0085 (released 29 June 2021).

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Air transportation safety investigation report A18A0085

Cat. No. TU3-10/18-0085E-PDF
ISBN: 978-0-660-39041-3

This report is available on the website of the Transportation Safety Board of Canada at www.tsb.gc.ca

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Executive summary

The Sky Lease Cargo Boeing 747-412F aircraft (U.S. registration N908AR, serial number 28026) was conducting flight 4854 (KYE4854) from Chicago/O'Hare International Airport, Illinois, U.S., to Halifax/Stanfield International Airport, Nova Scotia, with 3 crew members, 1 passenger, and no cargo on board.

The crew conducted the Runway 14 instrument landing system approach. When the aircraft was 1 minute and 21 seconds from the threshold, the crew realized that there was a tailwind; however, they did not recalculate the performance data to confirm that the landing distance available was still acceptable, likely because of the limited amount of time available before landing. The unexpected tailwind resulted in a greater landing distance required, but this distance did not exceed the length of the runway.

The aircraft touched down firmly at approximately 0506 Atlantic Standard Time, during the hours of darkness. After the firm touchdown, for undetermined reasons, the engine No. 1 thrust lever was moved forward of the idle position, causing the speed brakes to retract and the autobrake system to disengage, increasing the distance required to bring the aircraft to a stop. In addition, the right crab angle (4.5°) on initial touchdown, combined with the

crosswind component and asymmetric reverser selection, caused the aircraft to deviate to the right of the runway centreline.

During the landing roll, the pilot monitoring's attention was focused on the lateral drift and, as a result, the required callouts regarding the position of the deceleration devices were not made.

Although manual brake application began 8 seconds after touchdown, maximum braking effort did not occur until 15 seconds later, when the aircraft was 800 feet from the end of the runway. At this position, it was not possible for the aircraft to stop on the runway and, 5 seconds later, the aircraft departed the end of the runway at a speed of 77 knots and came to a stop 270 m (885 feet) past the end.

The aircraft struck the approach light stanchions and the localizer antenna array. The No. 2 engine detached from its pylon during the impact sequence and came to rest under the left horizontal stabilizer, causing a fire in the tail section following the impact. The emergency locator transmitter activated. Aircraft rescue and firefighting personnel responded. All 3 crew members received minor injuries and were taken to the hospital. The passenger was not injured.

During the overrun, the aircraft crossed a significant drop of 2.8 m (9 feet) approximately 166 m (544 feet) past the end of the runway and was damaged beyond repair. While this uneven terrain was beyond the 150 m (492 feet) runway end safety area proposed by Transport Canada, it was within the recommended International Civil Aviation Organization runway end safety area of 300 m (984 feet). In 2007, the Board recommended that

> the Department of Transport require all Code 4 runways to have a 300 m runway end safety area (RESA) or a means of stopping aircraft that provides an equivalent area of safety.
>
> **TSB Recommendation A07-06**

In addition, runway overruns is one of the issues on the TSB's Watchlist 2020. The TSB Watchlist identifies the key safety issues that need to be addressed to make Canada's transportation system even safer.

The investigation included a thorough fatigue analysis, which identified the presence of 2 fatigue risk factors that would have degraded the crew's performance during the approach and landing: the timing of the flight and insufficient restorative sleep in the 24-hour period leading up to the occurrence. Fatigue management is also one of the safety issues on the TSB's Watchlist 2020.

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1.0 FACTUAL INFORMATION

Information about the use of on-board recordings

The International Civil Aviation Organization's (ICAO's) Annex 13* requires states conducting accident investigations to protect cockpit voice recordings. Canada complies with this requirement by making all on-board recordings privileged in the *Canadian Transportation Accident Investigation and Safety Board Act*. While the TSB may make use of any on-board recording in the interests of transportation safety it is not permitted to knowingly communicate any portion of an on-board recording that is unrelated to the causes or contributing factors of an accident or to the identification of safety deficiencies.

The reason for protecting on-board recordings lies in the premise that these protections help ensure that pilots will continue to express themselves freely and that this essential material is available for the benefit of safety investigations. The TSB has always taken its obligations in this area very seriously and has vigorously restricted the use of on-board recording data in its reports. Unless the on-board recording is required to both support a finding and identify a substantive safety deficiency, it will not be included in the TSB's report.

To validate the safety issues raised in this investigation, the TSB has made use of the available on-board recording in its report. In each instance, the material has

been carefully examined in order to ensure that it is required to advance transportation safety.
* International Civil Aviation Organization (ICAO), Annex 13 to the *Convention on International Civil Aviation, Aircraft Accident and Incident Investigation*, 11th Edition (July 2016), paragraph 5.12.

1.1 History of the flight

The Sky Lease Cargo Boeing 747-412F aircraft (U.S. registration N908AR, serial number 28026) was conducting flight 4854 (KYE4854), a multi-leg flight that originated at Chicago/O'Hare International Airport (KORD), Illinois, U.S., with a final destination of Changsha/Huanghua Airport (ZGHA), Hunan, China.

The first leg of the flight was a positioning flight to Halifax/Stanfield International Airport (CYHZ), Nova Scotia, where cargo would be loaded onto the aircraft. The second leg of the flight was to Ted Stevens Anchorage International Airport (PANC), Alaska, U.S., for a technical stop to refuel and change crews before the aircraft would depart on its final leg to ZGHA.

The occurrence flight was scheduled to depart KORD at 1230[1] on 06 November 2018, with an augmented crew[2] made up of a captain, first officer (FO), and international relief officer (IRO).[3] This augmented crew would operate the first 2 legs of the flight, from KORD to CYHZ and then to PANC. Also on board the occurrence flight was a deadheading senior captain, who was in the passenger area on the upper flight deck during the flight.

The captain and FO arrived in Chicago on the evening of 05 November, and the IRO arrived in Chicago on the morning of 06 November.

On the morning of 06 November, the captain consulted with the company's flight operations, and they decided jointly to delay the departure by 13.5 hours, until 0200 on 07 November. The decision was based on forecast low ceilings and visibility that were below the company's approach minima for the active runway at CYHZ. The rest of the crew and the deadheading captain were informed of the delay by telephone and email.

In accordance with company policy, flight dispatch called the crew at 2300, 3 hours before the new departure time. The crew arranged to be picked up from the hotel at 0000.

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[1] All times are Atlantic Standard Time (Coordinated Universal Time minus 4 hours).

[2] Augmented crew "means a flightcrew that has more than the minimum number of flightcrew members required by the airplane type certificate to operate the aircraft to allow a flightcrew member to be replaced by another qualified flightcrew member for in-flight rest." (Source: Federal Aviation Administration, *Code of Federal Regulations*, Title 14: Aeronautics and Space, Chapter I: Federal Aviation Administration, Department of Transportation, Subchapter G: Air Carriers and Operators for Compensation or Hire: Certification and Operations, Part 117: Flight and Duty Limitations and Rest Requirements: Flightcrew members, section 117.3: Definitions.)

[3] An international relief officer (IRO) is a member of an augmented crew who serves as an additional flight crew member on aircraft that require 2 pilots. The IRO is a captain or first officer who possesses a type rating for the aircraft and will be second-in-command when actually serving as the IRO.

Operational paperwork—such as flight planning, weather, and NOTAMs—was emailed to the crew, who printed these documents at the hotel.

The crew received a briefing by telephone from flight dispatch about the route, the weather, and applicable NOTAMs. The deadheading pilot was included in the pre-departure planning discussion because he had several years of experience operating these flights with the company and he had flown into CYHZ the preceding week.

The pre-departure planning included preparing the weight and balance form which provided the departure and arrival runways. The Max Allowed Gross Weight Landing section of this form indicated 302 092 kg and flaps 25 for a landing on Runway 23, which was 10 500 feet (3200 m) long. However, after reviewing the weather and NOTAMs, the crew planned to land on Runway 14, which was 7700 feet (2347 m) long. After arriving at KORD, the crew met with maintenance staff, who provided a briefing of work completed on the aircraft while it was at KORD.

Following a 1-hour delay due to a paperwork issue, the flight departed KORD at 0302 (14.5 hours after the original planned departure time) for the 2-hour flight to CYHZ. The captain was the pilot flying (PF) and occupied the left seat, while the FO was the pilot monitoring (PM) and occupied the right seat. The IRO was seated in the jump seat behind the PM.

During the cruise portion of the flight, the crew reviewed the weather at CYHZ based on automatic terminal information service (ATIS)[4] information Sierra,[5] which was issued at 0403 via the aircraft communication addressing and reporting system (ACARS). ATIS information Sierra indicated the following weather at 0400:

- Winds from 230° magnetic (M) at 10 knots
- Visibility 7 statute miles (SM) in light rain and mist
- Broken ceiling at 500 feet above ground level (AGL)
- Overcast layer of cloud at 3600 feet AGL
- Temperature and dew point 15 °C
- Altimeter setting 29.68 inches of mercury (inHg)

ATIS information Sierra also indicated that

- the landing runway was Runway 14 and the departing runway was Runway 23;
- the runway surfaces were bare and wet;

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[4] "ATIS [automatic terminal information service] is the continuous broadcasting of recorded information for arriving and departing aircraft on a discrete VHF/UHF [very high/ultrahigh] frequency. Its purpose is to improve controller and flight service specialist effectiveness and to relieve frequency congestion by automating the repetitive transmission of essential but routine information." (Source: Transport Canada, TP14371, *Transport Canada Aeronautical Information Manual* [TC AIM], RAC – Rules of the Air and Air Traffic Services Communications [11 October 2018], section 1.3.)

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

- the Runway 23 threshold was displaced;
- the instrument landing system (ILS) for Runway 23 and the Runway 05 localizer were unserviceable;
- Taxiway B was closed; and
- pilots should advise air traffic control (ATC) of the requested approach on initial contact.

The crew inferred that Runway 23 was not available to them for landing.

After reviewing ATIS information Sierra, at 0433, the PF conducted an approach briefing for Runway 14. The briefing included the landing distance required and approach speed based on the landing weight in the flight management system. The briefing also included the planned flap configuration of flaps 25 and the autobrake setting 4. According to data from the CYHZ tower, from 0413 until 0430, the winds were from 220°M to 230°M at 15 knots, gusting to 21 knots. At 0435, the winds were from 240°M at 15 knots, gusting to 22 knots.

At 0443, when the occurrence aircraft was 153 nautical miles (NM) from CYHZ, the crew began a descent from the cruising altitude of flight level (FL) 370.[6]

At 0446, the Moncton Area Control Centre (ACC) controller asked the crew which approach they were requesting for CYHZ. The crew requested the Runway 14 ILS approach, and the controller cleared the flight directly to the intermediate fix TETAR (Appendix A).

Shortly before the occurrence flight landed, 3 other aircraft landed at CYHZ:

- a Boeing 757 aircraft landed on Runway 14 at 0444;
- a Boeing 757 aircraft landed on Runway 23 at 0452; and
- a Learjet 35 aircraft landed on Runway 14 at 0454.[7]

The occurrence flight crew was not on the same radio frequency as these other aircraft; therefore, they did not hear any communication regarding the arrivals and continued to be unaware that Runway 23 was available for landing. The crew did not request any pilot reports (PIREPs) from ATC during the flight, and ATC did not offer any information regarding the other aircraft that had landed.

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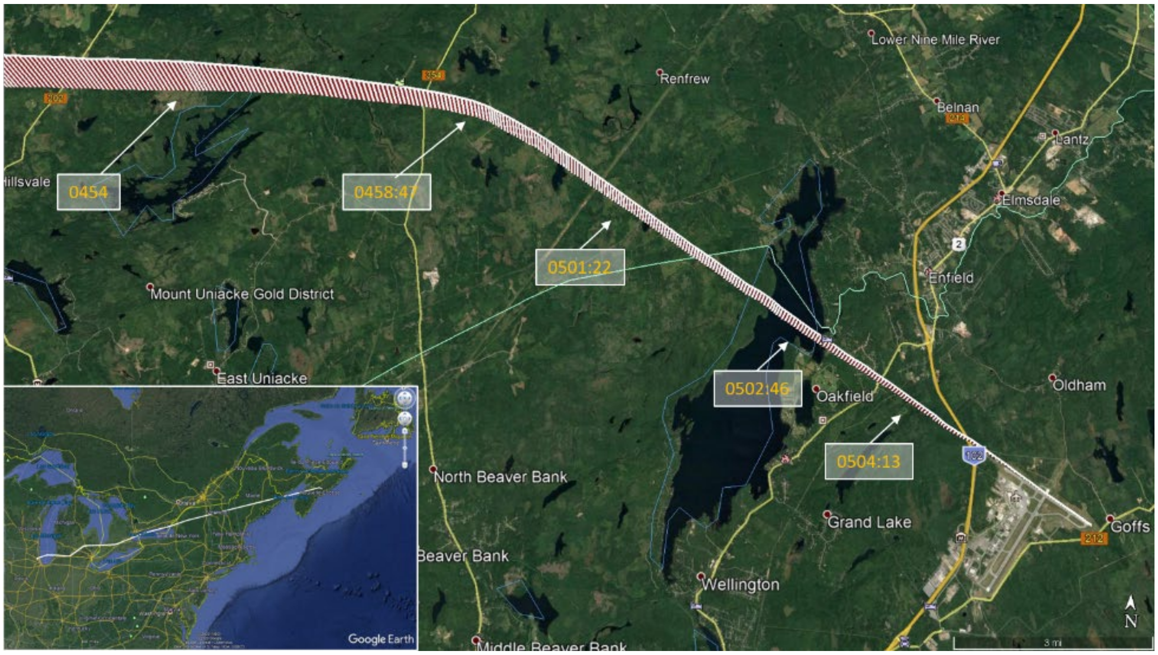
[6] Flight level (FL) is "the altitude expressed in hundreds of feet indicated on an altimeter set to 29.92 in. of mercury or 1013.2 mb." (Source: Ibid., GEN – General [11 October 2018], section 5.1). In this case, flight level 370 means 37 000 feet above mean sea level.

[7] Aircraft arrival times are based on NAV CANADA data.

Figure 1. Flight profile (Source: Google Earth, with TSB annotations)



At 0454, the CYHZ tower controller informed the Moncton area control centre (ACC) controller that the arrival runway was being changed from Runway 14 to Runway 23, due to wind direction change, and that the approach into the airport was now the Runway 23 area navigation (RNAV) approach. When this exchange of information took place, the occurrence aircraft was descending through 13 000 feet ASL and approximately 52 NM from the airport (Figure 1). The runway change information was not communicated to the crew.

At 0458, the crew was cleared for the Runway 14 ILS approach. At approximately the same time, the ATIS was updated to information Tango. The only significant changes were to the arrival runway (now Runway 23) and the approach in use (now the Runway 23 RNAV approach).

At 0501, the Moncton ACC controller instructed the occurrence crew to transfer to the CYHZ tower frequency. On initial contact, the CYHZ tower controller informed the crew that the winds were from 260°M at 15 knots and asked if the crew had ATIS information Tango. The crew replied that they had Tango; however, they remained unaware that Runway 23 was available.

At 0502:46, when the aircraft was 8.6 NM from Runway 14, the CYHZ tower controller informed the crew that the winds were from 260°M at 16 knots, gusting to 21 knots. These winds would result in a steady 7-knot tailwind component. The controller asked the crew to confirm whether Runway 14 was still acceptable. The PM confirmed that Runway 14 was acceptable, and the tower controller repeated that the winds were from 260°M at 16 knots, gusting to 21 knots, and cleared the aircraft to land on Runway 14. The tower controller's question as to the acceptability of Runway 14 prompted a brief conversation among the crew members about the perceived lack of runway options. However, the crew's understanding was that only Runway 14 was available to them, and so continued the approach to Runway 14.

At 0504:10, the aircraft passed the final approach fix IMANO on the localizer and glideslope, and stabilized at the planned approach indicated airspeed (IAS) of 164 knots, with a ground speed of 185 knots. Just after passing the final approach fix, when the aircraft was 4.0 NM, or 1 minute and 21 seconds, from the threshold of Runway 14, the crew confirmed the presence of a tailwind and the PF confirmed with the PM the direction and speed of the wind. However, they did not change their approach speed. When the aircraft was passing through 800 feet AGL, the PF reviewed the go-around procedure with the crew.

At 0504:58, when the aircraft was 1.7 NM from the threshold, its IAS was 164 knots, and its ground speed was 174 knots. The tower controller reported that the winds were from 250°M at 15 knots, gusting to 21 knots.

At 0505:10, when the aircraft was at 400 feet AGL, the PF disengaged the autothrottle and autopilot. The IAS was 167 knots, and the ground speed was 174 knots.

At 0505:34, the aircraft crossed the threshold of Runway 14 at a height of 62 feet AGL, 12 feet above the threshold-crossing altitude of 50 feet, 27 feet left of centreline, with an IAS of 173 knots and ground speed of 179 knots.

At 0505:36, the thrust levers were brought to idle, the pitch attitude increased from 0.9° to 2.6° nose-up, and the aircraft touched down firmly 1350 feet past the threshold of Runway 14. At that point, it had an IAS of 168 knots and ground speed of 179 knots.

Over the following 40 seconds, a number of events happened in rapid succession (Appendix B).

The aircraft landed on the runway centreline with a crab angle of 4.5° to the right and at an average rate of lateral displacement of approximately 6 feet per second over the next 4 seconds. The firm (1.75*g*) landing and the subsequent deviation from the runway centreline to the right surprised the PM, whose attention was directed outside the aircraft. The crew did not experience the expected deceleration associated with autobrake 4 selection.

The auto speed brake lever moved to the UP position, and the spoiler panels began to deploy up to 30%. The No. 1 thrust lever was advanced above idle; however, this action was not noticed by the crew. The advancing of the thrust lever caused the speed brakes to move back to the DOWN position and retract the spoiler panels. As the PF was bringing the No. 2, No. 3, and No. 4 thrust levers into reverse, the air-ground logic switches in the landing gear changed momentarily to AIR mode, meaning the weight of the aircraft was not completely on the wheels, before switching back to GROUND mode.

At 0505:44, the No. 1 thrust lever was reduced to just above flight idle (6 seconds, approximately 1700 feet, after touchdown), which allowed the speed brakes to fully deploy. Shortly after, the autobrake selector disarmed.

At 0505:46, the PF realized that the aircraft was not decelerating as expected and began using manual braking. At 0505:53, the PF called out, “Max braking,” and the PM attempted to rearm the autobrake selector. The PM did not make the callouts for the landing roll-out procedure.

At the same time, the PF used the rudder pedals, switching between neutral and maximum deflection to the left to regain the centreline.

At 0505:59, the aircraft’s ground speed was 100 knots, and the aircraft was 800 feet from the end of the runway. There was markedly greater deceleration for the next 7 seconds, at which point the aircraft overran the runway. The aircraft was travelling at a ground speed of 77 knots at the time.

After the aircraft departed the paved surface, the landing gear left ruts (ground scars) in the grass (Appendix C).

At 0506:11, while travelling at a ground speed of 50 knots, the aircraft struck the ILS localizer antenna on top of a berm. When the aircraft struck the antenna, the emergency escape devices inside the cockpit were projected from their storage compartment, injuring the IRO.

The nose of the aircraft came to rest 270 m (885 feet) past the runway threshold, 21 m (70 feet) to the right of the extended centreline, and 47 m (155 feet) from a public road (Figure 2). The aircraft was on a heading of 166°M (23° right of the runway heading).

Figure 2. Occurrence aircraft’s final position (Source: Steve Lawrence / CBC Licensing)

The CYHZ tower controller activated the crash alarm at 0506. Halifax International Airport Authority (HIAA) aircraft rescue and firefighting (ARFF) personnel responded; 5 vehicles arrived at the occurrence site 1 minute and 40 seconds later.

The No. 2 engine separated from the wing and was jammed under the left horizontal stabilizer and tail section, causing a fire in the tail section of the aircraft after the impact. ARFF extinguished the fire and laid foam to prevent spilled fuel from igniting. The emergency locator transmitter activated, and the tower controller requested that ARFF shut off the device. With the assistance of ARFF, the crew evacuated through the main deck entry door (1L) using a ladder.

1.2 Injuries to persons

Table 1. Injuries to persons

Degree of injury	Crew	Passengers	Persons not on board the aircraft	Total by injury
Fatal	0	0	0	0
Serious	0	0	0	0
Minor	3	0	0	3
Total injured	3	0	0	3

1.3 Damage to aircraft

The aircraft was damaged beyond repair.

1.4 Other damage

The ILS localizer antenna array was destroyed when it was struck by the aircraft. Fuel contaminated the soil adjacent to where the aircraft came to rest, and the aircraft damaged or destroyed several runway end lights and lighting stanchions.

1.4.1 Environmental cleanup

In response to the occurrence, the HIAA activated its emergency response plan, which included an immediate environmental assessment of the site and surrounding area. The HIAA ARFF and airfield maintenance personnel dug trenches and implemented environmental controls and other mitigation strategies.

An estimated 136 600 L of fuel were on board the aircraft upon landing. As part of the environmental cleanup of the occurrence site, the aircraft operator’s insurer hired a third-party contractor to remove the remaining fuel from the aircraft, and 107 250 L of fuel were recovered. Therefore, it is estimated that 29 350 L of fuel spilled.

HIAA immediately began to arrange the environmental cleanup of the occurrence area. The aircraft operator’s insurer hired an environmental consultant to remediate the site, and HIAA also hired another environmental consultant to oversee the remediation efforts. During the remediation, 278 450 L of a fuel/water mixture were removed from the site, treated, and disposed of at an approved water treatment facility. In addition, 4998 tons of soil were removed from the site, treated, and disposed of at an approved soil disposal facility.

1.5 Personnel information

Table 2. Personnel information

	Captain	First officer	International relief officer
Pilot licence	U.S. airline transport pilot license (ATPL)	U.S. ATPL	U.S. ATPL
Medical expiry date	28 February 2019	31 January 2019	31 January 2019
Total flying hours	21 134	7404	5005
Flight hours on type	166	1239	1675
Flight hours in the 7 days before the occurrence	14	14	14
Flight hours in the 30 days before the occurrence	71.2	74.4	47.5
Flight hours in the 90 days before the occurrence	148	187	134
Flight hours on type in the 90 days before the occurrence	148	187	134
Hours on duty before the occurrence	5	5	5
Hours off duty before the work period*	13 hours	13 hours	13 hours
Takeoffs during the day in the 90 days before the occurrence	9	5	2
Takeoffs during the night in the 90 days before the occurrence	4	1	2
Landings during the day in the 90 days before the occurrence	9	4	2
Landings during the night in the 90 days before the occurrence	4	1	2

* These hours represent the hours off duty during the day of 06 November, between the time the decision was made to delay the flight in the morning to the start of duty that night.

1.5.1 Captain

The captain was hired in February 2018 as a direct-entry captain. He completed all required company training, which included crew resource management (CRM) and fatigue risk management training, the month that he was hired. The captain completed a proficiency check in August 2018 and was released to line flying in September. At the time of the occurrence, he held a U.S. airline transport pilot license (ATPL) with an instrument rating.

Section 121.436 of the U.S. *Federal Aviation Regulations* (FARs) states the experience requirements for pilots operating under Part 121. The occurrence captain had more than 1000 hours PIC experience flying large aircraft worldwide, but did not meet the required

U.S.-based experience of paragraph 121.436(a)(3) of the FARs,[8] nor did he have a U.S. Federal Aviation Administration (FAA) exemption for these requirements. The lack of required U.S.-based experience was not considered a factor in this occurrence.

1.5.2 First officer

The FO was hired in July 2016. He completed all required company training, which included CRM and fatigue risk management training, in October 2018 and completed a proficiency check in September 2018. At the time of the occurrence, he held a U.S. ATPL with an instrument rating. He was qualified and certified in accordance with Part 121 of the U.S. FARs.

1.5.3 International relief officer

The IRO was hired in September 2015. He completed all required company training, which included CRM and fatigue risk management training, in October 2017 and completed a proficiency check in November 2017. At the time of the occurrence, he held a U.S. ATPL with a valid instrument rating. He was qualified and certified in accordance with Part 121 of the U.S. FARs.

1.6 Aircraft information

1.6.1 General

Table 3. Aircraft information

Manufacturer	Boeing
Type, model and registration	Boeing 747-412F, N908AR
Year of manufacture	1997
Serial number	28026
Certificate of airworthiness/flight permit issue date	Issued on 28 April 2017
Total airframe time	92 471 hours / 16 948 cycles
Engine type (number of engines)	Pratt & Whitney PW4056 (4)
Maximum allowable takeoff weight	394 625 kg
Recommended fuel type(s)	Jet A, Jet A-1, Jet B
Fuel type used	Jet A-1

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[8] FAR 121.436(a)(3) requires a pilot who is serving as pilot-in-command under FAR Part 121 to have "1,000 hours as second in command in operations under this part, pilot in command in operations under §91.1053(a)(2)(i) of this chapter, pilot in command in operations under §135.243(a)(1) of this chapter, or any combination thereof." (Source: Federal Aviation Administration, *Code of Federal Regulations*, Title 14: Aeronautics and Space, Chapter I: Federal Aviation Administration, Department of Transportation, Subchapter G: Air Carriers and Operators for Compensation or Hire: Certification and Operations, Part 121: Operating Requirements: Domestic, Flag, and Supplemental Operations, section 121.436.)

The Boeing 747-412F is a 4-engine, wide-body transport category aircraft. The aircraft design can accommodate different configurations: passenger, freighter, and others. The occurrence aircraft was in the freighter configuration.

Records indicate that the occurrence aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures. The weight and centre of gravity were within the prescribed aircraft limits. A number of the aircraft components were shipped to the TSB Engineering Laboratory in Ottawa, Ontario, where examinations found no indication of a component or system failure before the landing.

1.6.2 Landing gear

Boeing 747-400 series aircraft are supported on 4 main landing-gear assemblies and 1 nose landing-gear assembly. The main landing gear is made up of 2 assemblies under the body of the aircraft and 2 assemblies under the wings. The 2 assemblies under the wings are offset by approximately 19 feet (left and right) from the centre of the aircraft.

1.6.3 Brakes

All of the aircraft’s main wheel brakes are of the multi-disk type and have replaceable linings and segmented rotor brake disks. The brakes are fitted with automatic adjusters to compensate for brake wear. Each brake unit contains 2 wear-indicator pins to provide a visual indication as the wear approaches the limits.

For normal operation of the brakes, hydraulic system No. 4 supplies hydraulic pressure. For alternate operation, hydraulic system No. 1 or No. 2 can supply hydraulic pressure to the brakes.

The brake control system supplies brake torque control, anti-skid protection, and automatic braking (autobrake) during landing, takeoff, and taxiing. The brake torque control monitors torque of the brake during operation and releases brake pressure before the torque exceeds the maximum safe limit.

The flight data recorder (FDR) on the occurrence aircraft did not record brake pressure and brake pedal position, nor was it required to by regulation. The TSB laboratory determined that the lateral weight distribution did not cause the brake torque control to engage or prevent full brake pressure from being applied to the brakes.

The TSB laboratory also examined maintenance records associated with the landing-gear wheel assemblies and brake wear pin extensions. The brake wear indicator pin extensions were well within the manufacturer’s limits. No existing anomalies were found on the brake units that would have precluded normal operation during the occurrence flight.

1.6.3.1 Anti-skid system

The anti-skid system prevents wheels from locking up by controlling the brake pressure through anti-skid valves.

The anti-skid system electronically compares the airplane's ground speed from the internal reference system with the wheel speed from the wheel-speed transducers to supply touchdown protection and hydroplane protection. If there is a difference between ground speed and wheel speed, error signals operate anti-skid valves that release brake pressure and prevent wheel lock.

Wheel speeds (actual and from the transducers) are not recorded on the FDR. In this occurrence, non-volatile memory (NVM) data did not reveal any anti-skid malfunctions, nor were there any fault messages on the engine indicating and crew alerting system (EICAS) related to the anti-skid system. Inspection of anti-skid components did not reveal any abnormalities.

A physical examination of the tire condition of all 16 main wheels found they were well within the required specification for tire wear. There were no indications of reverted rubber hydroplaning (refer to Section 1.16.2.3) on any of the examined tires. All wheel overpressure relief valves and thermal relief plugs were intact.

1.6.3.2 Autobrake system

The autobrake system supplies braking at a constant deceleration rate without manual input from the flight crew.

The autobrake control panel contains a rotary selector switch that can be set to OFF, DISARM, 1, 2, 3, 4, MAX AUTO, or RTO (rejected takeoff). The rate of deceleration depends on the switch position. Selecting autobrake 1 provides a deceleration rate of 4.0 feet per second squared, while selecting MAX AUTO provides a deceleration rate of 11.0 feet per second squared.

The autobrake is applied if the system is armed, all thrust levers are at idle, both left-hand and right-hand air/ground relay systems are in ground mode, and the wheels have spun up to at least 60 knots. While on the ground, the autobrake system is disarmed if any thrust lever is advanced out of idle for more than 3 seconds or if manual braking is applied.

The aircraft manufacturer recommends the use of the autobrake system when the runway has limited distance and when the aircraft is landing on slippery surfaces or with a crosswind. This can ensure lower brake temperatures, reduced tire and brake wear, and reduced stopping distances on slippery surfaces. The autobrake system commands brake pressure to target a desired deceleration rate. As noted in the flight crew training manual (FCTM), after touchdown, crew members should be alert for autobrake disengagement and notify the PF if this occurs.[9]

The average deceleration during the occurrence rollout was 6.2 feet per second squared. If autobrake 4 had remained engaged, the system design would have provided a target deceleration of 7.5 feet per second squared.

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[9] Boeing Aircraft Company, *747 Flight Crew Training Manual*, revision 7 (30 June 2017), Chapter 6: Landing, p. 6.26.

1.6.3.3 Auto speed brake system

Speed brakes are designed to increase drag and reduce lift in flight and during the landing roll. When the aircraft is in flight, 8 of the 12 spoilers are used as speed brakes. When the aircraft is on the ground, all of the spoilers are used to slow the aircraft. Upon touchdown, the speed brakes can be extended manually or automatically.

The speed brakes are normally extended automatically if the following conditions are met:

- the speed brake control lever is in the ARM position;
- both left-hand and right-hand air/ground relay systems are in ground mode;
- hydraulic system No. 1 or No. 4 is pressurized; and
- thrust levers No. 1 and No. 3 are below approximately 20° thrust lever angle.[10]

When the speed brakes are extended automatically, the auto speed brake system moves the speed brake lever aft to the UP position (Figure 3), which, in turn, raises the spoiler panels on the wings. This significantly reduces the lift generated by the wings and transitions the weight of the aircraft onto the wheels. If the auto speed brakes are not deployed properly, the landing distance required on a dry runway may be increased by as much as 870 feet. The FCTM contains 2 specific sentences about the importance of deploying auto speed brakes:

- “If the speedbrakes are not raised after touchdown, braking effectiveness may be reduced initially as much as 60% […].”[11]
- “Pilot awareness of the position of the speedbrake lever during the landing phase is important in the prevention of over-run.”[12]

The automation of the speed brakes relieves the flight crew from the task of pulling the speed brake lever aft to the UP position and allows them to focus on other critical tasks, such as straightening the aircraft and removing the crab angle from crosswind correction, completing the flare, manoeuvring the aircraft onto the centreline, and applying reverse thrust.

If the control lever is not in the ARM position, the auto speed brake actuator moves the speed brake lever aft to the UP position when reverse thrust lever No. 2 or No. 4 is deployed and the other conditions for automatic extension are met.

If the speed brake lever begins moving aft toward the UP position, but the conditions are not met, the speed brake lever automatically moves back to the DN (down) position, which retracts the spoiler panels.

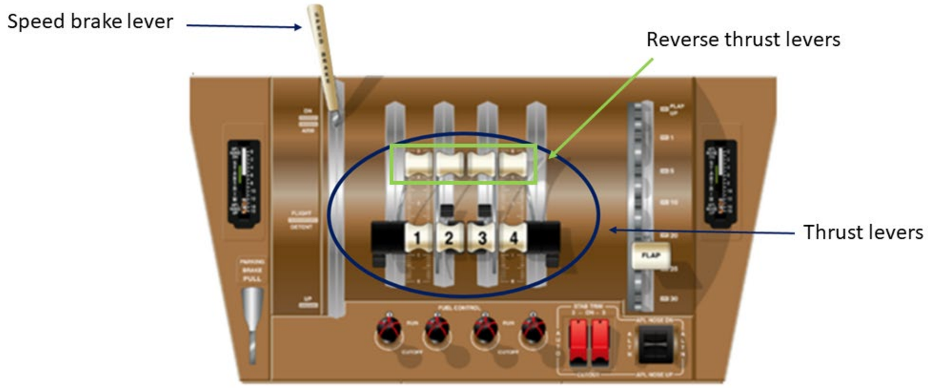
---

[10] Thrust lever angle is the angle between the thrust lever and the idle stop.

[11] Boeing Aircraft Company, *747 Flight Crew Training Manual*, revision 7 (30 June 2017), Chapter 6: Landing, p. 6.20.

[12] Ibid.

Figure 3. Boeing 747-400 centre pedestal (Source: Copyright © Boeing. Reprinted with permission of The Boeing Company, with TSB annotations)



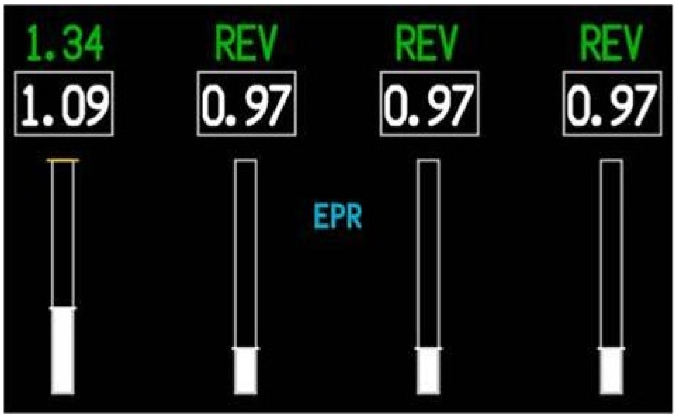
1.6.4 Thrust reversers

The fan section of each engine is equipped with a hydraulically actuated, cascade-type thrust reverser. The thrust reversers are for ground use only and are used only to decrease the speed of the airplane during landings or rejected takeoffs.

For the thrust reverser to operate, the airplane must be on the ground to close the air/ground relays, and the forward thrust lever must be in the idle position. When the reverse thrust lever is lifted, thrust reversers are deployed.

The reverse thrust indication is displayed on the primary EICAS display (Figure 4). A thrust reverser status annunciator is positioned above each digital exhaust pressure ratio indicator. The reverse (REV) annunciator appears amber when the related reverser is unlocked or moving. The annunciator changes to green when the reverser is fully deployed. When the reverser is stowed and locked, the annunciator is no longer visible.

Figure 4. Boeing 747 engine indicating and crew alerting system reverse thrust indication (Source: Boeing proprietary information. © Boeing. Reprinted with permission of The Boeing Company)



During the occurrence landing, 1 second after touchdown, the No. 1 thrust lever was advanced past flight idle, which inhibited the reverse thrust lever from deploying reverse thrust on that engine. The thrust reversers on engines No. 2, No. 3, and No. 4 operated as designed, with no anomalies.

1.6.5 Emergency exits

1.6.5.1 General

The Boeing 747-400F is equipped with 1 upper deck crew service door, 2 main deck entry doors, and 5 cargo doors. It is also equipped with an overhead hatch in the cockpit.

1.6.5.2 Upper-deck crew service door

The crew service door on the upper deck is located behind the cockpit, on the right side of the aircraft. It is used as a normal entry and exit as well as an emergency exit.

An emergency escape slide pack is mounted on and moves along tracks located to the right of the bulkhead. It runs horizontally and parallel to the door. To deploy the escape slide, the door must be open; the escape slide pack is then placed in front of the door and tilted, and the escape slide release handle is pulled.

1.6.5.3 Main deck entry door

The 2 main deck entry doors are located on the left side of the aircraft: 1 at the front of the aircraft and 1 at the rear. An escape rope that can be used in an emergency is stowed above both doors. The front entry door, identified as 1L, can be shut from inside or outside the aircraft. If the door is set to the AUTOMATIC position, lifting the door handle activates the emergency power system, and an escape slide deploys.

1.6.5.4 Flight deck overhead hatch

The aircraft cockpit is equipped with an overhead hatch that can be used by the cockpit crew to escape in an emergency. Eight emergency escape devices, consisting of inertial reels, are located in a side compartment, just above the IRO’s seat, encased and secured in position by a plastic cover. The crew members use these reels to limit the speed of their descent when exiting the aircraft.

1.6.6 Pilot anthropometric and ergonomic factors

Modern aircraft cockpits are designed to accommodate a broad range of human anthropometrics. The Boeing 747-400 is designed to accommodate pilots whose standing heights range from 5 feet 2 inches (the 20th percentile of height for women) to 6 feet 4 inches (the 99.5th percentile of height for men). Design eye reference point locators assist pilots in adjusting their seat position to maximize their field-of-view over the nose, as intended in the design of the aircraft.

Three-dimensional computer-aided design modelling conducted following the occurrence indicated that, when seated correctly using the design eye reference point locators, both pilots would have had full range of motion of the respective thrust levers and full rudder and brake pedal deflection. The investigation could not determine if the flight crew were seated correctly.

1.7 Meteorological information

1.7.1 General

On the morning of 06 November 2018, several aerodrome forecasts (TAFs)[13] were issued for CYHZ. The original departure time was scheduled for 1230, which meant the arrival time at CYHZ would have been 1500. The forecast weather at that time indicated a wind of 140° true (T) at 12 knots, visibility ¾ SM in light drizzle and mist, and an overcast ceiling at 300 feet AGL. At the time of arrival, the weather had a 30% probability of visibility ¼ SM in fog with vertical visibility of 100 feet AGL. This weather was below the company's approach minima for the active runway and played a part in the decision to delay the departure by 13.5 hours.

An aerodrome special meteorological report (SPECI)[14] was issued for CYHZ at 2315 on 06 November 2018. It reported:

- Wind 210°T at 16 knots, gusting to 26 knots
- Visibility ½ SM with a runway visual range for Runway 14 of greater than 6000 feet with a downward trend in light rain and fog
- Vertical visibility of 200 feet AGL
- Temperature and dew point 15 °C
- Altimeter setting 29.74 inHg

A TAF was issued for CYHZ on 06 November at 2238 for the period of arrival. It indicated the following:

- Wind 220°T at 12 knots, gusting to 22 knots
- Visibility 3 SM in light rain and mist
- Broken ceiling at 400 feet AGL
- Overcast cloud at 1000 feet AGL

On 07 November, another TAF was issued for CYHZ at 0442 for the period of arrival. It indicated the following:

- Wind 220°T at 12 knots, gusting to 22 knots
- Visibility 5 SM in light rain and mist
- Broken ceiling at 400 feet AGL

---

[13] "TAFs are intended to relate to weather conditions for flight operations within 5 NM of the centre of the runway complex, depending on local terrain." They "are generally issued every 6 hr with validity periods up to a maximum of 30 hr." (Source: Transport Canada, TP 14371, *Transport Canada Aeronautical Information Manual* [TC AIM], MET – Meteorology [10 October 2019], section 3.1)

[14] An aerodrome special meteorological report (SPECI) is "[a] special aviation weather observation issued at times other than on the hour, as a result of significant weather change." (Source: NAV CANADA, Terminav terminology database, at http://www1.navcanada.ca/logiterm/addon/terminav/termino.php [last accessed on 13 March 2020])

- Overcast layer at 3000 feet AGL

Between 0500 and 0700, there would be the following temporary change in conditions:

- Visibility increasing to 6 SM in mist
- Scattered clouds at 400 feet AGL
- Overcast ceiling at 3000 feet AGL

An aerodrome routine meteorological report (METAR)[15] was issued at 0500 and reported:

- Wind 230°T at 13 knots
- Visibility 7 SM in light rain and mist
- Broken ceiling at 500 feet AGL
- Overcast layer at 1300 feet AGL
- Temperature and dew point 14 °C
- Altimeter setting 29.67 inHg

1.7.2 Environment and Climate Change Canada weather assessment

The TSB asked Environment and Climate Change Canada to assess the weather conditions prevailing at specific times before and after the occurrence. Given the available data, the weather assessment report[16] concluded that the most probable conditions during the occurrence aircraft's descent and landing were as follows:

- No icing in cloud below approximately 12 000 feet ASL.
- Some borderline moderate mechanical turbulence may have been present below approximately 1000 feet ASL.
- The horizontal visibility at the airport was reported to be 7 SM; however, some mist may have still been in the area.
- The surface winds were from 230°T at 13 knots.
- The runway was wet from the significant rainfall in the previous 6 hours; light rain was falling when the aircraft arrived.

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[15] An aerodrome routine meteorological report (METAR) "[d]escribes actual weather at a specific location and at a specific time as observed from the ground." METARs are issued every hour on the hour but are not available 24 hours a day at all aerodromes. (Source: Transport Canada, TP 14371, *Transport Canada Aeronautical Information Manual* [TC AIM], MET – Meteorology [10 October 2019], section 3.2)

[16] Environment and Climate Change Canada, *Meteorological Assessment Halifax, NS, November 07, 2018* (06 February 2019).

1.8 Aids to navigation

1.8.1 NOTAMs

In its *Canadian NOTAM Procedures Manual*, NAV CANADA defines a NOTAM as

> a notice distributed by means of telecommunications containing information concerning the establishment, conditions or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations.[17]

The manual further states that

> [t]he basic purpose of NOTAM is the distribution of information that may affect safety and operations in advance of the event to which it relates, except in the case of unserviceable facilities or unavailability of services and activities that cannot be foreseen. Thus, to realize its purpose the addressee must receive a NOTAM in sufficient time to take any required action. The value of a NOTAM lies in its "news content" and its residual historical value is therefore minimal.[18]

NOTAMs for Canadian airports are produced and published by NAV CANADA based on information provided by aerodrome operators.

According to the *Canadian NOTAM Procedures Manual*, a

> NOTAM shall be as brief as possible, stating only the essential facts[4] and so compiled that its meaning is clear and unambiguous. Clarity shall take precedence over conciseness.
>
> [4] NOTAM are not issued after the fact just for the records to show that NOTAM were issued. For example, if no NOTAM were issued during the actual outage or closure, it is not permitted to promulgate the information after the fact.[19]

All NOTAMs were emailed to the crew by Sky Lease Cargo's System Operations Control Center (SOCC) flight planning system, and the crew printed them at the hotel. The email included all applicable NOTAMs for the departure airport, the enroute phase of the flight, the destination airport, and the alternate airport (Bangor International Airport [KBGR], Maine, U.S.). The flight crew reviewed a total of 98 NOTAMs, including 37 concerning CYHZ (Appendix D). Of those 37, 22 NOTAMs provided information related to Runway 05/23, such as the reduced level of services or unserviceable navigational aids, the unserviceable runway lighting, and the displaced threshold. Sixteen of the NOTAMs related to Runway 05/23 contained amended information, with modifications that needed to be compared with the previous versions to identify the differences.

With regards to runway length available, the NOTAMs advised that the first 1767 feet of Runway 23 were closed due to painting, and repairs to lighting, and the threshold was relocated and marked with banners and runway threshold lighting. The declared landing

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[17] NAV CANADA, *Canadian NOTAM Procedures Manual,* Version 17.6 (12 October 2017), Section 1.2: Definition of NOTAM, p. 11.

[18] Ibid.

[19] Ibid., Section 3.1: General Specifications, paragraph "e," p. 17.

distance available for both Runway 05 and Runway 23, which is normally 10 500 feet long, was reduced to 8733 feet.

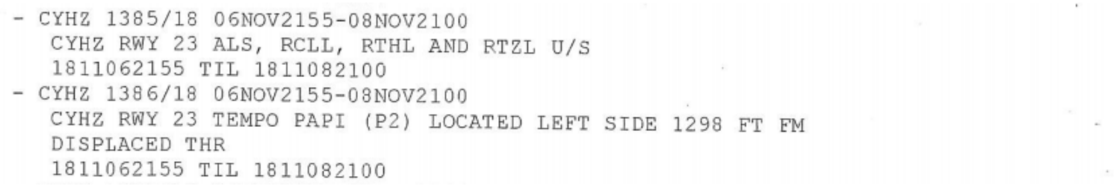
Although this distance was sufficient, when the occurrence crew reviewed the NOTAMs related to the approach to Runway 23, they concluded that this runway was not available to them due to approach restrictions. The use of the wording “NOT AUTH” [not authorized] in NOTAM A3261/18 (Figure 5) led the crew to believe that they could not use the RNAV Runway 23 approach; however, the LNAV (lateral navigation) portion of the approach could still be used under some conditions.

Figure 5. Example of Halifax/Stanfield International Airport (CYHZ) NOTAM Runway 23 (Source: Sky Lease Cargo NOTAM from occurrence flight paperwork)

```
- CYHZ A3261/18 06NOV1955-08NOV2100 EST
   RNAV (GNSS) Z RWY 23 APCH:
   LPV AND LNAV/VNAV MINIMA: NOT AUTH
   DIST/ALT TABLE, CONSTANT DESCENT ANGLE AND RATE OF DESCENT
   INFO NOT USABLE
```

Similarly, Runway 23 NOTAM 1385/18 and 1386/18 (Figure 6) indicated that the approach lighting system (ALS), the runway centreline lights (RCLL), the runway threshold lights (RTHL), and the runway touchdown lights (RTZL) were all unserviceable. From this list of unserviceable items, it can be concluded that the runway edge lights were still available; thus, the runway could have been used, but with limited lighting.

Figure 6. Example of Halifax/Stanfield International Airport (CYHZ) NOTAM unserviceable lighting Runway 23 (Source: Sky Lease Cargo NOTAMs from occurrence flight paperwork)



```
- CYHZ 1385/18 06NOV2155-08NOV2100
   CYHZ RWY 23 ALS, RCLL, RTHL AND RTZL U/S
   1811062155 TIL 1811082100
- CYHZ 1386/18 06NOV2155-08NOV2100
   CYHZ RWY 23 TEMPO PAPI (P2) LOCATED LEFT SIDE 1298 FT FM
   DISPLACED THR
   1811062155 TIL 1811082100
```

Reviewing the NOTAMs meant reviewing more than 7 pages of written information, including 3 pages just for Runway 05/23, presented using all capital letters.

A 2017 U.S. National Transportation Safety Board (NTSB) investigation into a near-miss taxiway landing at San Francisco International Airport (KSFO), California, U.S., concluded that

> [a]lthough the NOTAM about the runway 28L closure appeared in the flight release and the ACARS message that were provided to the flight crew, the presentation of the information did not effectively convey the importance of the runway closure information and promote flight crew review and retention.[20]

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[20] National Transportation Safety Board, Aircraft Incident Report NTSB/AIR-18/01 (25 September 2018).

The format and presentation of NOTAMs using all capital letters prove difficult for readability and interpretation because the letters are all the same size.[21,22] This may influence a reader's ability to interpret reduced services available at airports. Furthermore, NOTAMs are not prioritized based on importance, rather the order is based on the time of publishing. As a result, pilots must review all the information presented and determine how the reduced services will affect them.

NAV CANADA's *Canadian NOTAM Procedures Manual* is based on International Civil Aviation Organization (ICAO) standards.[23,24,25] On 10 October 2019, NAV CANADA started using the ICAO NOTAM format for all NOTAMs, both domestic and international NOTAMs. According to NAV CANADA, "The adoption of the ICAO NOTAM format—already used by most countries—will ensure compliance with international standards and will eliminate the need for pilots who fly international routes to be familiar with more than 1 NOTAM format. It will also pave the way for more advanced filtering functionality, reducing NOTAM clutter by helping pilots access just the NOTAMs pertinent to their flight."[26] While the ICAO format may communicate some information more effectively than the previous format, the presentation of text will continue to be of limited effectiveness because of the continued use of all capital letters.

1.8.1.1 Navigation aids and lighting

The following approach procedures were not authorized to be used due to the displaced threshold:

- Category I and II ILS Runway 23
- Localizer performance with vertical guidance (LPV) Runway 23
- Lateral navigation/vertical navigation (LNAV/VNAV) Runway 23
- Localizer Runway 05
- Required navigation performance (RNP) Y Runway 23

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[21] Miles Tinker, *Legibility of Print*, (Iowa State University Press, 1963).

[22] Page Laubheimer, "Typography for Glanceable Reading: Bigger Is Better" (26 November 2017), at https://www.nngroup.com/articles/glanceable-fonts/ (last accessed on 09 July 2020).

[23] International Civil Aviation Organization (ICAO), Annex 15 to the *Convention on International Civil Aviation*, *Aeronautical Information Services*, 15th Edition (July 2016).

[24] International Civil Aviation Organization (ICAO), Document 8400, *Procedures for Air Navigation Services-ICAO: Abbreviations and Codes*, 9th Edition (2016).

[25] International Civil Aviation Organization (ICAO), Document 8126 AN/872, *Aeronautical Information Services Manual*, 6th Edition (2003).

[26] NAV CANADA, NOTAM Transition FAQ [frequently asked questions] document, "Why is NAV CANADA transitioning to the ICAO NOTAM format?", available at https://www.navcanada.ca/en/icao%20notam%20-%20faq_en.pdf (last accessed on 05 March 2021)

In addition, the following lighting for Runway 23 was unserviceable:

- Approach lighting system
- Runway centreline lighting
- Runway threshold lighting
- Runway touchdown zone lighting

The following approach procedures were available at CYHZ at the time of the occurrence flight:

- RNAV (RNP) Y Runway 05
- RNAV (global navigation satellite system [GNSS]) Z[27] Runway 05
- ILS Runway 14
- RNAV (GNSS) Z Runway 14
- RNAV (RNP) Runway 14
- LPV Runway 32
- LNAV/VNAV Runway 32
- RNAV (RNP) Y Runway 32
- NDB Runway 23
- RNAV (GNSS) Z Runway 23 with no vertical guidance LNAV minimums only

The aircraft was capable of performing all approaches at CYHZ except the RNP approaches.

1.9 Communications

All communications between ATC and the aircraft were normal.

1.10 Aerodrome information

1.10.1 General

CYHZ has 2 runways constructed of asphalt and concrete (Appendix E): Runway 05/23 is 10 500 feet long; Runway 14/32 is 7700 feet long; both are 200 feet wide. The runways are not grooved.

Runway 05 is equipped with a high-intensity (AN), simplified short-approach lighting system with runway alignment indicator lights (SSALR), threshold/runway end lighting, centreline lighting and a precision approach path indicator (PAPI) P3, which provides an eye-to-wheel height greater than 45 feet.

---

[27] The letter suffix identifies that there are 2 or more performance based navigation (PBN) approaches for the same runway. (Source: International Civil Aviation Organization [ICAO], Circular 336/AN195, *Area Navigation [RNAV] to Required Navigation Performance [RNP] Instrument Approach Chart Depiction* (2015), p. 3)

Runway 23 is equipped with centreline lighting, a high-intensity approach lighting system with sequenced flashing lights for category II or III operations (ALSF-2), threshold/runway end lighting and touchdown zone lighting.

Runway 14 is equipped with an AN SSALR and threshold/runway end lighting.

Runway 32 is equipped with an AN SSALR, threshold/runway end lighting, and a PAPI P3.

1.10.2 Runway end safety area

In 2009, the Australian Transport Safety Bureau (ATSB) published a safety report on runway excursions, which stated, in part:

> Runway end safety areas [RESA] are designed to reduce the risk of damage to an aircraft that:
>
> • undershoots the runway (touches down before the runway threshold);
>
> • aborts a takeoff and overruns the runway end; or
>
> • cannot stop following a landing and overruns the runway end.
>
> A RESA achieves this by assisting aircraft to decelerate in a controlled manner.
>
> Surface materials used for RESAs vary widely, from natural surfaces to pavement. Common RESA surface materials include compact gravel pavement, pulverised fuel ash (PFA), grass, pavement quality concrete (PQC), compacted earth, or a combination of these. In all cases, the bearing strength of the RESA must be able to support movement of airport rescue and firefighting (ARFF) vehicles, and be resistant to blast erosion from jet engine exhaust from aircraft in day-to-day operations.[28]

ICAO, in its Annex 14,[29] requires that runways with a code number of 3 or 4[30] have a runway end safety area (RESA) of 90 m (295 feet) extending from the end of a 60 m (197 feet) runway strip, for a total of 150 m (492 feet). In addition, ICAO recommends that the RESA “should, as far as practicable, extend from the end of the runway strip to a distance of at least […] 240 m [787 feet],”[31] for a total of 300 m (984 feet). The recommendations for longitudinal slope suggests that the terrain should not exceed a downward slope of 5%. The

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[28] Australian Transport Safety Bureau, ATSB Transport Safety Report, Aviation Research and Analysis Report AR-2008-018(2), *Runway excursions, Part 2: Minimising the likelihood and consequences of runway excursions, An Australian perspective* (June 2009), p. 52.

[29] International Civil Aviation Organization (ICAO), Annex 14 to the *Convention on International Civil Aviation*, *Aerodromes*, Volume I: Aerodrome Design and Operations, 8th Edition (July 2018), section 3.5.3.

[30] Code 3 refers to a runway 1200 m up to, but not including, 1800 m in length. Code 4 refers to a runway 1800 m or more in length.

[31] International Civil Aviation Organization (ICAO), Doc 9157, *Aerodrome Design Manual*, 3rd Edition (2006), Part 1: *Runways*, section 5.4.5.

slope should be as gradual as practicable and avoid any abrupt changes or sudden reversals.[32]

In Canada, before 2015 the 150 m (492 feet) RESA was not a regulatory requirement; it was only a recommendation. In 2015, Transport Canada (TC) published a new edition of its *Aerodrome Standards and Recommended Practices* (TP 312),[33] in which it changed the previous RESA recommendations into standards. However, because a grandfathering clause[34] was included in the *Canadian Aviation Regulations* (CARs), Canadian airports are required to adhere to the latest RESA standards only when a new runway is constructed.

In 2016, TC issued a notice of proposed amendment (NPA) to the CARs[35] proposing requirements of 150 m (492 feet) RESA to be based on air traffic volume rather than runway length.

The characteristics[36] and description of RESAs in TP 312 are the following:

> **3.2.1.7** The runway end safety:
>
> (a) has a minimum width twice of the associated runway;
>
> (b) extends away from the runway;
>
> (c) is centred on the extended runway centerline; and
>
> (d) […] has a minimum length of 150 m to the end of the RESA.
>
> […]
>
> **3.2.1.9** The terrain in the runway end safety area:
>
> (a) has no abrupt slope changes or open ditches;
>
> (b) has adequate slope to prevent the accumulation of water;
>
> (c) beyond the runway strip, has maximum transverse and longitudinal slopes of 5% downwards;
>
> (d) does not protrude into an obstacle limitation surface (OLS); and
>
> (e) under dry conditions, is of sufficient strength to reduce the severity of structural damage to the critical aircraft overrunning/undershooting the runway.[37]

---

[32] International Civil Aviation Organization (ICAO), Annex 14 to the *Convention on International Civil Aviation*, *Aerodromes*, Volume I: Aerodrome Design and Operations, 8th Edition (July 2018), section 3.5.10.

[33] Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices: Land Aerodromes*, 5th Edition (15 September 2015).

[34] Transport Canada, Advisory Circular No. 302-018, *Grandfathering at Airports Pursuant to Canadian Aviation Regulation (CAR) 302.07*, Issue No. 01 (27 November 2014).

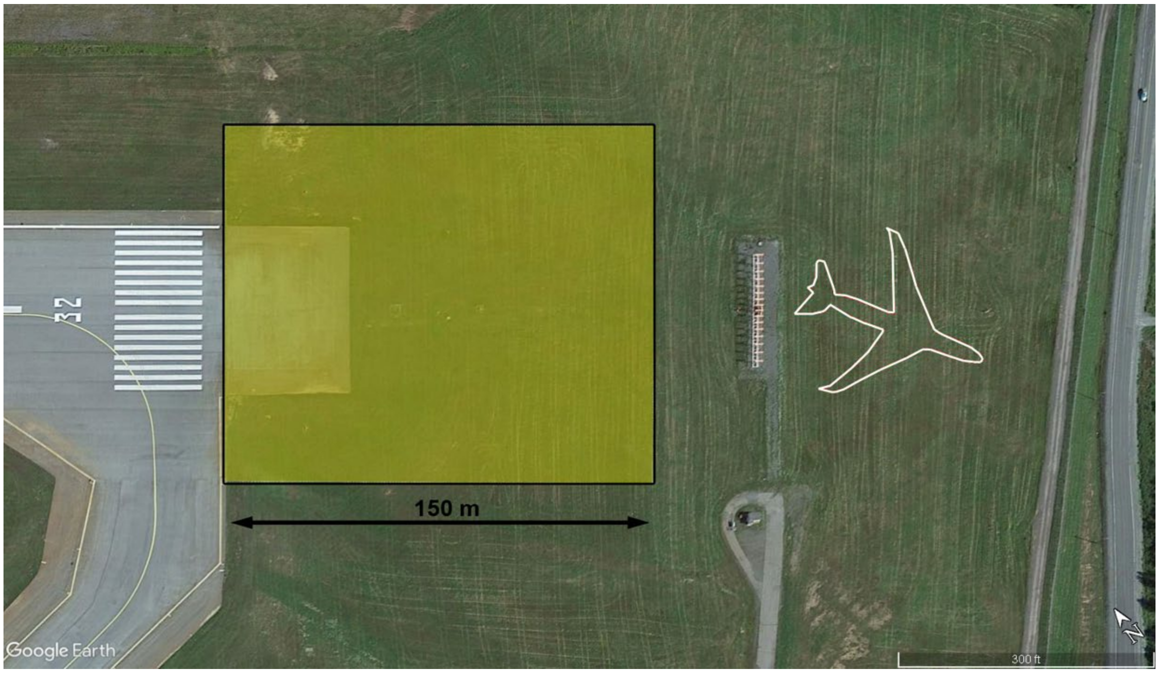
[35] Transport Canada, Canadian Aviation Regulation Advisory Council (CARAC), NPA 2016-007, *Notice of Proposed Amendment (NPA) on Runway End Safety Areas (RESA)*, 12 May 2016.

[36] Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices: Land Aerodromes*, 5th Edition (15 September 2015).

[37] Ibid., p. 47.

Runway 14 at CYHZ has a RESA that extends to 150 m (495 feet) past the runway end. This length had an average downward slope of 0.2%. These dimensions meet TC's and ICAO's standards for a 150 m (492 feet) RESA (Figure 7).

Figure 7. Depiction of Transport Canada's current requirement for runway end safety area on the occurrence runway with the location of the occurrence aircraft after the runway overrun (Source: Google Earth, with TSB annotations)



Approximately 166 m (544 feet) past the end of Runway 14, there is a significant drop of 2.8 m (9 feet), with a downward slope of 73%. This slope does not meet ICAO's recommendations for a 5% longitudinal slope for a RESA that extends to 300 m (984 feet) past the runway end (Figure 8).

Figure 8. Depiction of International Civil Aviation Organization and TSB recommendation for runway end safety area on the occurrence runway, with the location of the occurrence aircraft after the runway overrun (Source: Google Earth, with TSB annotations)

1.10.2.1 Previous TSB recommendation

Following the TSB's investigation[38] into a runway overrun accident involving an Airbus A340-313 aircraft in 2005 at Toronto/Lester B. Pearson International Airport (CYYZ), Ontario, the Board recommended that

> the Department of Transport require all Code 4 runways to have a 300 m runway end safety area (RESA) or a means of stopping aircraft that provides an equivalent area of safety.
>
> **TSB Recommendation A07-06**

This recommendation was in keeping with the recommendations of ICAO.

Since then, TC has provided several responses, all of which have been assessed by the TSB.

In February 2021, in an update to its most recent response, TC stated that the amendments to the CARs were published in the *Canada Gazette*, Part I on 07 March 2020. TC is aiming to publish these amendments in the *Canada Gazette*, Part II in May 2021.

In March 2021, in its reassessment of TC's latest response, the TSB noted that TC had proposed regulations to address RESAs. The proposed regulatory changes, as currently written, will reduce the risks associated with an overrun; however, not to the level that would be afforded by the ICAO-recommended 300 m RESA. At a minimum, the Board believes that the proposed regulations must meet the ICAO standard.

---

[38] TSB Aviation Investigation Report A05H0002.

The Board has maintained the inclusion of runway overruns on Watchlist 2020. Runway overruns continue to occur, and the lack of timely action will continue to expose commercial air travellers in Canada to unnecessary risks until these regulatory amendments are implemented.

Therefore, the Board reassessed TC's latest response to Recommendation A7-06 as **Satisfactory in Part**.[39]

1.10.3 Runway friction coefficient and certification

TC requires airport operators to periodically measure the friction characteristics of the runway surface. TC leaves it up to airport operators to conduct their own runway friction tests and establish the frequency of testing based on the unique history and circumstances of their sites.

On 19 October 2018, HIAA hired an independent contractor to complete a runway friction test for both runways. The test results met all required standards, in accordance with the 5th edition of TP 312.[40]

1.10.4 Transverse slope and runway drainage

Drainage paths and the transverse slope were assessed by HIAA, and all runways met all requirements in accordance with the 5th edition of TP 312.

1.11 Flight recorders

The aircraft was equipped with a solid-state digital FDR, which contained approximately 53.4 hours of flight data, covering the occurrence flight and 8 previous flights. The FDR data were successfully downloaded.

The aircraft was also equipped with a cockpit voice recorder (CVR), which had a recording capacity of 120 minutes; its recorded data included the occurrence flight. The CVR memory was successfully downloaded and contained good quality audio for the occurrence flight.

1.12 Wreckage and impact information

The aircraft overran Runway 14 and struck approach lighting stanchions and the ILS localizer antenna array. The aircraft proceeded approximately 270 m (885 feet) past the threshold and came to rest 47 m (155 feet) from a public road.

---

[39] TSB Recommendation A07-06: Runway end safety area (RESA) requirements, at https://www.tsb.gc.ca/eng/recommandations-recommendations/aviation/2007/rec-a0706.html?wbdisable=true (last accessed on 12 April 2021).

[40] Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices: Land Aerodromes*, 5th Edition, (15 September 2015), Chapter 9: Aerodrome Maintenance.

During the impact sequence, the nose gear collapsed rearward, the left-hand wing main landing gear separated from the fuselage, and the left-hand body main landing gear collapsed rearward, with the wheel assemblies pushing up into the fuselage fairing.

The right-hand wing main landing gear collapsed aft and rotated 45° with the wheel bogie, coming to rest below the right-hand flap assembly. The right-hand body main landing gear collapsed aft and was embedded in the fuselage fairing area.

All engines were damaged by impact forces and by ingesting foreign object debris. Engines No. 1 and No. 4 were still attached to the wing pylons. Engine No. 2 detached from its pylon during the impact sequence and came to rest under the left horizontal stabilizer. Engine No. 3 detached from its pylon during the impact sequence and came to rest on the right side of the fuselage, behind the right outboard flap.

The fuselage buckled behind the cockpit and behind the wing root.

1.13 Medical and pathological information

1.13.1 Fatigue

Human beings need 7 to 9 continuous hours of restorative sleep at night to perform at optimal levels.[41] Sleep-related fatigue—related to the amount and quality of sleep obtained—is biological in nature. Consequently, it is not prevented by personality characteristics, intelligence, education, training, skill, compensation, motivation, physical size, strength, or practice. Sleep-related fatigue can result from 1 or more of 6 risk factors: acute sleep disruptions (i.e., within the previous 24- to 72-hour period), chronic sleep disruptions, continuous wakefulness, circadian rhythm disruptions, sleep disorders or other medical and psychological conditions, and/or illnesses or drugs that affect sleep or sleepiness.

Inadvertently falling asleep at the controls is the most recognized risk of fatigue; however, less extreme fatigue levels are associated with more subtle performance impairments, such as a decrease of cognitive functioning and problem-solving abilities. These subtle impairments are significant risk factors and predictors of occupational accidents and injuries,[42] motor vehicle accidents,[43] and aviation occurrences.[44]

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[41] M. Hirshkowitz, K. Whiton, S. M. Albert, et al., "National Sleep Foundation's sleep time duration recommendations: methodology and results summary," *Sleep Health: Journal of the National Sleep Foundation*, Vol. 1, Issue 1 (March 2015), pp. 40–43.

[42] D. Dawson, and K. Reid, "Fatigue, alcohol and performance impairment," *Nature*, Vol. 388 (1997), p. 235.

[43] Traffic Injury Research Foundation (TIRF), *Fatigue-related fatal collisions in Canada, 2000–2016* (09 March 2020), at http://www.tirf.ca (last accessed on 03 July 2020).

[44] For examples, see TSB aviation investigation reports on occurrences involving flight crew sleep-related fatigue: A15O0031, A13C0105, A12W0004, A12Q0216, A11F0012, A08O0233, A05W0109, A04H0004, A04H0001, A01O0210, A97Q0183, A95W0093, A95P0007, A94C0119, and A94C0088.

Sleep-related fatigue impairs working memory (memory that temporarily stores information while it is being manipulated for tasks such as reasoning)[45] and problem-solving ability.[46] It also reduces flexibility in a person's problem-solving approach to a situation that is perceived to be different from the routine, so that the individual perseverates and repeats previously ineffective responses.[47] This increases the likelihood that a fatigued person will maintain the normal routine, failing to revise the original plan or to devise and try a novel solution.[48] This known effect of sleep-related fatigue on flight crew cognitive bias was identified in a recent, high-profile NTSB air occurrence involving flight crew perception and decision-making during final approach and landing. The investigation revealed that "fatigue likely contributed to the crewmembers' misidentification of the intended landing surface, their ongoing expectation bias, and their delayed decision to initiate a go-around."[49]

1.13.2 Circadian rhythm

The time of day has a strong effect on an individual's alertness and performance because of changes in body physiology that are synchronized to a circadian (daily) rhythm. The human body is physiologically ready for sleep at night and for wakefulness during the day. Likewise, due to the circadian rhythm, overall performance and cognitive functioning are at their worst during the nighttime circadian rhythm trough, from approximately 2230 to 0430, when fatigue increases significantly. Even if a person slept the previous night and is not feeling fatigued,[50] overall performance may be degraded during the circadian rhythm trough.

1.13.3 Sky Lease fatigue risk management training

Fatigue risk management training provides employees with knowledge of how to avoid, mitigate and report fatigue issues. At Sky Lease Cargo, all flight operations personnel were required to take annual recurrent fatigue risk management training. This training was given in a 1-hour lecture format using slides and videos, and included:

- the effects of fatigue on human performance (including, for example, its effects on "cognitive slowing" and short-term memory),

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[45] Q. Mu, Z. Nahas, K. A. Johnson, K. Yamanaka, A. Mishory, J. Koola, S. Hill, M. D. Horner, D. E. Bohning, and M. S. George, "Decreased cortical response to verbal working memory following sleep deprivation," *Sleep*, Vol. 28 (2005), pp. 55–67.

[46] H. Babkoff, M. Mikulincer, T. Caspy, D. Kempinski, and H. Sing, "The topology of performance curves during 72 hours of sleep loss: a memory and search task," *Quarterly Journal of Experimental Psychology*, Vol. 40 (1988), pp. 737–756.

[47] J. Horne, "Sleep deprivation and divergent thinking ability," *Sleep*, Vol. 11, Issue 6 (1988), pp. 528–536.

[48] Y. Harrison and J. A. Horne, "One night of sleep loss impairs innovative thinking and flexible decision making," *Organizational Behavior and Human Decision Processes*, Vol. 78, No. 2 (1999), pp. 128–145.

[49] National Transportation Safety Board, Aircraft Incident Report NTSB/AIR-18/01 (25 September 2018).

[50] T. Monk, S. Folkard, and A. A. I. Wedderburn, "Maintaining safety and high performance on shiftwork," *Applied Ergonomics*, Vol. 27, No. 1 (1996), pp. 17–23.

- the interaction between workload and fatigue during different phases of flight,
- sources of fatigue,
- recommended “do’s and don’t’s”,
- personal strategies to mitigate the effects of fatigue, and
- information on Sky Lease’s fatigue reporting policy.

1.13.4 Crew sleep-wake cycle

Before the occurrence flight, all 3 crew members had maintained a normal nighttime sleep schedule for at least 7 days.

The captain arrived at KORD on 05 November and slept 9.5 hours that night. On 06 November, at 1100, the decision was made to delay the departure to CYHZ until 0200 on 07 November. After he was notified of the delay, the captain had the opportunity to get uninterrupted rest on 2 occasions (for less than 2 hours each time) during the afternoon and the evening. If he slept during these periods, he would have had a total of approximately 5.75 hours of sleep in the 24-hour period leading up to the occurrence.

The FO arrived at KORD on 05 November and slept 8.5 hours that night. He had the opportunity to get 3 hours of uninterrupted rest during the afternoon of 06 November. If he slept during this period, he would have had a total of approximately 6 hours of sleep in the 24-hour period leading up to the occurrence.

The IRO spent 05 November at his home and slept about 7 hours that night. He arrived at KORD on the morning of 06 November. He had an opportunity to get 2 hours of sleep in the afternoon. He did sleep for 3 hours in the evening hours. If he slept on both occasions, he would have had a total of approximately 5 hours of sleep in the 24-hour period leading up to the occurrence.

Quantitative analysis of the crew’s sleep history using fatigue avoidance scheduling tool (FAST) software predicted that, because of acute sleep disruption and the timing of the occurrence during the nighttime circadian rhythm trough, the performance of the flight crew at the time of the accident would likely have been degraded by fatigue. However, the crew did not report feeling fatigued at the time of the occurrence.

1.14 Fire

The No. 2 engine detached from its pylon during the impact sequence and came to rest under the left horizontal stabilizer and tail section, which caused a post-impact fire in the tail section of the aircraft. Five ARFF crash rescue vehicles responded, and they extinguished the fire and laid foam to prevent spilled fuel from igniting.

1.15 Survival aspects

When the aircraft left the paved surface, emergency escape devices (see 1.6.5.4 *Flight deck overhead hatch*) were projected from the storage compartment, striking the IRO in the head.

The flight deck and upper deck passenger compartment were not compromised structurally during the runway overrun.

The crew began an evacuation from the upper deck crew service door; however, after placing the emergency escape slide pack into position, they had difficulty deploying the emergency slide. After the crew assessed the situation and the captain signalled with a flashlight to ARFF, they egressed through the main deck entry door (1L) using a ladder, with the assistance of ARFF. Emergency health services responded at 0545, evaluated the crew and transported them to hospital.

When the TSB investigators were on site, they moved the escape slide pack into position with no issues; however, they did not attempt to deploy the emergency slide. It could not be determined why the crew had difficulty deploying the slide.

1.16 Tests and research

1.16.1 Flight data recorder analysis

The TSB laboratory downloaded FDR data and provided factual data plots. It also reconstructed the events (Appendix F), analyzed the braking performance and deceleration devices, and assessed the likeliness of an engine strike. The FDR data indicated that, immediately after touchdown, the thrust levers for engines No. 2, No. 3, and No. 4 were moved to reverse thrust positions, while the thrust lever for engine No. 1 was advanced forward, past 20° thrust lever angle. This inhibited the autobrakes and the auto speed brakes.

Shortly after, the thrust lever for engine No. 1 was reduced to just above idle, which satisfied the conditions for the auto speed brakes to engage and the spoilers to extend.

CYHZ airport's closed-circuit television (CCTV) surveillance footage and the aircraft's FDR parameters were synchronized. During the landing, a light source briefly appeared in the background, silhouetted by the aircraft's fuselage. This light source was coincident with a maximum 6° left bank. The surveillance footage, FDR parameters, site survey data, and geometric analysis indicate that there was likely contact of the No. 1 or No. 2 engine nacelle with the runway (engine strike). After the likely engine strike, the FDR data did not indicate any abnormalities with engine performance. The engines continued to operate as commanded by the flight crew.

1.16.1.1 Yawing moments, rudder effectiveness, and asymmetrical braking

The crosswind component and the asymmetric thrust caused adverse yawing moments during the landing. The FDR data indicated that the PF used rudder deflections between neutral and maximum. Analysis of the yawing moments determined that the rudder had sufficient control authority to overcome the adverse yawing moments. Asymmetric braking was not required in order to maintain directional control.

1.16.2 Hydroplaning

1.16.2.1 General

In aviation, hydroplaning is used to describe a loss of braking friction due to liquid water. There are 3 main forms of hydroplaning—dynamic, reverted rubber, and viscous—and their characteristics are quite different.

1.16.2.2 Dynamic hydroplaning

During total dynamic hydroplaning, the tire lifts off the pavement and rides on a wedge of water like a water ski. Because the conditions required to initiate and sustain dynamic hydroplaning are extreme, the phenomenon rarely occurs. However, when it does, there is such a substantial loss of tire friction that the wheel may not spin up.

The conditions required for dynamic hydroplaning are high speed, standing water, and poor surface macrotexture. These conditions must continue without interruption to keep the tire planing on a wedge of water. In the absence of any of these conditions, dynamic hydroplaning either does not occur at all or affects only a portion of the tire footprint.[51]

The rainfall intensity was determined from weather records obtained from the Halifax Regional Municipality's water, wastewater, and storm water utility. A one-hour average rainfall intensity, preceding the event, was determined to have been 1.29 mm/hour. The 5-minute "instantaneous" rainfall intensity at the time of the landing was 1.20 mm/hour. The highest rainfall intensity during the one-hour window prior to the event, occurred at 0450 (over 15 minutes prior to landing), with 4.8 mm/hour.

The TSB laboratory used a rainfall intensity of 1.24 mm/hour to estimate the maximum possible water depth on the runway during the occurrence landing, and estimated it to be 0.24 mm or less. Given this estimation of water depth, in combination with the aircraft's speed and the runway macrotexture, the laboratory determined that dynamic hydroplaning almost certainly did not occur and did not have a significant effect on the landing.

1.16.2.3 Reverted rubber hydroplaning

Reverted rubber hydroplaning can occur when a tire is skidded along a very wet or icy runway long enough to generate frictional heat in the footprint area. This heat generates steam, which expands and reduces the traction of the contact patch. This steam can also leave characteristic "steam cleaning" marks on the runway where the rubber deposits have been removed or discoloured. It also causes a characteristic disfiguring on the tire's rubber tread.

Reverted rubber hydroplaning can start at any speed above about 20 knots and can result in tire friction comparable to that of icy runways.[52]

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[51] Smartcockpit.com (original idea from Boeing Airliner), "Landing on Slippery Runways," at http://www.smartcockpit.com/docs/Slippery_Runways.pdf (last accessed on 01 September 2020).

[52] Ibid.

In this occurrence, there was insufficient braking or deceleration to create the heat necessary for steam. There was no physical evidence of skidding, “steam cleaning,” or disfiguring of the rubber tread. Therefore, the investigation concluded that reverted rubber hydroplaning did not occur.

1.16.2.4 Viscous hydroplaning

Viscous hydroplaning occurs on all wet runways and is used to describe the normal slipperiness or lubricating action of the water. While viscous hydroplaning reduces friction, it would not reduce friction to such a low level that the wheel cannot be spun up shortly after touchdown to initiate the anti-skid system. Viscous hydroplaning is the most commonly encountered cause of low friction on wet runways, and occurrences are often mistaken for dynamic hydroplaning.[53] Some level of viscous hydroplaning occurs on all wet runways.

The theoretical wet runway aircraft braking coefficient (ABC) represents the aircraft’s ability to grip the surface of the runway given the value of the maximum braking effort required for anti-skid operation under specific conditions. This theoretical wet runway ABC was calculated for Runway 14 under the conditions at the time of the occurrence.

Using FDR data, the actual ABC for the occurrence flight was calculated, and it was determined that during the period of ground roll before maximum braking was applied, the coefficient was lower than expected with autobrake 4 selected. After maximum braking effort was applied, the actual ABC was consistent with the theoretical ABC on Runway 14 under the existing wet runway conditions.

1.16.3 TSB laboratory reports

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

- LP248-2018 – Site Survey Halifax Stanfield International Airport
- LP249-2018 – NVM Download
- LP252-2018 – FDR Report
- LP265-2018 – Wheel and Brake Examination

1.17 Organizational and management information

1.17.1 Sky Lease Cargo

1.17.1.1 General

Sky Lease Cargo is a U.S. company that provides domestic and international non-scheduled and ad hoc heavy cargo lift. It holds a Supplemental Operations Certificate for all-cargo operations under the U.S. FARs, Part 121. The company is based in Miami, Florida, U.S.

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[53] Ibid.

At the time of the occurrence, the company had 320 employees, and its fleet consisted of 3 Boeing 747-400 and 2 MD-11 aircraft. As required by the FARs, Sky Lease Cargo has implemented a safety management system and a fatigue risk management plan, which included: policy statements for the management of fatigue, a training requirement for its flight crew members, and an audit system to assess fatigue levels within the organization.

Sky Lease Cargo pilots complete their Boeing 747-400 training in Miami. The required training consists of classroom and computer-based training, both conducted internally, as well as aircraft simulator training, which is conducted through an external vendor but by company instructors and a check airman.[54]

1.17.1.2 Pre-departure planning

Pre-departure planning plays an important role in establishing a clear picture for the crew of the influences (positive or negative) that may affect the flight, while ensuring that the flight meets regulatory requirements.

Sky Lease Cargo's SOCC is located in Miami, Florida, and includes the flight following centre. The operations centre provides flight planning, weather briefings, and flight releases for the Boeing 747 and MD-11 fleets. When the crews are not in Miami, flight dispatch provides all required flight paperwork to the crew by email and conducts any required briefings over the telephone. Before a flight departs, the pilot-in-command must communicate with the SOCC and secure a flight release. The following are required in duplicate for the flight, and signed copies are required onboard the aircraft:[55]

- Flight release
- Load manifest
- Operational flight plan
- Pilot route certification
- Weight and balance
- Aircraft logbook (with a valid airworthiness release)

1.17.1.2.1 Landing limitations: destination airports

Sky Lease Cargo provides performance data for its specific aircraft to an independent vendor, who, in turn, provides runway analysis charts for various airports to Sky Lease Cargo. The charts indicate specific landing performance data, including the maximum landing weight permitted for a specific runway (Appendix G). The runway analysis charts

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[54] As described in the Sky Lease Cargo *General Operations Manual*, a check airman is an individual who reports to the chief pilot and director of flight standards and is responsible for conducting training and evaluation for the specific aircraft and crew position, and ensuring that all trainees and qualified crew members adhere to company policies and procedures. (Source: Sky Lease Cargo, *General Operations Manual*, Revision 144, 16 October 2017, p. 2–15)

[55] Sky Lease Cargo, *General Operations Manual*, Revision 137 (15 April 2014), p. 3-20.

are used for pre-departure planning and cannot be used to determine landing distances required.

Section 121.195 of the FARs[56] prohibits the takeoff of a transport category aircraft unless its weight on arrival, allowing for normal consumption of fuel and oil in flight, allows a full-stop landing at the intended destination airport within 60% of the effective runway length. To determine the allowable landing weight at the destination airport, the following 3 assumptions are made:

1. The aircraft is landed on the most favourable runway in still air.
2. The aircraft is landed on the most suitable runway, considering probable wind, landing aids and terrain.
3. If the runway is forecast to be wet or slippery at the time of arrival, the required field length is increased by 15%.

Sky Lease Cargo and Boeing both use the FAA regulatory requirements and guidance when referring to a “wet runway,” defined as when more than 25% of the runway surface area (within the reported length and width being used) is covered by any visible dampness or water that is less than 1/8 inch (3 mm) deep.[57,58]

Sky Lease Cargo’s *General Operations Manual* contains a policy specific to wet and slippery runways:

> It is Skylease Cargo policy to release all flights assuming wet destination runways unless existing conditions on a particular flight will unduly restrict fuel and/or payload. When a particular flight appears so restricted, the Captain will jointly determine in advance the advisability of using dry runway lengths for planning purposes.
>
> CFR 121.195(d) must be applied when weather reports, forecasts, or a combination of the two indicated that the runways at the destination airport maybe [*sic*] wet or slippery at the estimated time of arrival. The required runway length must then be at least 115% [*sic*] greater than the normal (dry) required runway length for landing. The tabular runway analysis utilized by the Company complies with this requirement.[59]

All runways at CYHZ had been reported as bare and wet, and light rain had been reported for the previous 24 hours.

Sky Lease Cargo uses charts that provide the maximum landing weight that meets the requirements of section 121.195 of the FARs, for each destination runway and each

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[56] Federal Aviation Administration (FAA), *Federal Aviation Regulations*, Edition 1-1-11, section 121.195.

[57] Sky Lease Cargo, *General Operations Manual*, Revision 137 (15 April 2014), p. 3-13.

[58] Federal Aviation Administration (FAA), Advisory Circular (AC) 91-79A: *Mitigating the Risks of a Runway Overrun Upon Landing* (17 September 2014), Appendix 1, p. 3.

[59] Sky Lease Cargo, *General Operations Manual*, Revision 137 (15 April 2014), p. 3-11.

approved landing configuration (flaps 25 and flaps 30). The pre-departure maximum landing weights with flaps 25 and flaps 30 were determined using these charts (Table 4).

Table 4. Landing runway limit weight (Source: Sky Lease Cargo landing runway limit weight charts)

Flaps	Runway	Length (feet)	Aircraft systems	Landing conditions	Limit weight (kg)
25°	14	7700	All operating	Wet, no wind	261 500
30°	14	7700	All operating	Wet, no wind	279 400

The performance-limited landing weight for Runway 14 was not recorded on any documentation used by the crew. Based on the operational flight plan, the aircraft's estimated landing weight on arrival in CYHZ was 265 852 kg.

1.17.2 Stabilized approach criteria

1.17.2.1 Flight crew training manual

Sky Lease Cargo provides guidance and directives to its pilots regarding stabilized approach criteria through flight safety letters, briefings in initial and recurrent ground school, simulator training, and company documentation. One of the main sources of information for the crews, however, is the FCTM.

The Boeing FCTM states:

> Maintaining a stable speed, descent rate, and vertical/lateral flight path in landing configuration is commonly referred to as stabilized approach concept.
>
> Any significant deviation from planned flight path, airspeed, or descent rate should be announced. The decision to execute a go-around is not an indication of poor performance.
>
> **Note:** Do not attempt to land from an unstable approach.
>
> **Recommended Elements of a Stabilized Approach**
>
> The following recommendations are consistent with criteria developed by the Flight Safety Foundation.
>
> All approaches should be stabilized by 1,000 feet AFE [above field elevation] in instrument meteorological conditions (IMC) and by 500 feet AFE in visual meteorological conditions (VMC). An approach is considered stabilized when all of the following criteria are met:
>
> - the airplane is on the correct flight path.
> - only small changes in heading and pitch are required to maintain the correct flight path.
> - the airplane should be at approach speed. Deviations of +10 knots to -5 knots are acceptable if the airspeed is trending toward approach speed.
> - the airplane is in the correct landing configuration.
> - sink rate is no greater than 1,000 fpm; if an approach requires a sink rate greater than 1,000 fpm, a special briefing should be conducted.
> - thrust setting is appropriate for the airplane configuration.

- all briefings and checklists have been conducted.[60]

1.17.2.2 U.S. Federal Aviation Administration advisory circular

The FAA published an advisory circular (AC) in which it defined a stabilized approach as "one of the key features of safe approaches and landings in air carrier operations, especially those involving transport category airplanes." The FAA also indicated that

> An approach is stabilized when all of the following **criteria** are maintained from 1000 HAT [height above threshold] (or 500 HAT in visual meteorological conditions [VMC]) to landing in the touchdown zone:
>
> The airplane is on the correct[1] track.
>
> The airplane is in the proper landing configuration.[...]
>
> The airplane speed is within the acceptable range specified in the approved operating manual used by the pilot.
>
> The rate of descent is no greater than 1000 feet per minute (fpm).[...]
>
> Power setting is appropriate for the landing configuration selected, and is within the permissible power range for approach specified in the approved operating manual used by the pilot.
>
> **Note [1]:** A **correct track** is one in which the correct localizer, radial, or other track guidance has been set, tuned, and identified, and is being followed by the pilot. Criteria for following the correct track are discussed in FAA Advisory Circulars relating to Category II and Category III approaches. Criteria for following track in operations apart for Category II and Category III are under development.[61]

1.17.3 Company flight manual

Checklists and operating procedures provide guidance to assist flight crew during normal operations, abnormal operations, and emergencies. Sky Lease Cargo's main reference for operating the Boeing 747-400 aircraft is the *747-400 Company Flight Manual*. The manual provides detailed information on limitations in one chapter (Chapter L), normal procedures and amplified procedures in another chapter (Chapter NP), and supplementary procedures in another chapter (Chapter SP). Supplementary procedures include procedures such as adverse weather operations, non-normal operations, system tests, and other procedures not included in Chapter NP.

The *747-400 Company Flight Manual* contains information about the automatic flight system, including the use of autopilot. While it does not state when the autopilot needs to be disconnected on approach, it does provide guidance on minimum altitudes for

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[60] Boeing Aircraft Company, *747 Flight Crew Training Manual*, revision 7 (30 June 2017), Chapter 5: Approach and Missed Approach, p. 5.4.

[61] Federal Aviation Administration (FAA), Advisory Circular (AC) 120-71A, *Standard Operating Procedures for Flight Deck Crew Members*, Appendix 2 (27 February 2003).

disconnecting the autopilot. In the case of an ILS approach, the autopilot must be disconnected by 150 feet AGL.[62]

The *747-400 Company Flight Manual* also contains the standard operating procedures (SOPs) for landing rolls[63] (Table 5), including actions to be taken by the various flight crew members. It provides the verbal callouts to be made by the flight crew members so they may take their respective appropriate actions.

Table 5. Sky Lease Cargo's landing roll standard operating procedure (Source: Sky Lease Cargo, 747-400 Company Flight Manual, revision 1 [19 June 2017], Chapter NP: Landing Roll Procedure, p. NP.21.51)

Pilot flying	Pilot monitoring
Verify that the thrust levers are closed Verify that the SPEEDBRAKE lever is UP.	Verify that the SPEEDBRAKE lever is UP. Call “SPEEDBRAKES UP” If the SPEEDBRAKE lever is not UP, call “SPEEDBRAKES NOT UP”.
Monitor the rollout progress.	
Verify correct autobrakes operation.	
WARNING: After the reverse thrust levers are moved, a full stop landing must be made. If an engine stays in reverse, safe flight is not possible.	
Without delay, move the reverse thrust levers to the interlocks and hold light pressure until the interlocks release. Apply reverse thrust as needed.	Verify that the forward thrust levers are closed. When all REV indications are green, call “REVERSERS NORMAL.” If there is no REV indication(s) or the indication(s) stays amber, call “NO REVERSER(S) ENGINE NUMBER ___” or “NO REVERSERS”.
By 60 knots, start movement of the reverse thrust levers to be at the reverse idle detent before taxi speed.	Call “60 KNOTS”.
After the engines are at reverse idle, move the reverse thrust levers full down.	
Before taxi speed, disarm the autobrakes. Use manual braking as needed.	
Before turning off the runway, disconnect the autopilot.	

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[62] Sky Lease Cargo, *747-400 Company Flight Manual,* revision 1 (19 June 2017), Chapter L: Autoflight, p. L.10.5.

[63] Ibid., Chapter NP: Landing Roll Procedure, p. NP.21.51.

Normal checklist procedures and non-normal checklist procedures are available to the crew in the *Quick Reference Handbook* (QRH).[64] The non-normal checklist items are organized by aircraft systems and package model identification of the specific 3 aircraft in the fleet.

1.17.4 Landing performance calculations

1.17.4.1 General

Sky Lease Cargo crews base the landing performance numbers on the landing weight in the flight management system. The aircraft QRH's performance section is referenced to determine the reference speed (V_{REF})[65] and to calculate the approach speed[66] (command speed[67]) and landing distance required. This document is available to the crew in the electronic flight bag and as a paper copy document, both of which are located on the flight deck.

The typical flap setting for Sky Lease Cargo operations is flaps 25; however, flaps 30 may be required due to a limited runway length or the weather conditions. The crew completed the landing distance calculation at the time of the approach briefing using flaps 25, and estimated the landing distance required to be around 6000 feet. Although there were no restrictions or limitations preventing the use of flaps 30 at CYHZ, this flap setting was not considered by the crew because the landing distance available of 7700 feet was greater than the crew thought they needed.

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[64] Sky Lease Cargo, *747 Flight Crew Operations Manual*: *747 Quick Reference Handbook,* Revision 01 (01 May 2017).

[65] V_{REF} refers to the approach speed at a height of 50 feet above the runway in the landing configuration.

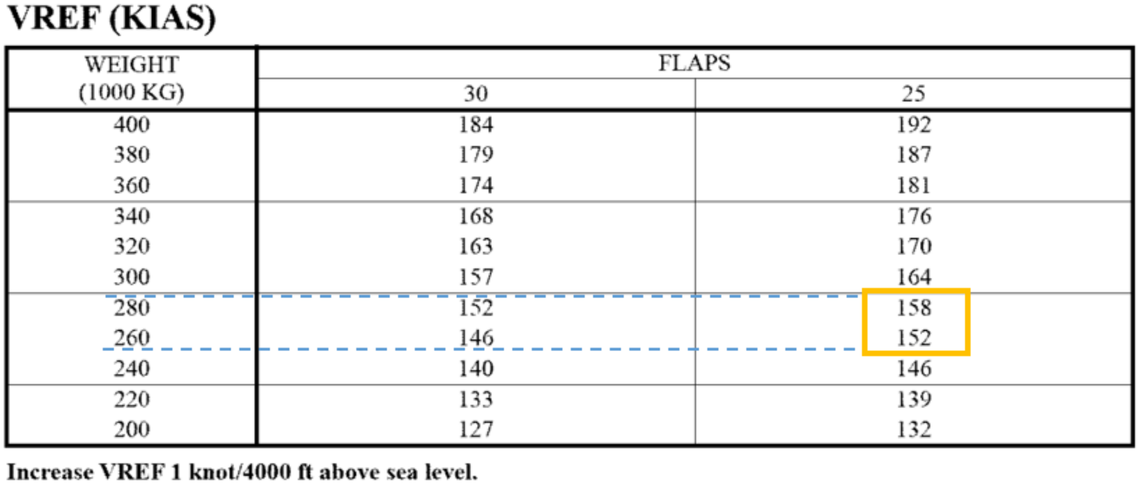
[66] Approach speed is based on the combination of V_{REF} speed for the aircraft's weight and landing flaps and the wind additive.

[67] Command speed is the speed set by the pilot through the mode control panel or the flight management computer computed speed that is displayed as command speed on both primary flight displays airspeed displays. (Source: Boeing Aircraft Company, *Flight Crew Training Manual*, revision 7 [30 June 2017], Chapter 6: Landing, section 1.23)

1.17.4.2 Approach speed

The Boeing FCTM provides guidance on how to calculate the approach speed based on the estimated landing weight and wind. Based on the estimated landing weight for CYHZ of 265 800 kg, the crew calculated a V_{REF} of 154 knots with flaps 25 for landing (Figure 9).

Figure 9. Reference speed (V_{REF}) determination (Source: Sky Lease Cargo, 747 Flight Crew Operations Manual: 747 Quick Reference Handbook, Revision 01 [05 May 2017], p. PI-QRH.10.5, with TSB annotations)



VREF (KIAS)

WEIGHT (1000 KG)	FLAPS	
	30	25
400	184	192
380	179	187
360	174	181
340	168	176
320	163	170
300	157	164
280	152	158
260	146	152
240	140	146
220	133	139
200	127	132

Increase VREF 1 knot/4000 ft above sea level.

If the autothrottle is disconnected, or is planned to be disconnected before landing, the recommended method for approach speed correction is to add to the reference speed one half of the reported steady headwind component plus the full gust increment above the steady wind. The minimum command speed setting is V_{REF} + 5 knots.[68] When making adjustments for winds, the maximum approach speed should not exceed V_{REF} + 20 knots. Figure 10 shows examples of wind additives when the runway heading is 360°.

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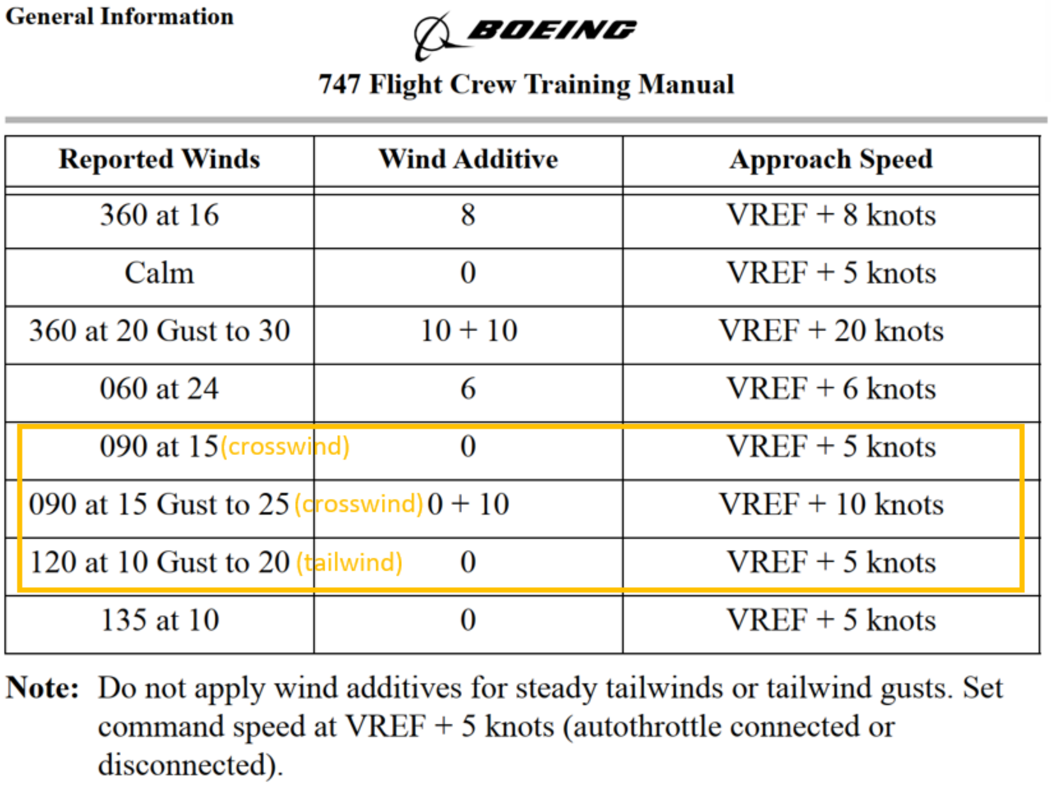
[68] Ibid., section 1.21, p. 55.

Figure 10. Wind additive (Source: Copyright © Boeing. Reprinted with permission of the Boeing Company, 747 Flight Crew Training Manual, revision 7 [30 June 2017], Chapter 1: General Information, Wind additive section 1.22 [30 June 2017], p. 56, with TSB annotations)



General Information

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Reported Winds	Wind Additive	Approach Speed
360 at 16	8	VREF + 8 knots
Calm	0	VREF + 5 knots
360 at 20 Gust to 30	10 + 10	VREF + 20 knots
060 at 24	6	VREF + 6 knots
090 at 15 (crosswind)	0	VREF + 5 knots
090 at 15 Gust to 25 (crosswind)	0 + 10	VREF + 10 knots
120 at 10 Gust to 20 (tailwind)	0	VREF + 5 knots
135 at 10	0	VREF + 5 knots

Note: Do not apply wind additives for steady tailwinds or tailwind gusts. Set command speed at VREF + 5 knots (autothrottle connected or disconnected).

In this occurrence, based on the guidance from the FCTM, the approach speed is V_{REF} plus any wind additive, with a minimum approach (command) speed of V_{REF} + 5 knots, or 159 knots minimum. The winds provided by ATIS information Sierra of 230°M at 10 knots would have resulted in a direct right crosswind for landing on Runway 14. Therefore, there was no headwind component, and the wind additive was 0, resulting in an approach (command) speed of 159 knots. When the winds changed to 260°M at 16 knots, gusting up to 21 knots, resulting in a steady 7-knot tailwind component, the wind additive remained at 0 knots, as no wind additives are applied for steady or tailwind gusts (Figure 10). Hence the recommended approach speed remained at 159 knots.

During the approach preparation, the crew used ATIS information Sierra and calculated the wind additive to be 5 knots (half of 10 knots), and then added that to Vref+5, to get V_{REF} + 10 knots, or 164 knots, as the approach (command) speed. A previous TSB investigation into an overrun that occurred in 2015[69] determined that the occurrence pilots added half of the total steady state wind, rather than half of the headwind component. The report also stated that company check pilots noted that this error was common.

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[69] TSB Aviation Investigation Report A15Q0075.

1.17.4.3 Unfactored (actual) landing distances

The charts for normal configuration landing distance in the QRH "performance package model identification" section for the occurrence aircraft were unfactored; thus, they provided actual landing distance data (without any additional safety margin). The QRH contained no factored charts for the occurrence aircraft. During the approach preparation, the crew used the data from ATIS information Sierra.

The crew used the typical flaps 25 configuration for landing and calculated the approach speed using V_{REF} + 10 knots, or 164 knots. Using the QRH data (Appendix H), the crew calculated the landing distance required at approximately 6000 feet, with autobrakes 4. This landing distance was not recorded on any flight documentation.

Post-flight calculations using the QRH guidance under the existing conditions, with flaps 25, autobrakes 4, and an approach speed of 159 knots (V_{REF} + 5 knots), resulted in a landing distance of 6375 feet (Appendix H). However, if the actual landing distance was corrected for the higher (V_{REF} + 10 knots) approach speed, it would increase to 6735 feet. Table 6 indicates the actual landing distances using flaps 25 and flaps 30, based on the winds

- as discussed during the briefing,
- when ATC asked the crew to confirm that Runway 14 was still acceptable (when the aircraft was 8.6 NM from landing on its final approach),
- when ATC provided a wind check at 1.7 NM on its final approach, and
- when the aircraft crossed the threshold of the runway.

Table 6. Quick Reference Handbook actual landing distance based on the changes in existing conditions (Source: TSB, based on Sky Lease Cargo, 747 Flight Crew Operations Manual: 747 Quick Reference Handbook, Revision 01 [05 May 2017], p. PI-QRH.12.2 and PI-QRH.12.3)

Flaps	Position	Wind direction and speed	Wind component (knots)	Approach speed	Actual (unfactored) landing distance required (feet)	Extra runway (feet)
Flaps 25	Briefing	230°, 10 knots	Headwind 0.5	V_{REF}+10 (164 knots)	6735	965
	8.6 NM final	260°, 16 knots, gusting to 21 knots	Tailwind 7.3	V_{REF}+10 (164 knots)	7514	186
	1.7 NM final	250°, 15 knots	Tailwind 4.4	V_{REF}+10 (164 knots)	7211	489
	Runway threshold*	250°, 15 knots	Tailwind 4.4	V_{REF}+19 (173 knots)	8088*	−388*
Flaps 30	Briefing	230°, 10 knots	Headwind 0.5	V_{REF}+10 (158 knots)	6241	1459
	8.6 NM final	260°, 16 knots gusting to 21 knots	Tailwind 7.3	V_{REF}+10 (158 knots)	6991	709
	1.7 NM final	250°, 15 knots	Tailwind 4.4	V_{REF}+10 (158 knots)	6700	1000
	Runway threshold*	250°, 15 knots	Tailwind 4.4	V_{REF}+19 (167 knots)	7541*	159*

* This landing distance includes the fact that the aircraft was 9 knots above the target speed used for the other calculations and 12 feet above the reference threshold crossing height of 50 feet.

NOTE: The unfactored landing distance required with flaps at 25 was greater than the runway length when the aircraft crossed the runway threshold.

1.17.4.4 Factored landing distance

The normal configuration landing distance charts in the QRH "performance package model identification" section for the other 2 company Boeing 747-400 aircraft are factored by 1.15. At the time of the occurrence, the company was updating the occurrence aircraft's manual to reflect factored numbers.

Post-flight calculations using the unfactored (actual) landing distance, factored by 1.15, resulted in the values shown in Table 7.

Table 7. Quick Reference Handbook unfactored landing distance then factored by 1.15 (Source: TSB, based on Sky Lease Cargo, 747 Flight Crew Operations Manual: 747 Quick Reference Handbook, Revision 01 [05 May 2017], p. PI-QRH.12.2 and PI-QRH.12.3)

Flaps	Position	Wind direction and speed	Wind component (knots)	Actual (factored) landing distance required (feet)	Extra runway (feet)
Flaps 25	Briefing	230°, 10 knots	Headwind 0.5	7745	−45
	8.6 NM final	260°, 16 knots, gusting to 21 knots	Tailwind 7.3	8641	−941
	1.7 NM final	250°, 15 knots	Tailwind 4.4	8293	−593
	Runway threshold*	250°, 15 knots	Tailwind 4.4	9301*	−1601*
Flaps 30	Briefing	230°, 10 knots	Headwind 0.5	7177	523
	8.6 NM final	260°, 16 knots gusting to 21 knots	Tailwind 7.3	8039	−339
	1.7 NM final	250°, 15 knots	Tailwind 4.4	7705	−5
	Runway threshold*	250°, 15 knots	Tailwind 4.4	8672*	−972*

* This landing distance includes the fact that the aircraft was 9 knots above the target speed used for the other calculations and 12 feet above the reference threshold crossing height of 50 feet.

NOTE 1: With flaps at 25, the actual landing distance required was greater than the runway length when the aircraft was 8.6 NM from landing, when it was 1.7 NM from landing, and when it crossed the runway threshold.

NOTE 2: With flaps at 30, the actual landing distance required was greater than the runway length when the aircraft crossed the runway threshold.

1.17.5 NAV CANADA

1.17.5.1 General

NAV CANADA is a private company that provides air navigation services for commercial and general aviation in Canadian airspace. NAV CANADA operates under Subpart 8 of the CARs and meets the requirement to have a safety management system set out in section 801.05.

1.17.5.2 Unit operations manual for Halifax air traffic control tower

The NAV CANADA *Manual of Air Traffic Services – Tower* provides guidance for assigning an active runway.[70] If the winds at the airport are 5 knots or more, the manual specifies that the tower should "assign the operationally suitable runway most closely aligned into the wind." [71]

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[70] Any runway or runways currently being used for takeoff or landing. When multiple runways are used, they are all considered active runways. When an aircraft is landing or taking off on an airport surface other than a runway, the direction of flight determines the active runway. (Source: NAV CANADA, *Manual of Air Traffic Services – Tower* [effective 10 October 2019], Glossary)

[71] Ibid., Table 7: Assigning Runways, p. 84.

The suitable runway selection is based on the runway aligned into wind. The manual specifies that an airport controller may assign "a runway with a tailwind component,"[72] under the following circumstances:

- The runway is dry.
- You [they] indicate the wind direction and speed to the pilot.
- The tailwind component, including gusts, does not exceed 5 knots.[73]

Airport controllers may also assign a runway with a crosswind. However, the *Manual of Air Traffic Services – Tower* specifies that, when the runway condition is wet, the maximum crosswind component,[74] including gusts, is 15 knots and adds, "The pilot makes the final decision on the acceptability of a runway."[75]

An airport controller is required to coordinate with all operating positions concerned if an active runway is changed. The arrangement between CYHZ tower and Moncton ACC[76] specifies that the airport controller verbally coordinates a change in the active runway at the airport with the Moncton ACC controller in addition to updating the information on the controller's workstation.

NAV CANADA Unit Operations Manual (UOM) for the Halifax ATC tower[77] provides direction and information for the controllers on procedures. According to the UOM, an airport controller must not designate a runway with a tailwind component as the arrival runway or advertise it as available on the controller's workstation if the wind component exceeds the criteria in the NAV CANADA *Manual of Air Traffic Services – Tower*. However, the UOM also states that an airport controller may assign a runway with a tailwind component if it is most nearly aligned into the wind or the only runway available.[78]

The UOM adds "[i]f a pilot requests arrival on a runway for which the tailwind component is exceeded you [a controller] may approve that request provided you [he/she] advise[s] the pilot of the wind direction and speed."[79]

An ACC controller is required to issue landing information before or shortly after an aircraft is cleared to descend. If the information is included in the current ATIS broadcast and a

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[72] A tailwind component is "the wind speed measured in knots at angles from 91° to 179° from the runway in use that would equal the effect of a wind applied at 180° to the runway in use." (Source: NAV CANADA, *Manual of Air Traffic Services – Tower* [effective 10 October 2019], Glossary)

[73] Ibid., p. 84.

[74] A crosswind component is the wind speed measured in knots at angles from 20° to 90° from the runway in use that would equal the effect of a wind applied at 90° to the runway in use. (Source: Ibid., Glossary)

[75] Ibid., p. 85.

[76] NAV CANADA, Arrangement between Halifax Tower and Moncton ACC (Maritime Specialty) (30 June 2018).

[77] NAV CANADA, *Unit Operations Manual: Halifax Air Traffic Control Tower* (21 July 2018).

[78] Ibid., Coordination, p. 35.

[79] Ibid.

flight crew acknowledges receipt of the broadcast, there is no requirement for the controller to issue the information a second time.[80]

After issuing landing information, if an ACC controller learns of information that may affect an aircraft's descent, approach, or landing, the controller is required to inform the pilot.[81] Furthermore, the controller is required to inform the flight crew of any new and pertinent information that differs from the current ATIS message.[82] At 0454, the CYHZ tower controller informed the Moncton ACC controller that the designated arrival runway was being changed from Runway 14 to Runway 23 and that the approach to the airport was now the RNAV approach to Runway 23. The runway change information was not communicated to the crew.

1.18 Additional information

1.18.1 Pilot decision making

1.18.1.1 General

An important component of pilot decision making is the ability to recognize changes in a situation and reinitiate the decision-making process to ensure that necessary changes are made and plans are modified. In particular, in-flight decisions are typically prompted by unanticipated events that require adjustment of the planned course of action. Situation assessment allows crews to make more effective decisions by interpreting the pattern of cues that define an issue, assessing the level of risk, and determining the time available to reach a solution.[83]

Failure to adequately consider the potential implications of a situation during decision making increases the risk that decisions and subsequent associated action(s) will result in adverse outcomes.

1.18.1.2 Situational awareness

Situational awareness is "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."[84] Accurate situational awareness maximizes effective and safe decision making in the cockpit. To maintain accurate situational awareness, a pilot must first

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[80] NAV CANADA, *Manual of Air Traffic Services – ACC* [effective 10 October 2019], Landing Information, p. 106.

[81] Ibid.

[82] Ibid.

[83] J. Orasanu-Engel and K. L. Mosier, "Flight Crew Decision-Making," in: B. G. Kanki, J. Anca and T. R. Chidester (eds.), *Crew Resource Management,* 3rd edition*,* (Cambridge, MA: Academic Press, 2019), pp. 139–183.

[84] M. R. Endsley, "Design and Evaluation for Situation Awareness Enhancement," presented in January 1988 at the Annual Meeting of the Human Factors Society: 32nd Annual Meeting, Santa Monica, CA, pp. 97–101.

perceive information from the environment, then establish its relevance in terms of achieving operational goals, and, finally, use it to project and predict future states and events, allowing the ability to "plan ahead and prepare for contingencies."[85] A pilot's knowledge, experience, and expectations are some of the individual factors that influence situational awareness.[86] A construct proposed[87] to underpin situational awareness is called "affective awareness" or a pilot's "gut feeling" (for threats to safety), which is characterized by an emotional, sensory experience that triggers further cognitive analysis.

Errors at the most basic level of situational awareness involve failure to correctly perceive the situation. This can happen because critical information is not available to the individual, either because it was not presented effectively by the system or because it was not communicated effectively among individuals. Research[88] on causal factors underlying aviation occurrences has found that most of the accidents involving a substantial human error and situational awareness component can be attributed to failures to correctly perceive some piece(s) of information, either because data were unavailable or were difficult to detect or understand.

Team situational awareness is the degree to which every team member possesses the situational awareness required for his or her responsibilities[89] and the degree of shared understanding among crew members.[90] While a captain has ultimate responsibility for decision making and the overall safety of an aircraft, other crew members provide critical redundancy. In addition to their individual tasks, crew members support each other by monitoring the situation and one another's performance, and by intervening if a problem is detected. Individuals outside of the aircraft (e.g., air traffic controllers, flight dispatchers) also play a role in informing and calibrating team situational awareness by providing crews with accurate and timely information on weather, traffic, and runway environment.

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[85] J. Orasanu, "Decision-Making in the Cockpit," in: E. L. Wiener, B. G. Kanki and R. L. Helmreich (eds.), *Cockpit Resource Management* (San Diego, CA: Academic Press, 1993).

[86] M. R. Endsley, "Toward a theory of situational awareness in dynamic systems," *Human Factors,* Vol. 37, No. 1 (1995), pp. 32–64.

[87] T. Blajev and W. C. Curtis, "Go-Around Decision-Making and Execution Project," final report to Flight Safety Foundation, (Flight Safety Foundation: March 2017), at https://flightsafety.org/wp-content/uploads/2017/03/Go-around-study_final.pdf (last accessed on 07 May 2020).

[88] M. R. Endsley, "Situation Awareness in Aviation Systems," in: J. A. Wise, V. D. Hopkin, and D. J. Garland (eds.), *Handbook of Aviation Human Factors* (Boca Raton, FL: Taylor and Francis, 2010), pp. 12-1 – 12-22.

[89] M. R. Endsley, *Final Report: Situation Awareness In An Advanced Strategic Mission (NOR DOC 89-32). Hawthorne, CA: Northrop Corporation* (1989), in: "Situation Awareness in Aviation Systems," in: J. A. Wise, V. D. Hopkin, and D. J. Garland (eds.), *Handbook of Aviation Human Factors* (Boca Raton, FL: Taylor and Francis, 2010), pp. 12-1 – 12-22.

[90] E. Salas, E. J. Muniz and C. Prince, "Situation Awareness in Teams," in: W. Karwowski (ed.), *International Encyclopedia of Ergonomics and Human Factors (Volume 1)* (Boca Raton, FL: Taylor and Francis, 2001), pp. 555–557.

Accuracy of team situational awareness is improved when individual team members share a consistent understanding and representation—or "mental model"—of how a system works. Flight crews who share a mental model are more likely to arrive at a common understanding of a given situation without needing as much verbal communication than crews who do not. Teams who do not share a mental model tend to require more real-time coordination and communication to ensure that their activities are carried out properly.[91]

1.18.1.3 Factors affecting pilot decision making and situational awareness

1.18.1.3.1 Knowledge

Knowledge gained through experience and training on an aircraft type, and through experience with a runway environment, facilitates flight crew decision making by improving the accuracy of situational awareness.[92] Expertise can facilitate effective pilot decision making by 1) facilitating rapid and accurate perception of information or cues that signal a problem; 2) estimating the likelihood of various outcomes; and 3) facilitating an accurate mental model of a situation so that the best option can be chosen.[93]

The captain was experienced in various large aircraft; however, he had limited experience on the Boeing 747 (166 hours of flight time), with a total of 13 takeoffs and landings, including 4 takeoffs and landings at night. The operating crew had been to CYHZ previously; however, they had not landed on Runway 14, nor had they made an approach to CYHZ at night.

During the flight, some crew conversation touched on the captain's feelings of apprehension, or anxiety, about the conditions at CYHZ. The other flight crew members were aware of the captain's limited experience on the Boeing 747 and of his feelings of anxiety regarding the crosswind expected during the impending landing at CYHZ.

During pre-flight planning at the hotel, the crew, including the deadheading pilot, were briefed by flight dispatch on the weather in CYHZ as well as on the NOTAMs regarding runway landing conditions. The plan was made to land on Runway 14.

Although he was not a member of the operating crew, because of his extensive experience on the Boeing 747 and with the company, the deadheading captain was asked by the crew about any known issues with landing in CYHZ, including the viability of landing on Runway 14. The deadheading captain had been captain on a daytime flight into CYHZ about 1 week before the occurrence. That previous flight had landed on Runway 23. At the time, the

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[91] M. R. Endsley, "Situation Awareness in Teams: Models and Measures," in: M. McNeese, E. Salas and M. Endsley (eds.), *Handbook of Distributed Team Cognition: An Examination of the State of the Art* (Boca Raton, FL: CRC Press, *in press*).

[92] M. R. Endsley, "Toward a theory of situational awareness in dynamic systems," *Human Factors* Vol. 37, No. 1 (1995), pp. 32–64.

[93] J. Orasanu-Engel and K. L. Mosier, "Flight Crew Decision-Making," in: B. G. Kanki, J. Anca and T. R. Chidester (eds.), *Crew Resource Management,* 3rd edition (Cambridge, MA: Academic Press, 2019), pp.139–183.

deadheading captain found that Runway 23's usable length was not clearly marked, even under daytime conditions.

1.18.1.3.2 Communications and crew resource management

Effective communications—within the cockpit and among flight crew and ground-based personnel such as ATC and flight dispatch—are an important element in the decision-making process. According to the European Aviation Safety Administration and Transport Canada, crew resource management (CRM) "is the effective utilization of all resources including crew members, aircraft systems, supporting facilities and persons to achieve safe and efficient operations."[94]

One of the primary goals of CRM training is to "enhance communication, interaction, human factors and management skills of the crew members concerned."[95] Traditional CRM training stresses the importance of using clear, assertive language when communicating in the cockpit. The Sky Lease Cargo CRM training curriculum included modules on "communication barriers" and "assertiveness."

Research on speech comprehension[96,97] shows that certain elements of speech quality, tone, and content can be interpreted by listeners as indicating uncertainty and/or ambiguity. During the flight, in the minutes preceding the transfer to the tower frequency, the crew made 24 statements and callouts related to the configuration of the aircraft. The tone, timing, and content of some of the crew's speech communications indicated some level of uncertainty and ambiguity and of limited confidence in their ability to manage the impending landing.

1.18.1.3.3 Workload

Workload is a function of the number of tasks that must be completed within a given time. Workload increases if the number of tasks to be completed increases or if the time available decreases. Individuals use both physiological (i.e., increased heart rate) and cognitive (i.e., focusing attention) resources to manage high-workload situations.

An individual may experience acute stress and associated anxiety if a high-workload situation becomes physically threatening and the individual is uncertain of their ability to

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[94] Transport Canada, Advisory Circular (AC) 700-042: Crew Resources Management (CRM) (31 January 2019), at https://www.tc.gc.ca/media/documents/ca-opssvs/AC_700_042.pdf (last accessed on 01 September 2020).

[95] Ibid.

[96] V.L. Smith and H.H. Clark, "On the course of answering questions," *Journal of Memory and Language*, Vol. 32 (1993), pp. 25–38.

[97] E. Schleef, "Gender, power, discipline, and context: On the sociolinguistic variation of *okay*, *right*, *like,* and *you know* in English academic discourse," Proceedings of the Twelfth Annual Symposium about Language and Society, Austin, TX (16–18 April 2004).

manage the threat. This anxiety is maladaptive, because it disrupts the person's ability to manage a high-workload situation by degrading attention and working memory capacity.[98]

High levels of mental workload can thereby adversely affect a pilot's ability to perceive and evaluate cues from the environment and can negatively affect situational awareness by causing attentional narrowing.[99] Those experiencing acute stress are also "more likely to be distracted from a crucial task by highly salient stimuli, such as an alarm."[100] Consequently, their management of a high-workload situation "may become disjointed and chaotic."[101] "In some cases, [problems in situational awareness] may occur […] owing to a momentary overload in the tasks to be performed or in information being presented."[102]

> Because anxious thoughts tend to pre-empt working memory's limited storage capacity, the individual may have difficulty performing computations that would normally be easy and have difficulty making sense of the overall situation and updating their mental model of the situation.[103]

The expression of high mental workload and stress in one person can be communicated to other team members, leading to increased levels of team workload. Research has found that acute stress negatively affects team performance by impairing team integration and mental models.[104]

1.18.1.3.4 Cognitive influences

Pilots operate in a complex environment, monitoring multiple sources and types of information. To help them cope with the large amount of information in the environment that is available to the senses at any given time, humans have developed cognitive skills or "biases" that can facilitate information processing. These normal biases, however, have an unintended consequence: not all of the – potentially critical – elements in the environment will be attended to, which can lead to uninformed decisions.

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[98] M. W. Eysenck, N. Derakshan, R. Santo, and M. G. Calvo, "Anxiety and cognitive performance: attentional control theory," *Emotion,* Vol. 7 (2007), pp. 336–353.

[99] M. R. Endsley, "Situation awareness in aviation systems," in: J. A. Wise, V. D. Hopkin, and D. J. Garland (eds.), *Handbook of Aviation Human Factors* (Taylor and Francis, 2010), pp. 12-1 – 12-22.

[100] R. K. Dismukes, T. E. Goldsmith, and J. A. Kochan, "Effects of Acute Stress on Aircrew Performance: Literature Review and Analysis of Operational Aspects," report no. NASA/TM—2015–218930 (2015), at http://www.sti.nasa.gov (last accessed on 04 May 2020).

[101] Ibid.

[102] M. R. Endsley, "Situation awareness in aviation systems," in: J. A. Wise, V. D. Hopkin, and D. J. Garland (eds.), *Handbook of Aviation Human Factors* (Taylor and Francis, 2010), pp. 12-1 – 12-22.

[103] R. K. Dismukes, T. E. Goldsmith, and J. A. Kochan, "Effects of Acute Stress on Aircrew Performance: Literature Review and Analysis of Operational Aspects," report no. NASA/TM—2015–218930 (2015), at http://www.sti.nasa.gov (last accessed on 04 May 2020).

[104] A. P. Ellis, "System breakdown: the role of mental models and transactive memory in the relationship between acute stress and team performance," *Academy of Management Journal,* Vol. 49 (2006), pp. 576–589.

When the amount of available information about a situation is limited, people tend to rely on the first piece of credible information that is available to them to inform situation assessments. This is known as "anchoring bias" and can make it difficult to assess unfolding situations. Similarly, having only limited information about a situation can increase an individual's tendency to look for evidence that confirms or matches their current assessment or decision, a phenomenon known as "confirmation bias." These biases can make it less likely for a crew member to reassess their initial assessment and update it with new information, or lead them to attend to information that supports their current decision, while dismissing information that is contrary to what is expected.[105] The danger in both circumstances is that alternative outcomes will not be given an appropriate level of consideration when deciding on the best possible course of action.

Research and past accident investigations have demonstrated that, once a plan is made and committed to, it becomes increasingly difficult for flight crew to recognize stimuli or conditions in the environment that necessitate a change to the plan.[106] "Plan continuation bias" is the "deep-rooted tendency of individuals to continue their original plan of action even when changing circumstances require a new plan."[107] A condition or stimulus needs to be perceived as sufficiently salient to be recognized and acted upon in a timely manner. When plan continuation interferes with a crew's ability to detect important cues, or if the crew fails to recognize the implications of those cues, situational awareness can break down.[108,109] These breakdowns can result in non-optimal decisions that can compromise safety.

1.18.1.4 Unexpected abnormal conditions and workload

The physical movement skills required for flying become faster, more accurate and coordinated with repeated practice, allowing a pilot to reach a control or make a correct

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[105] A. Tversky and D. Kahneman, "Causal schemas in judgments under uncertainty," in: D. Kahneman, P. Slovic and A. Tversky (eds.), *Judgment Under Uncertainty: Heuristics and Biases*, (New York, NY: Press Syndicate of the University of Cambridge, 1982).

[106] J. Orasanu, L. Martin and J. Davison, "Errors in aviation decision making: bad decisions or bad luck?" NASA–Ames Research Center paper presented in May 1998 at the Fourth Conference on Naturalistic Decision Making, Warrington, VA.

[107] B. Berman and R. K. Dismukes, "Pressing the approach," *Aviation Safety World*, Vol. 1, Issue 6 (December 2006), p. 28.

[108] J. Goh and D. A. Wiegmann, "Visual flight rules flight into instrument meteorological conditions: An empirical investigation of the possible causes," *International Journal of Aviation Psychology*, Vol. 11, Issue 4 (2001).

[109] J. Orasanu, L. Martin and J. Davison, "Cognitive and contextual factors in aviation accidents: decision errors," in: E. Salas and G. A. Klein (eds.), *Linking Expertise and Naturalistic Decision Making* (Mahwah, NJ: Lawrence Erlbaum Associates, Inc., 2001), pp. 209–225.

size of action without visually checking.[110] Response accuracy also depends on timely feedback regarding the consequences of control movements.[111]

Emergencies or abnormal conditions that are unexpected[112] can create high workload and stress, and can impair performance in situations where people have limited time to process critical information and adjust actions accordingly.[113] Unexpected events surprise pilots because what happens in the environment does not match the individual's or team's mental model of the situation and of what is supposed to happen.[114] Situations involving very high levels of workload can result in important steps, such as SOP calls during a landing rollout, being delayed or omitted.

These omissions are called slips (of attention), and are the error type most frequently associated with the performance of routine, well-practiced tasks under conditions that are unexpected, or unusual. A slip of attention occurs when a check on the progress of a task sequence is mistimed or does not occur because an operator's attention is focused elsewhere. Both experienced and inexperienced pilots can make slips, but, since pilots who are learning new aspects of a familiar task typically need to devote more attention to it than a more experienced pilot does, slips tend to be more common in those with less experience on a given task.[115]

1.18.2 Runway overrun initiatives

1.18.2.1 Flight Safety Foundation

An analysis of a 14-year period of runway overrun data by the Flight Safety Foundation (FSF) states that "the risk of runway excursion increases when more than one risk factor is present. Multiple risk factors create a synergistic effect (i.e., two risk factors more than double the risk)."[116] These factors involved weather, aircraft performance, crew technique

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[110] L. Bainbridge and M. S. Dorneich, "Processes underlying human performance," in: J. A. Wise, V. D. Hopkin, and D. J. Garland (eds.), *Handbook of Aviation Human Factors* (Boca Raton, FL: Taylor and Francis, 2010), pp. 7-1 – 7-68.

[111] R. W. Proctor and K-P.L. Vu, "Selection and Control of Action", in G. Salvendy (ed.), *Handbook of Human Factors and Ergonomics, 4th edition* (Hoboken, NJ: John Wiley & Sons, Inc., 2012), pp. 95-116.

[112] A. Landman, E. L. Groen, R. van Paassen, A. W. Bronkhorst and M. Mulder, "Dealing with unexpected events on the flight deck: a conceptual model of startle and surprise," *Human Factors*, Vol. 59, No. 8 (2011), pp. 1161–1172.

[113] M. Yu, T. Zhu, and S. Donaldson, "Effects of time pressure on behavioural decision making in natural disasters: based on an online experimental system," *Journal of Geography & Natural Disasters*, Vol. 8, No. 1 (2018), p. 220.

[114] J. A. Kochan, E. G. Breiter, and F. Jentsch. "Surprise and unexpectedness in flying: Database reviews and analyses," In: *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting* (New Orleans, LA: Human Factors and Ergonomics Society, 2004).

[115] J. Reason, *Human Error* (Cambridge: Cambridge University Press, 1990), pp. 57–60.

[116] Flight Safety Foundation (FSF), *Reducing the Risk of Runway Excursions: Report of the Runway Safety Initiative* (May 2009), pp. 157–160.

and decision making, or aircraft systems. Of relevance to this occurrence, the review found that the following were frequent contributors:

- Unanticipated wind shear or tail wind
- Incorrect assessment of landing distance for prevailing wind and runway conditions
- Landing fast
- Excessive height over threshold, resulting in landing long
- Failure to detect non-deployment of ground spoilers (e.g., absence of related standard call)
- Bouncing and incorrect bounce recovery
- Late braking (or late takeover from autobrake system, if required)
- Increased landing distance resulting from the use of differential braking or the discontinued use of reverse thrust to maintain directional control in crosswind conditions

The FSF's recommended mitigations for these included:

- Defined policies for a rejected landing (bounce recovery)
- Defined task-sharing and standard calls for final approach and roll-out phases in SOPs
- Published procedures for adverse runway conditions
- Published procedures for optimum use of autobrake and reverse thrust on contaminated runways

1.18.2.2 Boeing

Boeing published AERO magazine quarterly from 1998 to 2014, providing operators with supplemental technical information to promote continuous safety and efficiency in their daily fleet operations. Data collected and analyzed from 2003 to 2010 and published in AERO in 2012 showed that the factors contributing to landing overruns occurred at the following frequencies:

- 90% landed on a runway that was not dry
- 68% occurred after stable approaches
- 55% touched down within the touchdown zone
- 42% landed with a tailwind of 5 knots or greater

This review showed that a runway overrun is typically caused by multiple factors. As a result, a multi-faceted approach to reducing the incidence of runway overruns would be required.

Among the factors listed, the following were applicable to this occurrence:

- Tailwinds
- High touchdown speed
- Speed brakes deployed late or not deployed

- Reversers deployed late or not deployed

Event data suggest that a number of runway overruns can be avoided if the flight crew has a more thorough understanding of the interrelationship between the landing environment and the current risks (e.g., weather, winds, runway conditions, minimum equipment list items, airplane weight). Pilots need to better understand the relationships among these factors for each flight:

- A stabilized approach
- Known and accounted for runway contamination
- Available versus required runway length
- Reported conditions compared with actual conditions
- Speed for the flight's approach
- Energy to be dissipated after landing
- Speed additives and effect on landing distances
- Reliability of runway braking action
- Proper, timely use of all deceleration devices

A failure or misunderstanding of each of these factors can lead to runway overrun excursions. Several of the mitigations recommended by Boeing to reduce runway overruns focus on increasing crew awareness.

1.18.3 U.S. Federal Aviation Administration

1.18.3.1.1 Mitigating the risks of a runway overrun

To provide pilots and operators with a way "to identify, understand, and mitigate risks associated with runway overruns during the landing phase of flight," the FAA issued AC 91-79A on 17 September 2014.[117] The AC was intended for use in the development of SOPs to mitigate such risks.

According to the AC, specific SOPs are "a primary risk mitigation tool" and should "[a]s a minimum" address the overrun hazards. Furthermore, it is "imperative" that these SOPs be executed faithfully by flight crews. An effective training program on runway overrun mitigation provided by operators also provides flight crews with "academic knowledge and skill to increase the pilot's awareness of the factors that can cause a runway overrun."

1.18.3.1.2 Standard operating procedures for flight deck crew members

The FAA also published an advisory circular on SOPs for flight deck crew members, which stated the following:

> Standard operating procedures (SOPs) are universally recognized as basic to safe aviation operations. Effective crew coordination and crew performance, two central

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[117] Federal Aviation Administration (FAA), Advisory Circular (AC) 91-79A: *Mitigating the Risks of a Runway Overrun Upon Landing* (17 September 2014).

> concepts of crew resource management (CRM), depend upon the crew's having a shared mental model of each task. The mental model, in turn is founded on SOPs.[118]

The AC also "emphasizes that SOPs should be clear, comprehensive, and readily available in manuals used by flight deck crewmembers."

The intent of SOPs is to provide effective and efficient communication to all crew members and to ensure that specific actions are taken in various phases of flight. Traditional CRM training for pilots stresses the importance of using clear, assertive language when communicating in the cockpit.

1.18.3.1.3 Safety alerts for operators: landing distance

The FAA also issues Safety Alerts for Operators (SAFOs), "an information tool that alerts, educates, and makes recommendations to the aviation community. […] Each SAFO contains important safety information and may contain recommended actions. SAFO content should be especially valuable to air carriers in meeting their statutory duty to provide service with the highest possible degree of safety in the public interest. The information and recommendations in a SAFO are often time critical."[119]

In 2006, the FAA issued a SAFO concerning landing distance, in which the FAA

> urgently recommends that operators of turbojet airplanes develop procedures for flight crews to assess landing performance based on conditions actually existing at time of arrival, as distinct from conditions presumed at time of dispatch. Those conditions include weather, runway conditions, the airplane's weight, and braking systems to be used. Once the actual landing distance is determined an additional safety margin of at least 15% should be added to that distance.
>
> The FAA considers a 15% margin between the expected actual airplane landing distance and the landing distance available at the time of arrival as the minimum acceptable safety margin for normal operations.[120]

In 2019, the FAA issued a SAFO[121] that replaced this previous SAFO "to assist operators in developing methods to ensure sufficient landing distance exists to safely make a full stop landing."

This SAFO reiterates that, "Once the actual landing distance is determined at the time of arrival, an additional safety margin of at least 15 percent should be added to actual landing

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[118] Federal Aviation Administration (FAA), Advisory Circular (AC) 120-71A: *Standard Operating Procedures for Flight Deck Crew Members* (10 January 2017).

[119] Federal Aviation Administration (FAA), https://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/safo/ (last accessed on 01 September 2020).

[120] Federal Aviation Administration (FAA), Safety Alert for Operators (SAFO06012): *Landing Performance Assessments at Time of Arrival* (31 August 2006), 3. Applicability: a, 1. Purpose, p. 1.

[121] Federal Aviation Administration (FAA), Safety Alert for Operators (SAFO19001): *Landing Performance Assessments at Time of Arrival* (11 March 2019), at https://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/safo/all_safos/media/2019/SAFO19001.pdf (last accessed on 01 September 2020).

distance. Except under emergency conditions, flight crews should not attempt to land on runways that do not meet the assessment criteria and safety margins as specified in this SAFO."

1.18.4 TSB Watchlist

The TSB Watchlist identifies the key safety issues that need to be addressed to make Canada's transportation system even safer. Runway overruns and fatigue management in air transportation are 2 Watchlist issues that are relevant to this occurrence.

1.18.4.1 Runway overruns

Despite the millions of successful movements on Canadian runways each year, aircraft sometimes continue past the end of the runway surface during landings or rejected takeoffs. These events, known as runway overruns, can result in aircraft damage, injuries, and even loss of life—and the consequences can be particularly serious when there is no adequate RESA or suitable arresting system designed to stop an aircraft.

Since 2005, there have been on average 9.7 runway overrun occurrences per year at Canadian airports, of which 7.5 occur during landing. Additionally, from 2005 to 2019 the TSB investigated 19 such occurrences and issued 4 recommendations to Canadian authorities. Three of those recommendations remain active[122] and 1 is closed.[123]

In March 2020, TC proposed regulations that would, among other things:

- require a 150 m RESA at airports with over 325 000 commercial passengers annually;
- require the use of an arresting system on runways where the 150 m RESA cannot be implemented; and
- be limited to runways serving commercial passenger services.

According to TC, these regulations, once implemented, will increase runway overrun protection to passengers from 75% of passenger traffic in 2017 to 95% by 2038. However, these regulations focus only on the risk to a majority of, but not all, passengers and do not consider non-passenger air traffic or the terrain at the end of all runways. Also, the proposed regulations may not fully meet the ICAO standard, which requires a 150 m RESA for all runways that are 1200 m in length and longer, and provisions for other types of runways.[124] Therefore, the TSB remains concerned that, without further action, risks to the public, property, and the environment remain.

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[122] TSB recommendations A07-06, A07-05, and A07-01.

[123] TSB Recommendation A07-03.

[124] International Civil Aviation Organization (ICAO), Annex 14 to the *Convention on International Civil Aviation, Aerodromes*, Volume I: Aerodrome Design and Operations, 8th Edition (July 2018), section 3.5.3.

Runway overruns: ACTIONS REQUIRED

- Despite the action taken to date, the number of runway overruns in Canada has remained constant since 2005 and demands a concerted effort to be reduced.
- Operators of airports with runways longer than 1800 m must conduct formal runway-specific risk assessments and take action to mitigate the risks of overruns to the public, property, and the environment.
- TC must adopt at a minimum the ICAO standard for RESAs, or a suitable arresting system designed to stop an aircraft.

1.18.4.2 Fatigue management in air transportation

In the transportation industry, crews often work long and irregular schedules—sometimes crossing multiple time zones or facing challenging conditions—that are not always conducive to proper restorative sleep. Fatigue poses a risk to the safety of air operations because of its potential to degrade several aspects of human performance.

ACTIONS REQUIRED

Fatigue management in air transportation will remain on the Watchlist until the following actions are taken:

- Canadian air operators that operate under CARs subparts 703, 704 and 705 implement, and comply with, the new regulations on flight crew fatigue management.
- The impact of these new regulations on aviation operations in Canada is assessed by the TSB.

While the TSB Watchlist targets Canadian operators, the issue of fatigue management has also been highlighted on the NTSB's Most Wanted List since 2016.[125]

1.19 Useful or effective investigation techniques

Not applicable.

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[125] U.S. National Transporation Safety Board (NTSB), Most Wanted List: Reduce Fatigue-Related Accidents – Aviation, at https://www.ntsb.gov/safety/mwl/Pages/mwlfs-19-20/mwl2-fsa.aspx (last accessed on 21 September 2020).

2.0 ANALYSIS

The aircraft was certified, equipped, and maintained in accordance with existing regulations, and no discrepancies were noted that would have prevented it from operating normally during the occurrence flight.

In an effort to understand why this runway excursion occurred, this analysis will focus on the crew assessment of the approach and landing and their actions based on the information available, the factors contributing to runway overruns, and the crew's management of the operational threats.

2.1 Pre-departure planning

Pre-departure planning plays an important role in establishing a clear picture for the crew of the influences (positive or negative) that may affect the flight, while ensuring that the flight meets regulatory requirements.

2.1.1 Weather and NOTAMs

Because the low ceilings and visibility were below the company's approach minima for the active runway at Halifax/Stanfield International Airport (CYHZ), the captain and Sky Lease Cargo flight operations jointly decided to delay the flight for 13.5 hours.

As part of the pre-departure planning at Chicago/O'Hare International Airport (KORD), the crew and flight dispatch reviewed 98 NOTAMs, including 37 concerning CYHZ that were presented in the sequence they were issued, in all-capitalized text, and not prioritized. Of these 37 CYHZ NOTAMs, 22 concerned Runway 05/23 and involved reduced services or unserviceable navigational aids, runway lighting, and a displaced threshold. Ten of these 22 contained repeated information with modifications, yet had to be compared with the previous version to identify the differences.

NOTAMs are intended to be a clear, concise, and unambiguous presentation of essential information. However, it is difficult to reliably extract the crucial information because of their presentation style, using all capital letters, and because of their sequence, in which important approach and runway NOTAMs are not prioritized but buried among other information. As a result, to determine which approaches and runways are available, users must extract the important items, search back and forth to compare repeated information, build a list of unavailable items, and compare this list with the approach charts. This extraction process of elimination is usually performed mentally, increasing the risk of misinterpretation, resulting in the crew having an inaccurate mental model of the operational hazards affecting a flight, and reducing the crew's situational awareness.

For example, in this occurrence, the 10 NOTAMs related to the approaches on Runway 23 were buried in the sequential list of 37 for CYHZ. Through a back-and-forth process of elimination, the crew believed that there were no approaches or lighting available on Runway 05/23. However, 2 approaches were available on Runway 23: the non-directional beacon (NDB) and the lateral navigation (LNAV) portion of the area navigation (RNAV), both with restrictions on the use of charted information.

Based on their review of the NOTAMs, the crew concluded that the instrument landing system (ILS) approach to Runway 14 was the only option.

Finding as to causes and contributing factors

The ineffective presentation style and sequence of the NOTAMs available to the crew and flight dispatch led them to interpret that Runway 23 was not available for landing at CYHZ.

2.1.2 Landing limitations: destination airports

Sky Lease Cargo's policy is to use wet runway calculations for the planning of all of its flights. To meet the requirements of section 121.195 of the U.S. *Federal Aviation Regulations* (FARs), Sky Lease Cargo uses runway analysis charts to determine the maximum landing weight for the runway expected at its destination, based on the weather, the approach, and landing aids.

This pre-departure maximum landing weight determination includes additional safety margins that are not included in the landing distance charts used in flight.

The Max Allowed Gross Weight Landing section of the weight and balance form indicated 302 092 kg and flaps 25 for landing on Runway 23. However, the interpretation of the weather and NOTAMs led the crew to plan on using Runway 14 in CYHZ. Using the runway analysis charts and the conditions expected in CYHZ at the time of arrival, the pre-departure maximum landing weight on Runway 14 was 261 500 kg for landing with flaps 25 and 279 400 kg for landing with flaps 30. Theses limits were not recorded on any flight documentation.

In establishing an accurate, shared mental model and situational awareness of potential threats to a flight, it is essential that crews determine accurate landing performance limits before departure. Based on the operational flight plan, the estimated landing weight on arrival in CYHZ was 265 852 kg; therefore, the occurrence flight only met the pre-departure maximum landing weight requirements using flaps 30.

Finding as to causes and contributing factors

The crew was unaware that the aircraft did not meet the pre-departure landing weight requirements using flaps 25 for Runway 14.

2.2 Approach preparation

The departure from KORD and cruise portion of the flight were uneventful. The approach preparation was carried out before the descent, in accordance with the standard operating procedure (SOP). During this approach preparation, the crew obtained automatic terminal information service (ATIS) information Sierra, determined the approach speed and required landing distance for the existing conditions, and performed an approach briefing for an ILS approach to Runway 14.

A comparison of the computed fuel according to the operational flight plan and the actual fuel on board at the top of descent point indicated that the landing in CYHZ would be close to the initial estimated landing weight of 265 852 kg. Using the *Quick Reference Handbook* (QRH), the crew calculated the unfactored landing distance, using autobrakes 4, with flaps 25, as approximately 6000 feet. Since that calculation determined the distance required was substantially less than the 7700 feet of runway available, they chose to continue with the typical flaps 25 landing configuration. Post-flight calculations using the QRH guidance for the existing conditions, with flaps 25, autobrakes 4, and an approach speed of 159 knots resulted in an unfactored landing distance of 6375 feet.

In the occurrence flight, the crew calculated a V_{REF} of 154 knots and intended to disengage the autothrottle before landing. Given that Boeing's minimum (command) approach speed is V_{REF} + 5 knots, the crew then calculated this speed to be 159 knots. The crew next added half of the steady wind of 230° magnetic (M) at 10 knots, for an approach speed of 164 knots; however, the wind was actually a 90° crosswind. Boeing recommends that no wind additive be applied in 90° crosswind or tailwind conditions. Therefore, a zero wind additive should have been used, and the calculated approach speed should have been V_{REF} + 5 knots, or 159 knots (see section 1.17.4.2, Approach speed).

Finding as to causes and contributing factors

When planning the approach, the crew calculated a faster approach speed of V_{REF} + 10 knots instead of the recommended V_{REF} + 5 knots, because they misinterpreted that a wind additive was required for the existing conditions.

Based on this higher approach speed of 164 knots, the investigation's post-flight calculations showed an increased landing distance of 6735 feet. The available landing distance on Runway 14 is 7700 feet, leaving a safety margin of 965 feet. Under the existing conditions in CYHZ, there were no limitations or restrictions on the use of flaps 30 for the occurrence landing. Using the QRH data for landing with flaps 30, under the same conditions, also using V_{REF} + 10 knots, results in a landing distance required of 6241 feet compared to 6735 feet for flaps 25.

Finding as to causes and contributing factors

For the approach, the crew selected the typical flap setting of flaps 25 rather than flaps 30, because they believed they had a sufficient safety margin. This setting increased the landing distance required by 494 feet.

2.3 Descent and approach

At 0443, the crew began the descent from flight level (FL) 370 when the aircraft was 153 nautical miles (NM) from CYHZ. At 0446, the Moncton area control centre (ACC) controller asked the flight crew which approach they were planning, and the pilot monitoring (PM) advised that the plan was for the ILS approach to Runway 14. The Moncton ACC controller then cleared the flight directly to the intermediate fix TETAR (Appendix A).

At 0454, the tower controller advised the Moncton ACC controller that the primary runway was changing to Runway 23 via the RNAV 23 approach. This new landing information (a change in the approach in use) was not passed directly to the crew and was contrary to the crew's understanding that Runway 23 was unavailable. Having access to this information would have improved the crew's situational awareness and possibly reinitiated the decision-making process to consider Runway 23 as an option.

At 0458, the ATIS was updated to information Tango, with the only significant changes being the change of approach to RNAV 23 and the landing on Runway 23. At this moment, the Moncton ACC controller cleared the flight for an ILS approach to Runway 14.

At 0501, as the aircraft was 14 NM from the runway and about to intercept the final approach, the flight was transferred to the CYHZ tower, and the tower controller informed the crew that the winds were now 260°M at 15 knots and that the information was ATIS information Tango. The PM's reply to the tower was that they had information Tango.

During this time, the aircraft was approaching the final approach course in the presence of a tailwind, and the crew was reducing the speed to configure the aircraft for the ILS. As a result, in the minutes preceding the transfer to the tower frequency, the crew made 24 statements and callouts related to the configuration of the aircraft. The tone of many of the captain's statements indicated some apprehension, suggesting that he was seeking validation of his actions. The frequency and tone of communication were also indicative of a high workload, which can make it more challenging to effectively and correctly recognize the changes in conditions.

Given the high workload during this time, it is unlikely that the contents of ATIS Tango were reviewed in detail. In any case, the crew remained unaware that the approach had changed to Runway 23. Also, the crew did not understand that the information on winds just provided to them by the tower had changed significantly since ATIS information Sierra and Tango were issued, and that they now resulted in a 7-knot tailwind component for landing.

At 0502:46, when the aircraft was 8.6 NM from the threshold on its final approach, the CYHZ tower informed the crew that the winds were from 260°M at 16 knots, gusting to 21 knots, and asked the crew to confirm that Runway 14 was still acceptable. The PM confirmed that it was and the tower controller repeated the winds and cleared the flight to land on Runway 14.

The crew did not realize that the approach and landing runway had changed to Runway 23 and had not yet understood that the newly provided information on winds resulted in a 7-knot tailwind component for Runway 14. Since the crew had limited situational awareness of the conditions at CYHZ, they concluded that continuing the approach to Runway 14 was the only option available to them.

Over the next 20 seconds, the crew briefly reviewed calculations involving the wind strength and gusts to confirm that they would continue to use their planned approach speed of 164 knots, then performed the landing checklist. The captain's apprehension regarding the upcoming approach, of which the other crew members were aware; subtle performance-impairing effects of fatigue; and elevated workload, likely acted to limit working memory and impair the crew's ability to perform the normally easy approach speed computations.

In light of the tailwind present, the higher approach speed of 164 knots increased the landing distance required to 7514 feet, reducing the safety margin to 186 feet.

Just after passing the final approach fix, when the aircraft was 4.0 NM or 1 minute and 21 seconds from the threshold, the crew confirmed for the first time the presence of a tailwind (Table 8).

Table 8. Events on approach (Source: TSB, based on information obtained from the occurrence aircraft's flight data recorder and from air traffic control recordings)

Time	Event	Wind direction and speed	Ground speed (knots)	Altitude (feet) or height (AGL)	Distance from threshold (NM)	Elapsed time to threshold
0504:13	Crew confirms presence of tailwind	260° 16 knots, gusting to 21 knots	185	1300	4.0	0:01:21
0504:46	Crew reviews go-around items	N/A	179	800	2.3	0:00:48
0504:58	Tower provides crew with wind information	250° 15 knots, gusting to 21 knots	176	600	1.7	0:00:36
0505:11	Crew disconnects autopilot	N/A	174	400	1.1	0:00:23
0505:34	Aircraft at threshold of Runway 14	N/A	179	62	0	0:00:00

When the aircraft was passing through 800 feet above ground level (AGL), the PF reviewed the go-around procedure with the crew. This go-around review at this late stage of the approach indicates that the PF was aware that the presence of a tailwind had further reduced the runway margin on this 7700 foot runway. A few seconds later, the CYHZ tower transmitted a "wind check 250°M at 15 knots, gusting to 21 knots," resulting in a steady 4-knot tailwind component and a landing distance of 7211 feet. Shortly afterward, the crew had a short exchange about whether the PF was comfortable with the landing, and the crew agreed to continue the approach.

The tone, timing, and content of the crew communications during the flight indicated a limited degree of confidence in the execution of this landing. These communications just before landing and during a high-workload moment of the flight indicate heightened crew anxiety concerning the imminent crosswind landing.

Other than the limitation to have the autopilot disconnected by 150 feet AGL on an ILS approach, there was no company guidance as to when the autopilot should be disconnected on approach. In this occurrence, the captain disconnected the autopilot and autothrottle at 400 feet AGL and the airspeed increased to V_{REF} + 19 knots, as the aircraft deviated slightly left of the localizer and slightly above the glideslope. The airspeed increased to 173 knots as the aircraft crossed the runway threshold at a ground speed of 179 knots, higher than planned.

The aircraft crossed the threshold 14 knots faster than the required approach speed, with a 4.4 knot tailwind, and 12 feet above the glide path threshold-crossing altitude of 50 feet. These increased the landing distance required by 1368 feet, 460 feet, and 229 feet, respectively, which, in turn, increased the landing distance to 8088 feet.

Finding as to causes and contributing factors

The higher aircraft approach speed, the presence of a tailwind component, and the slight deviation above the glideslope increased the landing distance required to a distance greater than the runway length available.

Therefore, the higher airspeed and glideslope deviation, in the presence of the 4-knot tailwind resulted in the aircraft landing in conditions where it was not possible to stop on this 7700-foot wet runway. Although the aircraft was flown within the stable approach criteria, this occurrence demonstrates that, when operating very close to the performance limits of an aircraft, any deviations, no matter how small, may result in the aircraft no longer being able to be stopped within the confines of the runway.

In conditions of reduced runway margin and high PF workload and stress, timely and accurate PM callouts of deviations, such as increased approach speed, are crucial. In this occurrence, the 9-knot deviation further increased the landing distance required.

Finding as to risk

If the PM does not call out approach conditions or approach speed increases, the PF might not make corrections, increasing the risk of a runway overrun.

2.4 Landing

At 25 feet above the runway, all four thrust levers were reduced to the idle position. The firm (1.75*g*) aircraft touchdown occurred 1350 feet from the threshold (0505:38), which is consistent with a 3° descent from 62 feet to the runway surface.

Finding as to causes and contributing factors

After the firm touchdown, for undetermined reasons, the engine No. 1 thrust lever was moved forward of the idle position, causing the speed brakes to retract and the autobrake system to disengage, increasing the distance required to bring the aircraft to a stop.

One-half second later, reverse thrust was selected on engines Nos. 2, 3, and 4. Engine No. 1 thrust lever was then returned to near-idle, and the speed brake logic extended the speed brakes. Engine No. 1 reverse thrust was not selected, and the engine remained in forward thrust for the remainder of the landing rollout. The investigation was unable to determine the direct cause of the advancement of the engine No. 1 thrust lever.

Since the main landing gear is offset approximately 19 feet (left or right) from the centre of the aircraft, the firm touchdown, which was first on the right main gear, caused a left roll movement that peaked at 6°, when the left-hand wheel trucks compressed. This left bank, combined with the downward flex of the wing after the firm touchdown, likely resulted in the bottom nacelle of either engine No. 1 or No. 2 striking the surface of the runway; however, these engines continued to operate as commanded by the flight crew.

Finding as to causes and contributing factor

The right crab angle (4.5°) on initial touchdown, combined with the crosswind component and asymmetric reverser selection, caused the aircraft to deviate to the right of the runway centreline.

This combined right yaw tendency increased the rudder inputs required to regain the runway centreline. The rate of lateral displacement during the first 4 seconds after initial touchdown was approximately 6 feet per second. Based on this rate, if this displacement had not been reduced, a lateral runway side excursion would have occurred in approximately 10 seconds. Analysis of the FDR data indicated that the PF used rudder deflections between neutral and maximum left. The TSB laboratory analysis of the yawing moments and rudder effectiveness concluded that differential braking was not required for the pilot to regain the runway centreline.

The landing roll procedure of Sky Lease Cargo's SOP requires both pilots to verify that the thrust levers are closed and the speed brake lever is UP, and to monitor the rollout progress and verify autobrake operation. Additionally, the SOP directs that the PM calls "speed brakes up" or, if they do not deploy, "speed brakes not up," and then calls "reversers normal" or, if engine reversers are not all deployed, "no reverser(s) engine number ___." However, the crew did not complete the company's landing roll procedures during this occurrence.

The unexpected intensity of the landing impact, coupled with the lateral movement of the aircraft towards the runway's right edge, surprised the flight crew, who were already experiencing high workload. The resulting acute situational stress heightened their potential to become distracted by highly salient stimuli. The flight crew's attention was thus captured by the visual stimuli outside and ahead of the aircraft, and preventing a runway side excursion became their priority. The crew would have also been experiencing attentional narrowing, which limited their ability to detect and perceive other cues in the environment that would have indicated that deceleration devices had not deployed.

Finding as to causes and contributing factors

During the landing roll, the PM's attention was focused on the lateral drift and, as a result, the required callouts regarding the position of the deceleration devices were not made.

Because none of the landing rollout SOP calls were made, neither pilot was aware that

- the engine No. 1 thrust lever was advanced forward of idle,
- the speed brakes had retracted momentarily, and
- the engine No. 1 thrust reverser was not deployed.

The absence of SOP callouts to provide feedback to the PF that the speed brakes did not deploy as planned, that the autobrakes had disengaged, and that the engine No. 1 thrust reverser was not deployed, collectively increased the distance required to bring the aircraft to a stop, increasing the severity of the runway overrun. The captain's misapplication of the No. 1 reverse thrust lever was a slip of attention: he intended to apply the reverse thrust lever correctly. However, because his attention was directed toward preventing the runway side excursion, he did not notice that the No. 1 thrust lever movement to the reverse position had been interrupted.

Finding as to causes and contributing factors

The PF focused on controlling the lateral deviation and, without the benefit of the landing rollout callouts, did not recognize that all of the deceleration devices were not fully deployed and that the autobrake was disengaged.

Finding as to causes and contributing factors

Although manual brake application began 8 seconds after touchdown, maximum braking effort did not occur until 15 seconds later, when the aircraft was 800 feet from the end of the runway. At this position, it was not possible for the aircraft to stop and 5 seconds later, the aircraft departed the end of the runway at a speed of 77 knots and came to a stop 270 m (885 feet) past the end of the runway.

As this occurrence demonstrates, continuing a landing when the runway safety margin is reduced requires precise execution of the landing and the deployment of the deceleration devices as prescribed by the manufacturer, as any deviation increases the risk of a runway overrun.

In this occurrence, when the aircraft passed the end of the runway, it sustained damage beyond repair. Runway 14 at CYHZ has a 150 m (495 feet) runway safety area and a downward slope of 0.2%. Approximately 166 m (544 feet) past the end of Runway 14, there is a significant drop of 2.8 m (9 feet) at a downward slope of 73%. CYHZ meets Transport Canada's (TC's) standard, but not the International Civil Aviation Organization (ICAO)'s recommendations for a maximum longitudinal slope of 5%, and for a total runway safety area (RESA) of 300 m (984 feet).

Finding as to causes and contributing factors

During the overrun, the aircraft crossed a significant drop of 2.8 m (9 feet) approximately 166 m (544 feet) past the end of the runway and was damaged beyond repair. While this uneven terrain was beyond the 150 m (492 feet) RESA proposed by TC, it was within the recommended ICAO RESA of 300 m (984 feet).

2.5 Aircraft braking

To determine whether the braking efforts by the pilot were hindered by external factors that may have reduced the aircraft's ability to decelerate, the investigation analyzed the following:

- Runway marks, friction, and drainage
- Precipitation amounts
- Dynamic and reverted rubber hydroplaning
- Cockpit ergonomics and brake application

- Aircraft tires, brakes, anti-skid, auto speed brakes, autobrakes
- Viscous hydroplaning and aircraft braking coefficient

Physical examination and analysis of the runway did not reveal any evidence that would have impeded the deceleration of the aircraft.

There was no evidence of tire skidding. Additionally, using the interpolated rainfall intensity value during the occurrence landing, it was estimated that the water depth on the runway was less than considered necessary for dynamic hydroplaning.

Finding: Other

The investigation concluded that there was no reverted rubber hydroplaning and almost certainly no dynamic hydroplaning during this occurrence.

An analysis of ergonomic factors concluded that, when seated correctly using the design eye reference point locators, both pilots would have had full range of motion of the respective thrust levers and full rudder and brake pedal deflection. However, the investigation could not determine if the flight crew were seated correctly at the time of the occurrence.

Examination of the aircraft revealed no anomaly that would have affected the deceleration devices and TSB laboratory FDR analysis of these systems, indicating that they functioned as designed. Physical examination of the tires, brakes, and wheel torque limiters at the TSB laboratory found no evidence of any anomalies that would have reduced maximum braking.

The occurrence aircraft FDR was not capable of recording brake pedal position or the amount of brake pressure applied. However, since the investigation established that the PF was applying maximum braking effort in the last 800 hundred feet of runway remaining, FDR data was used to determine the deceleration rate of the aircraft for comparison with the theoretical wet runway deceleration using maximum braking effort. Wet runway aircraft braking coefficient (ABC) data provided values using maximum braking effort sufficient for anti-skid operation. The TSB laboratory calculated the occurrence's actual ABC and found that, during the final 800 feet, it was consistent with the theoretical ABC on a wet runway. Having established that the maximum braking effort was consistent with the wet runway ABC data, a baseline for comparison with the landing roll up to that point was established.

The lower aircraft deceleration rate from touchdown to this point indicates a lesser braking effort. From these changes in deceleration rates, coupled with FDR and CVR data, it was determined that maximum braking effort did not occur until the aircraft was 800 feet from the end of the runway, which further exacerbated the extent of the runway overrun.

Finding: Other

Although viscous hydroplaning can be expected on all wet runways, the investigation found that when maximum braking effort was applied, the aircraft braking was consistent with the expected braking on Runway 14 under the existing wet runway conditions.

2.6 Factors contributing to runway overruns

The Flight Safety Foundation (FSF), the U.S. Federal Aviation Administration (FAA), and Boeing have all identified factors contributing to runway overruns.

Boeing states that a runway overrun is typically caused by multiple factors. The FSF, as well, found that runway overruns usually resulted from 1 or more factors involving weather, aircraft performance, crew technique and decision making, or aircraft systems. The factors present in this occurrence have all been identified as contributing to runway overruns:

- Landing with a tailwind
- Excess speed and height at the threshold
- Delayed use of the deceleration devices

According to the QRH, with flaps 25, the tailwind at the threshold increased the landing distance by 460 feet. Furthermore, the higher approach speed at the threshold (V_{REF} + 19) increased the landing distance by 1368 feet, and the extra 12 feet of height at the threshold increased the landing distance by 229 feet. Together, these factors increased the landing distance to 8088 feet for the landing on this 7700-foot runway.

While preparing for the approach, the crew used the actual landing distance charts to determine that the landing performance on Runway 14 was approximately 6000 feet. This may have given the impression that they had a 1700 foot runway margin on this 7700 foot runway. However, these charts are based on the approach and landing being performed precisely on speed, on profile, with a touchdown 4.22 seconds after passing the threshold and with deceleration devices used immediately after landing. In reality, the initial actual landing distance (V_{REF} +10) was 6735 feet, and increased to 7514 feet with the tailwind. This left 186 feet of runway remaining, which is a margin of 2.4%. The FAA considers a 15% margin between the expected airplane landing distance and the landing distance available at the time of arrival as the minimum acceptable safety margin for normal operations.

In this occurrence, using the actual landing distance data, the aircraft could have been stopped within the runway surface, up until it passed the threshold faster and higher than planned. However, a successful landing on the runway would have been possible only if the approach and landing had been executed precisely according to the conditions mentioned in the QRH.

If the flight crew had used the FAA recommended factored landing distance, they would have become aware at the briefing stage that the runway available was 45 feet less than required, rather than the 965 feet extra using actual landing distance data (Table 9).

Table 9. Unfactored versus factored landing distances (flaps 25) at various positions on approach (Source: TSB, based on Sky Lease Cargo, 747 Flight Crew Operations Manual: 747 Quick Reference Handbook, Revision 01 [05 May 2017], p. PI-QRH.12.2 and PI-QRH.12.3)

Position	Wind direction and speed (knots)	Wind component (knots)	Actual (unfactored) landing distance calculations (feet) Flaps 25		FAA-recommended factored landing distance (feet)	
			Quick Reference Handbook unfactored	Extra runway	Factored 1.15	Extra runway
Briefing	230°, 10 knots	Headwind 0.5	6735	965	7745	–45
8.6 NM final	260°, 16 knots, gusting to 21 knots	Tailwind 7.3	7514	186	8641	–941
1.7 NM final	250°, 15 knots	Tailwind 4.4	7211	489	8293	–593
Runway threshold*	250°, 15 knots	Tailwind 4.4	8088*	–388*	9301*	–1601*

* This landing distance includes the fact that the aircraft was 9 knots above the target speed used for the other calculations and 12 feet above the reference threshold crossing height of 50 feet.

NOTE 1: The unfactored landing distance was greater than the runway length when the aircraft crossed the runway threshold.

NOTE 2: The FAA-recommended factored landing distances were greater than the available runway length when the aircraft was 8.6 NM from landing, when it was 1.7 NM from landing, and when it crossed the runway threshold.

At the time of the occurrence, the company was in the process of updating the QRHs with factored landing distances, but had not done it for the occurrence aircraft. Since the QRH landing distance data for this aircraft was unfactored, it may have affected the crew's situational awareness of the landing on Runway 14.

Finding as to causes and contributing factors

Using unfactored (actual) landing distance charts may have given the crew the impression that landing on Runway 14 would have had a considerable runway safety margin, influencing their decision to continue the landing in the presence of a tailwind.

2.7 Pilot decision making

An important component of pilot decision making is the ability to recognize changes in a situation and reinitiate the decision-making process to ensure that necessary changes are made and plans modified. It is important to consider the context in which the crew were operating throughout the flight to understand why it made sense to them to continue the approach after acknowledging, at 1 minute 21 seconds from the threshold, that the winds had resulted in a tailwind, rather than to take the time necessary to reconsider the plan in light of the new information.

2.7.1 Team situational awareness

Accurate situational awareness is achieved through perception, understanding, and projecting a situation in time. Individuals outside of the aircraft (e.g., company dispatch, air traffic control, other aircraft crew) play a role in informing and calibrating team situational awareness by providing crews with accurate and timely information.

There were several instances during the flight in which information that was not communicated to the flight crew could have improved the accuracy of their team situational awareness.

During the approach preparation, ATIS information Sierra indicated that Runway 23 was to be used for departure; however, because of the misinterpretation of the NOTAMs, the crew believed that Runway 23 was not available for landing. As the occurrence flight descended, another aircraft that was on a different radio frequency landed on Runway 23. The tower controller advised the Moncton ACC controller that the approach runway was changed to 23 and, as the aircraft was cleared for the ILS runway 14, ATIS information Tango was updated with the change to Runway 23. However, the crew was not verbally informed by Moncton ACC that the approach runway had changed to Runway 23.

When the flight was subsequently transferred to CYHZ tower, the controller advised the crew that information Tango was current. The PM responded that they "had" ATIS information Tango. However, none of the crew members was aware of the change of landing runway. This lack of awareness that the landing runway had changed to Runway 23 limited the completeness and accuracy of their team situational awareness and extended the crew's misunderstanding that this option was unavailable. As a result, they continued the approach to Runway 14.

Finding as to causes and contributing factors

New information regarding a change of active runway was not communicated by ATC directly to the crew, although it was contained within the ATIS broadcast; as a result, the crew continued to believe that the approach and landing to Runway 14 was the only option available.

2.7.2 Fatigue

The investigation included a thorough fatigue analysis, including consideration of the flight crew's work schedule, their sleep history, and circadian rhythm timing. The analysis identified 2 fatigue risk factors that would have degraded the crew's performance during the flight and at the time of the occurrence. First, the timing of the flight was during the nighttime circadian trough (2230 to 0430), when overall performance and cognitive functioning are at their worst. Second, the crew had not had sufficient restorative sleep in the 24-hour period leading up to the occurrence, which is considered an acute sleep disruption.

Efforts were made to provide opportunities for the crew to rest during the 13.5-hour departure delay. However, because it would have been difficult for the crew—who were used to sleeping at night—to sleep during the afternoon and evening, they were unable to obtain sufficient restorative sleep in the 24-hour period before the occurrence to avoid becoming fatigued.

As required by the Sky Lease fatigue risk management plan, the occurrence flight crew members had attended annual recurrent training in fatigue risk management that included material describing some of the more subtle performance impairments of fatigue. However, for the occurrence flight, this training was not salient enough for the crew to recognize and consider the more subtle effects of fatigue on performance when operating the early morning flight.

Sleep-related fatigue impairs working memory that is used for problem solving and reduces flexibility in an individual's problem-solving approach to a situation. It also makes it difficult for the fatigued person to devise and try a novel solution, increasing the likelihood that the normal routine will be maintained and leading to a failure to revise the original plan.

A test of the influence of fatigue was conducted to understand whether the actions of the crew were consistent with what is known about human performance in a state of fatigue. In terms of influence, some elements of the crew's performance and cognitive functioning were consistent with known performance impairments of fatigue, including: challenges in performing the normally easy approach speed computations, limitations in their ability to determine the effect of a tailwind, and limited flexibility to question the ongoing plan to land on Runway 14 despite the existence of new and relevant information.

Finding as to causes and contributing factors

Due to the timing of the flight during the nighttime circadian trough and because the crew had had insufficient restorative sleep in the previous 24 hours, the crew was experiencing sleep-related fatigue that degraded their performance and cognitive functioning during the approach and landing.

Stress and workload can also limit working memory capacity and the ability to perform calculations that would otherwise be easy, and can negatively affect team performance by impairing team integration and mental models.

Finding as to causes and contributing factors

An elevated level of stress and workload on short final approach likely exacerbated the performance-impairing effects of fatigue to limit the crew's ability to determine the effect of the tailwind, influencing their decision to continue the approach.

2.7.3 Cognitive influences

To cope with the large amount of sensory information in the environment at a given time, humans have developed normal cognitive coping skills to facilitate information processing, such as anchoring to the first credible piece of information (anchoring bias) or looking for information that confirms one's current assessment or decision (confirmation bias). The captain's relative inexperience in the aircraft type and the crew's inaccurate situational awareness of the other available landing option on Runway 23 created conditions that can facilitate these cognitive biases. During pre-flight planning, the crew consulted with the deadheading captain, who was very experienced on the aircraft type and had recently flown the approach to Runway 23 and found it to be challenging. The deadheading captain confirmed the crew's understanding that Runway 14 was appropriate for the weather and aircraft conditions, and that Runway 23 was not available to them. The crew's mental model of the landing plan in CYHZ was thus reinforced, and an anchoring bias developed among the crew concerning this information. The deadheading captain was not present in the cockpit during the approach and landing, thus was not present when the new wind information was received.

During the flight, confirmation and plan-continuation biases limited the likelihood that the flight crew would seek out, detect, and identify relevant cues in the environment that would indicate that they should reconsider their plan to land on Runway 14.

In spite of these biases, because of his significant overall aviation experience, the captain was likely aware on a subconscious, affective level (i.e., had a "gut feeling") that the runway margin was becoming critical as the flight continued. The captain's briefing of the go-around on short final approach indicates that he was concerned, on some level, with the landing plan. However, being new on the aircraft type and having only performance data based on actual landing distance, he was not situationally aware of precisely how limited the runway margin was. The captain's imprecise situational awareness of the landing distance computations made it more likely that he would rely on the knowledge and opinions of the more experienced crew members (e.g., the first officer and the international relief officer) to confirm the intention to continue the landing.

This continuation with the plan, despite some anxiety on the part of both the PF and PM, is consistent with research on decision making that has found that, under certain circumstances, cognitive influences such as anchoring, confirmation, and plan continuation biases can make individuals less likely to change a decision once it is made. In order to disrupt the plan or perform a go-around, so that the crew could take the time needed to reconsider the approach, a cue would have had to be sufficiently salient for the crew to detect, perceive, and understand its implications (i.e., that the aircraft was likely to overrun the runway).

The crew's limited flexibility to challenge the ongoing plan to land despite the existence of new and relevant information is also consistent with some of the known performance impairment effects of fatigue.

Finding as to causes and contributing factors

The crew were operating in a cognitive context of fatigue and biases that encouraged anchoring to and confirming information that aligned with continuing the initial plan, increasing the likelihood that they would continue the approach.

2.7.4 Unanticipated tailwind

The style and sequence of the NOTAMs led the crew and flight dispatch to believe that Runway 23 was not available for landing in CYHZ. Because they had not reviewed the latest ATIS information, the crew did not realize that Runway 23 was available. However, the critical point on this approach was when the crew realized on short final that they were landing with a tailwind. Since they had insufficient time to recalculate the landing distance required and review their options, they were faced with a decision to continue or go-around. From their perspective, and according to the actual landing distance chart they were using, the landing could still be performed within the surface of the runway. As a result, the crew agreed to continue.

Although the aircraft was flown within the stable approach criteria, the accident demonstrates how several factors affecting landing distance, although individually small, can combine to result in a reduced margin of safety, in which any additional factor can push the approach to a point that the aircraft can no longer stop on the available runway surface.

When crew are landing on a short runway, there is a heightened sense of awareness that the landing margin is small, so that any deviations or change in condition must be either immediately corrected or the approach must be discontinued. However, when operating on a runway where a greater margin is present, the crew does not necessarily have the same heightened awareness. Although there was originally a reasonable runway margin of safety during this approach and landing, conditions changed to a tailwind, resulting in a significant reduction in length available.

From a perspective of managing operational threats and following mitigations recommended by many organizations, it appears clear in hindsight that a go-around was the safest course of action. However, analysis of this occurrence shows how fatigue, cognitive biases, workload, and stress can hinder any crew's decision making. Since these influences may prevent crews from understanding that there is no longer an acceptable margin of safety for the upcoming landing, a trigger to re-evaluate should be a defense. Specifically, an unanticipated tailwind component should be a trigger to review the landing performance to determine whether the runway safety margin is still acceptable.

Finding as to causes and contributing factors

The crew recognized the presence of a tailwind on approach 1 minute and 21 seconds from the threshold; likely due to this limited amount of time, the crew did not recalculate the performance data to confirm that the runway safety margin was still acceptable.

3.0 FINDINGS

3.1 Findings as to causes and contributing factors

These are conditions, acts or safety deficiencies that were found to have caused or contributed to this occurrence.

1. The ineffective presentation style and sequence of the NOTAMs available to the crew and flight dispatch led them to interpret that Runway 23 was not available for landing at Halifax/Stanfield International Airport.

2. The crew was unaware that the aircraft did not meet the pre-departure landing weight requirements using flaps 25 for Runway 14.

3. Due to the timing of the flight during the nighttime circadian trough and because the crew had had insufficient restorative sleep in the previous 24 hours, the crew was experiencing sleep-related fatigue that degraded their performance and cognitive functioning during the approach and landing.

4. Using unfactored (actual) landing distance charts may have given the crew the impression that landing on Runway 14 would have had a considerable runway safety margin, influencing their decision to continue the landing in the presence of a tailwind.

5. When planning the approach, the crew calculated a faster approach speed of reference speed + 10 knots instead of the recommended reference speed + 5 knots, because they misinterpreted that a wind additive was required for the existing conditions.

6. New information regarding a change of active runway was not communicated by air traffic control directly to the crew, although it was contained within the automatic terminal information service broadcast; as a result, the crew continued to believe that the approach and landing to Runway 14 was the only option available.

7. For the approach, the crew selected the typical flap setting of flaps 25 rather than flaps 30, because they believed they had a sufficient safety margin. This setting increased the landing distance required by 494 feet.

8. The crew were operating in a cognitive context of fatigue and biases that encouraged anchoring to and confirming information that aligned with continuing the initial plan, increasing the likelihood that they would continue the approach.

9. The crew recognized the presence of a tailwind on approach 1 minute and 21 seconds from the threshold; likely due to this limited amount of time, the crew did not recalculate the performance data to confirm that the runway safety margin was still acceptable.

10. An elevated level of stress and workload on short final approach likely exacerbated the performance-impairing effects of fatigue to limit the crew's ability to determine the effect of the tailwind, influencing their decision to continue the approach.

11. The higher aircraft approach speed, the presence of a tailwind component, and the slight deviation above the glideslope increased the landing distance required to a distance greater than the runway length available.

12. After the firm touchdown, for undetermined reasons, the engine No. 1 thrust lever was moved forward of the idle position, causing the speed brakes to retract and the autobrake system to disengage, increasing the distance required to bring the aircraft to a stop.

13. The right crab angle (4.5°) on initial touchdown, combined with the crosswind component and asymmetric reverser selection, caused the aircraft to deviate to the right of the runway centreline.

14. During the landing roll, the pilot monitoring's attention was focused on the lateral drift and, as a result, the required callouts regarding the position of the deceleration devices were not made.

15. The pilot flying focused on controlling the lateral deviation and, without the benefit of the landing rollout callouts, did not recognize that all of the deceleration devices were not fully deployed and that the autobrake was disengaged.

16. Although manual brake application began 8 seconds after touchdown, maximum braking effort did not occur until 15 seconds later, when the aircraft was 800 feet from the end of the runway. At this position, it was not possible for the aircraft to stop on the runway and, 5 seconds later, the aircraft departed the end of the runway at a speed of 77 knots and came to a stop 270 m (885 feet) past the end of the runway.

17. During the overrun, the aircraft crossed a significant drop of 2.8 m (9 feet) approximately 166 m (544 feet) past the end of the runway and was damaged beyond repair. While this uneven terrain was beyond the 150 m (492 feet) runway end safety area proposed by Transport Canada, it was within the recommended International Civil Aviation Organization runway end safety area of 300 m (984 feet).

3.2 Findings as to risk

These are conditions, unsafe acts or safety deficiencies that were found not to be a factor in this occurrence but could have adverse consequences in future occurrences.

1. If the pilot monitoring does not call out approach conditions or approach speed increases, the pilot flying might not make corrections, increasing the risk of a runway overrun.

3.3 Other findings

These items could enhance safety, resolve an issue of controversy, or provide a data point for future safety studies.

1. The investigation concluded that there was no reverted rubber hydroplaning and almost certainly no dynamic hydroplaning during this occurrence.
2. Although viscous hydroplaning can be expected on all wet runways, the investigation found that when maximum braking effort was applied, the aircraft braking was consistent with the expected braking on Runway 14 under the existing wet runway conditions.

4.0 SAFETY ACTION

4.1 Safety action taken

4.1.1 Sky Lease Cargo

The Board is aware of some safety actions that were taken by the operator following the occurrence; however, the TSB did not receive sufficient documentation to validate these actions.

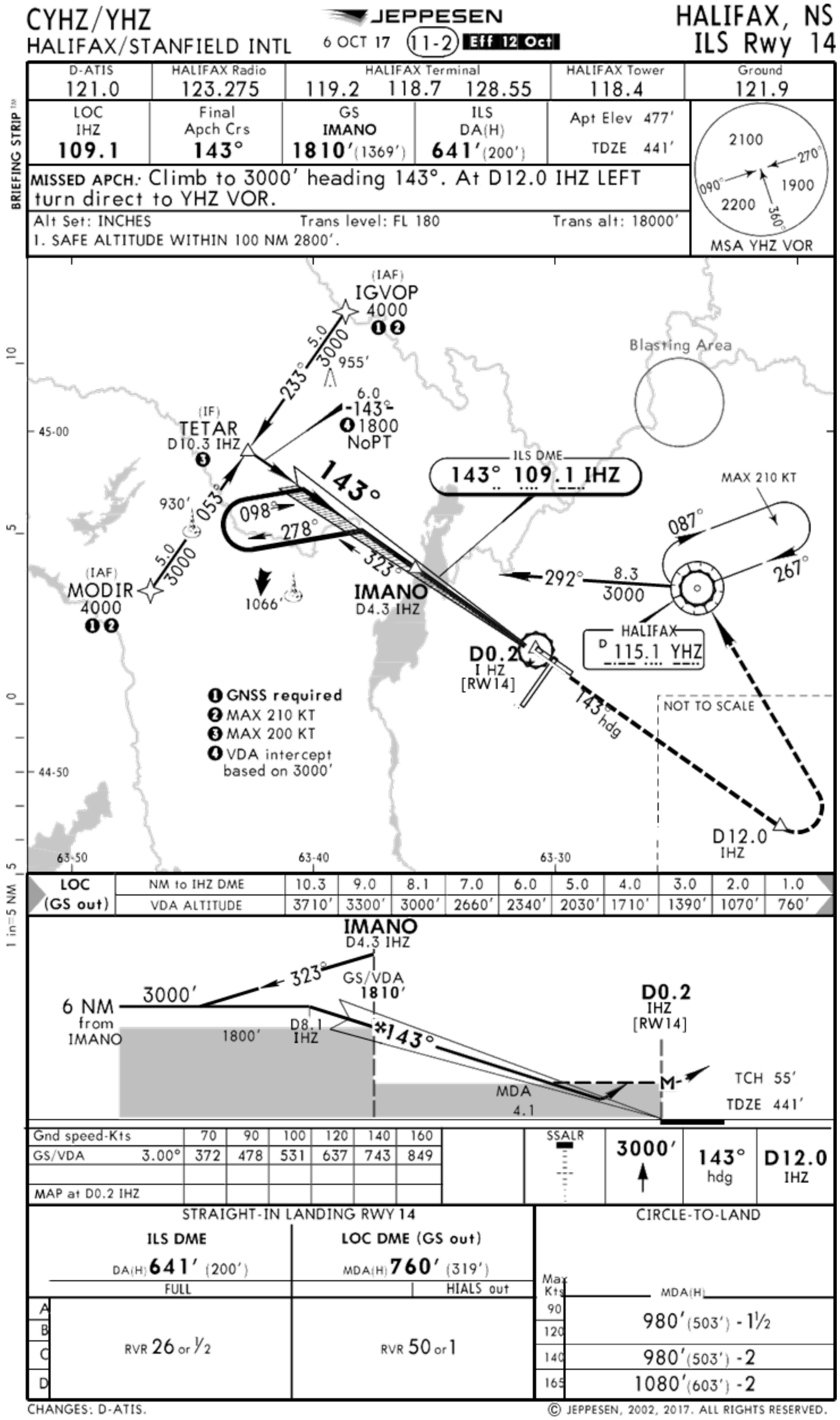
4.1.2 NAV CANADA

NAV CANADA published a bulletin to highlight the importance of issuing landing information to pilots and to remind controllers of the procedures in the Landing Information section of the *Manual of Air Traffic Services*.

This report concludes the Transportation Safety Board of Canada's investigation into this occurrence. The Board authorized the release of this report on 21 April 2021. It was officially released on 29 June 2021.

APPENDICES

Appendix A – Halifax/Stanfield International Airport ILS RWY 14 approach chart



CYHZ/YHZ
HALIFAX/STANFIELD INTL
JEPPESEN
6 OCT 17 (11-2) Eff 12 Oct
HALIFAX, NS
ILS Rwy 14

D-ATIS	HALIFAX Radio	HALIFAX Terminal	HALIFAX Tower	Ground
121.0	123.275	119.2 118.7 128.55	118.4	121.9

LOC IHZ	Final Apch Crs	GS IMANO	ILS DA(H)	
109.1	**143°**	**1810′** (1369′)	**641′** (200′)	Apt Elev 477′ TDZE 441′

MISSED APCH: Climb to 3000′ heading 143°. At D12.0 IHZ LEFT turn direct to YHZ VOR.

Alt Set: INCHES Trans level: FL 180 Trans alt: 18000′
1. SAFE ALTITUDE WITHIN 100 NM 2800′.

LOC (GS out)	NM to IHZ DME	10.3	9.0	8.1	7.0	6.0	5.0	4.0	3.0	2.0	1.0
	VDA ALTITUDE	3710′	3300′	3000′	2660′	2340′	2030′	1710′	1390′	1070′	760′

Gnd speed-Kts		70	90	100	120	140	160
GS/VDA	3.00°	372	478	531	637	743	849
MAP at D0.2 IHZ							

SSALR
3000′ ↑ 143° hdg D12.0 IHZ

STRAIGHT-IN LANDING RWY 14

	ILS DME DA(H) **641′** (200′)	LOC DME (GS out) MDA(H) **760′** (319′)		CIRCLE-TO-LAND Max Kts	MDA(H)
	FULL		HIALS out		
A	RVR 26 or ½	RVR 50 or 1		90	980′ (503′) - 1½
B				120	
C				140	980′ (503′) - 2
D				165	1080′ (603′) - 2

CHANGES: D-ATIS.

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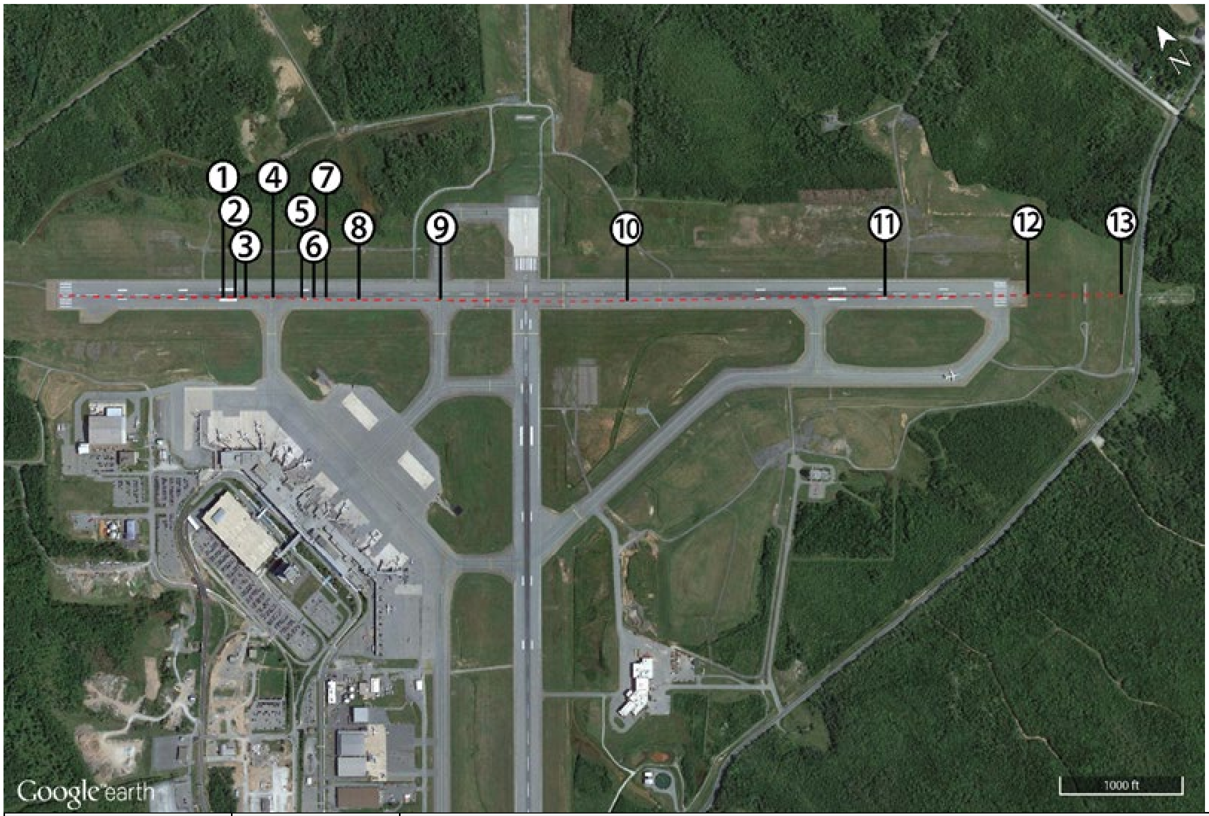
Source: Jeppesen

Appendix B – Events during the landing roll out



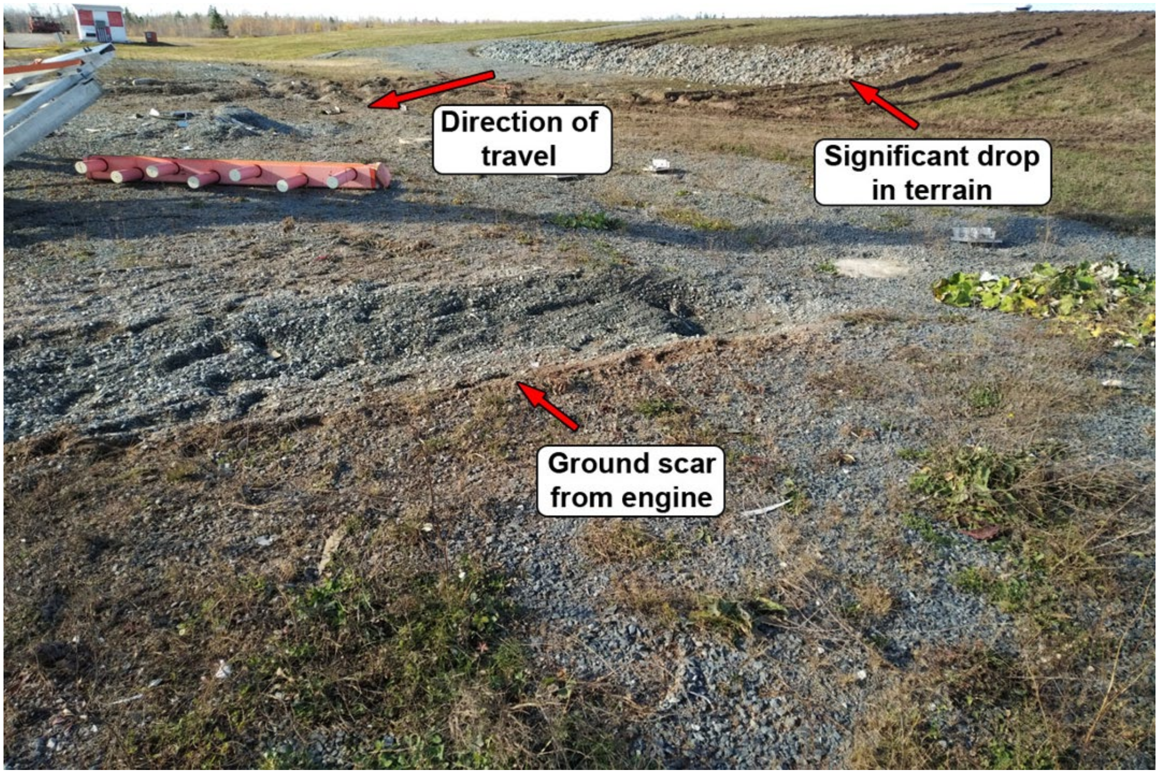
Position marked	Time	Activity
1	0505:37.95	Aircraft initially touches down
2	0505:38.30	Auto speed brake lever moves to the UP position
3	0505:38.56	No. 1 thrust lever is advanced above idle
4	0505:39.16	Auto speed brake lever moves to the DOWN position
5	0505:39.31	Thrust levers No. 2, No. 3, and No. 4 are brought into reverse thrust
6	0505:40.42	Air-ground logic switches indicate a momentary AIR mode logic position
7	0505:40.90	Air-ground logic switches indicate a GROUND mode logic position.
8	0505:41.69	No. 2, No. 3, and No. 4 thrust reversers are deployed
9	0505:44.02	No. 1 thrust lever is reduced; auto speed brakes are deployed to 100%.
10	0505:49.54	Maximum lateral deviation to the right of centreline
11	0505:59	Deceleration rate increases markedly
12	0506:06	Aircraft departs paved surface
13	0506:16 (estimated)	Aircraft comes to rest

Source: Google Earth, with TSB annotations

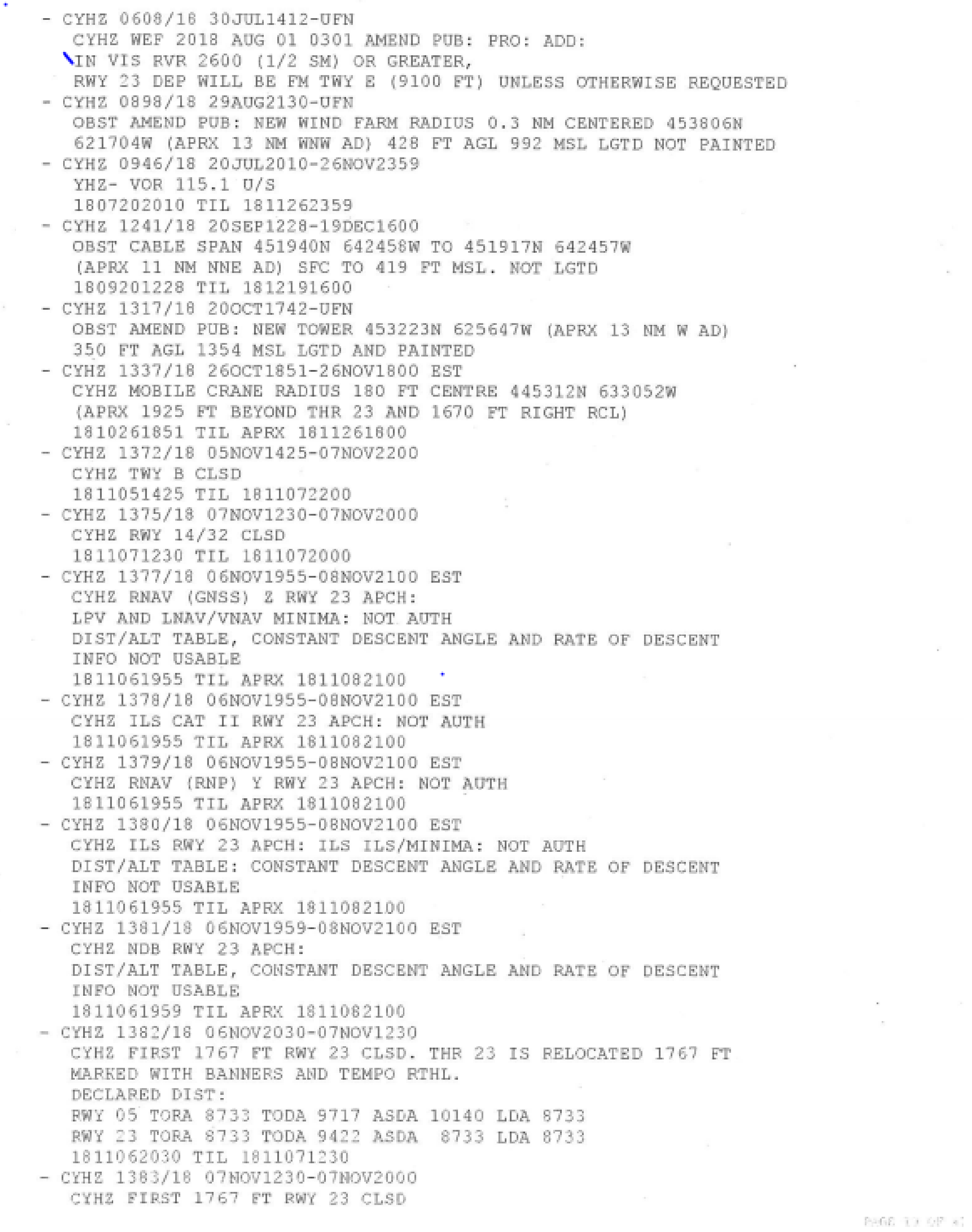
Appendix C – Ground scars

Figure C1. Ground scars (Source: TSB)

Figure C2. Close-up of ground scars (Source: TSB)



Appendix D – NOTAMs for Halifax/Stanfield International Airport



```
- CYHZ 0608/18 30JUL1412-UFN
   CYHZ WEF 2018 AUG 01 0301 AMEND PUB: PRO: ADD:
   IN VIS RVR 2600 (1/2 SM) OR GREATER,
   RWY 23 DEP WILL BE FM TWY E (9100 FT) UNLESS OTHERWISE REQUESTED
- CYHZ 0898/18 29AUG2130-UFN
   OBST AMEND PUB: NEW WIND FARM RADIUS 0.3 NM CENTERED 453806N
   621704W (APRX 13 NM WNW AD) 428 FT AGL 992 MSL LGTD NOT PAINTED
- CYHZ 0946/18 20JUL2010-26NOV2359
   YHZ- VOR 115.1 U/S
   1807202010 TIL 1811262359
- CYHZ 1241/18 20SEP1228-19DEC1600
   OBST CABLE SPAN 451940N 642458W TO 451917N 642457W
   (APRX 11 NM NNE AD) SFC TO 419 FT MSL. NOT LGTD
   1809201228 TIL 1812191600
- CYHZ 1317/18 20OCT1742-UFN
   OBST AMEND PUB: NEW TOWER 453223N 625647W (APRX 13 NM W AD)
   350 FT AGL 1354 MSL LGTD AND PAINTED
- CYHZ 1337/18 26OCT1851-26NOV1800 EST
   CYHZ MOBILE CRANE RADIUS 180 FT CENTRE 445312N 633052W
   (APRX 1925 FT BEYOND THR 23 AND 1670 FT RIGHT RCL)
   1810261851 TIL APRX 1811261800
- CYHZ 1372/18 05NOV1425-07NOV2200
   CYHZ TWY B CLSD
   1811051425 TIL 1811072200
- CYHZ 1375/18 07NOV1230-07NOV2000
   CYHZ RWY 14/32 CLSD
   1811071230 TIL 1811072000
- CYHZ 1377/18 06NOV1955-08NOV2100 EST
   CYHZ RNAV (GNSS) Z RWY 23 APCH:
   LPV AND LNAV/VNAV MINIMA: NOT AUTH
   DIST/ALT TABLE, CONSTANT DESCENT ANGLE AND RATE OF DESCENT
   INFO NOT USABLE
   1811061955 TIL APRX 1811082100
- CYHZ 1378/18 06NOV1955-08NOV2100 EST
   CYHZ ILS CAT II RWY 23 APCH: NOT AUTH
   1811061955 TIL APRX 1811082100
- CYHZ 1379/18 06NOV1955-08NOV2100 EST
   CYHZ RNAV (RNP) Y RWY 23 APCH: NOT AUTH
   1811061955 TIL APRX 1811082100
- CYHZ 1380/18 06NOV1955-08NOV2100 EST
   CYHZ ILS RWY 23 APCH: ILS ILS/MINIMA: NOT AUTH
   DIST/ALT TABLE: CONSTANT DESCENT ANGLE AND RATE OF DESCENT
   INFO NOT USABLE
   1811061955 TIL APRX 1811082100
- CYHZ 1381/18 06NOV1959-08NOV2100 EST
   CYHZ NDB RWY 23 APCH:
   DIST/ALT TABLE, CONSTANT DESCENT ANGLE AND RATE OF DESCENT
   INFO NOT USABLE
   1811061959 TIL APRX 1811082100
- CYHZ 1382/18 06NOV2030-07NOV1230
   CYHZ FIRST 1767 FT RWY 23 CLSD. THR 23 IS RELOCATED 1767 FT
   MARKED WITH BANNERS AND TEMPO RTHL.
   DECLARED DIST:
   RWY 05 TORA 8733 TODA 9717 ASDA 10140 LDA 8733
   RWY 23 TORA 8733 TODA 9422 ASDA  8733 LDA 8733
   1811062030 TIL 1811071230
- CYHZ 1383/18 07NOV1230-07NOV2000
   CYHZ FIRST 1767 FT RWY 23 CLSD
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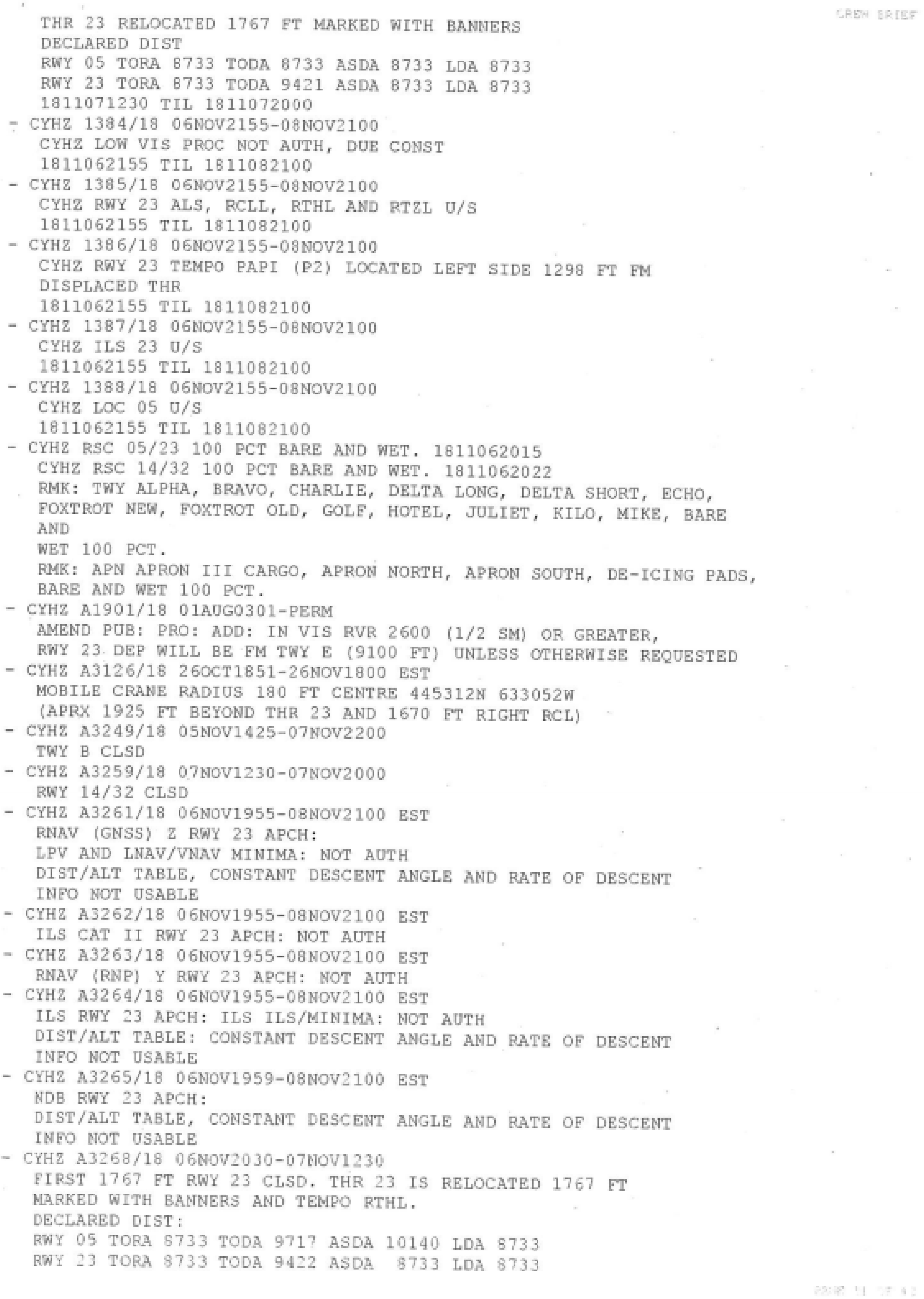
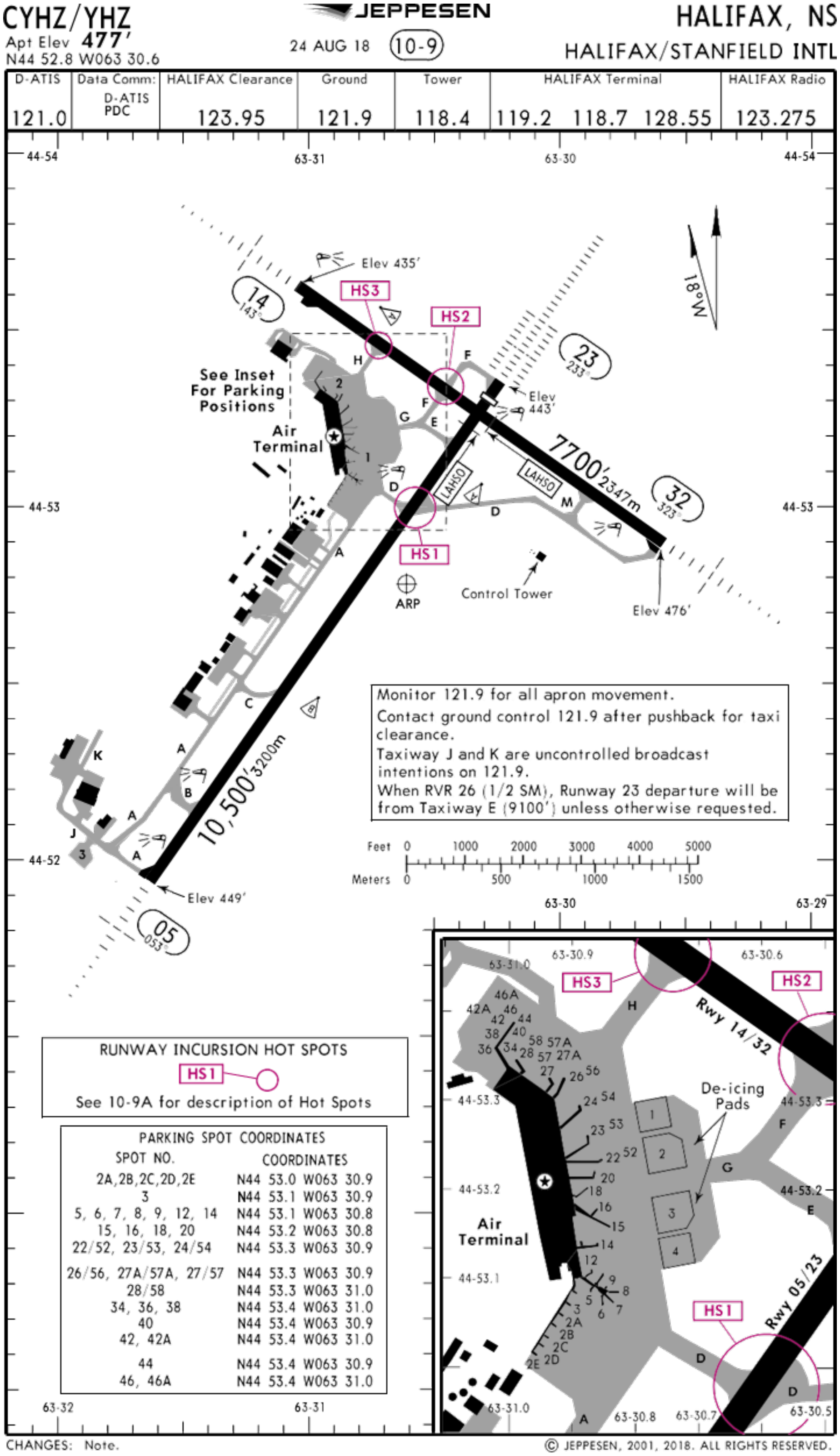


```
                                                                 CREW BRIEF
  THR 23 RELOCATED 1767 FT MARKED WITH BANNERS
  DECLARED DIST
  RWY 05 TORA 8733 TODA 8733 ASDA 8733 LDA 8733
  RWY 23 TORA 8733 TODA 9421 ASDA 8733 LDA 8733
  1811071230 TIL 1811072000
- CYHZ 1384/18 06NOV2155-08NOV2100
  CYHZ LOW VIS PROC NOT AUTH, DUE CONST
  1811062155 TIL 1811082100
- CYHZ 1385/18 06NOV2155-08NOV2100
  CYHZ RWY 23 ALS, RCLL, RTHL AND RTZL U/S
  1811062155 TIL 1811082100
- CYHZ 1386/18 06NOV2155-08NOV2100
  CYHZ RWY 23 TEMPO PAPI (P2) LOCATED LEFT SIDE 1298 FT FM
  DISPLACED THR
  1811062155 TIL 1811082100
- CYHZ 1387/18 06NOV2155-08NOV2100
  CYHZ ILS 23 U/S
  1811062155 TIL 1811082100
- CYHZ 1388/18 06NOV2155-08NOV2100
  CYHZ LOC 05 U/S
  1811062155 TIL 1811082100
- CYHZ RSC 05/23 100 PCT BARE AND WET. 1811062015
  CYHZ RSC 14/32 100 PCT BARE AND WET. 1811062022
  RMK: TWY ALPHA, BRAVO, CHARLIE, DELTA LONG, DELTA SHORT, ECHO,
  FOXTROT NEW, FOXTROT OLD, GOLF, HOTEL, JULIET, KILO, MIKE, BARE
  AND
  WET 100 PCT.
  RMK: APN APRON III CARGO, APRON NORTH, APRON SOUTH, DE-ICING PADS,
  BARE AND WET 100 PCT.
- CYHZ A1901/18 01AUG0301-PERM
  AMEND PUB: PRO: ADD: IN VIS RVR 2600 (1/2 SM) OR GREATER,
  RWY 23 DEP WILL BE FM TWY E (9100 FT) UNLESS OTHERWISE REQUESTED
- CYHZ A3126/18 26OCT1851-26NOV1800 EST
  MOBILE CRANE RADIUS 180 FT CENTRE 445312N 633052W
  (APRX 1925 FT BEYOND THR 23 AND 1670 FT RIGHT RCL)
- CYHZ A3249/18 05NOV1425-07NOV2200
  TWY B CLSD
- CYHZ A3259/18 07NOV1230-07NOV2000
  RWY 14/32 CLSD
- CYHZ A3261/18 06NOV1955-08NOV2100 EST
  RNAV (GNSS) Z RWY 23 APCH:
  LPV AND LNAV/VNAV MINIMA: NOT AUTH
  DIST/ALT TABLE, CONSTANT DESCENT ANGLE AND RATE OF DESCENT
  INFO NOT USABLE
- CYHZ A3262/18 06NOV1955-08NOV2100 EST
  ILS CAT II RWY 23 APCH: NOT AUTH
- CYHZ A3263/18 06NOV1955-08NOV2100 EST
  RNAV (RNP) Y RWY 23 APCH: NOT AUTH
- CYHZ A3264/18 06NOV1955-08NOV2100 EST
  ILS RWY 23 APCH: ILS ILS/MINIMA: NOT AUTH
  DIST/ALT TABLE: CONSTANT DESCENT ANGLE AND RATE OF DESCENT
  INFO NOT USABLE
- CYHZ A3265/18 06NOV1959-08NOV2100 EST
  NDB RWY 23 APCH:
  DIST/ALT TABLE, CONSTANT DESCENT ANGLE AND RATE OF DESCENT
  INFO NOT USABLE
- CYHZ A3268/18 06NOV2030-07NOV1230
  FIRST 1767 FT RWY 23 CLSD. THR 23 IS RELOCATED 1767 FT
  MARKED WITH BANNERS AND TEMPO RTHL.
  DECLARED DIST:
  RWY 05 TORA 8733 TODA 9717 ASDA 10140 LDA 8733
  RWY 23 TORA 8733 TODA 9422 ASDA  8733 LDA 8733
                                                                 PAGE 11 OF 42
```

```
                                                              CREW BRIEF
- CYHZ A3269/18 07NOV1230-07NOV2000
   FIRST 1767 FT RWY 23 CLSD
   THR 23 RELOCATED 1767 FT MARKED WITH BANNERS
   DECLARED DIST
   RWY 05 TORA 8733 TODA 8733 ASDA 8733 LDA 8733
   RWY 23 TORA 8733 TODA 9421 ASDA 8733 LDA 8733
- CYHZ A3272/18 06NOV2155-08NOV2100
   LOW VIS PROC NOT AUTH, DUE CONST
- CYHZ A3273/18 06NOV2155-08NOV2100
   RWY 23 ALS, RCLL, RTHL AND RTZL U/S
- CYHZ A3274/18 06NOV2155-08NOV2100
   RWY 23 TEMPO PAPI (P2) LOCATED LEFT SIDE 1298 FT FM
   DISPLACED THR
- CYHZ A3275/18 06NOV2155-08NOV2100
   ILS 23 U/S
- CYHZ A3276/18 06NOV2155-08NOV2100
   LOC 05 U/S
```

Source: Sky Lease Cargo

Appendix E – Aerodrome diagram for Halifax/Stanfield International Airport



CYHZ/YHZ
Apt Elev 477′
N44 52.8 W063 30.6

JEPPESEN
24 AUG 18 (10-9)

HALIFAX, NS
HALIFAX/STANFIELD INTL

D-ATIS	Data Comm:	HALIFAX Clearance	Ground	Tower	HALIFAX Terminal	HALIFAX Radio
121.0	D-ATIS PDC	123.95	121.9	118.4	119.2 118.7 128.55	123.275

Monitor 121.9 for all apron movement.
Contact ground control 121.9 after pushback for taxi clearance.
Taxiway J and K are uncontrolled broadcast intentions on 121.9.
When RVR 26 (1/2 SM), Runway 23 departure will be from Taxiway E (9100′) unless otherwise requested.

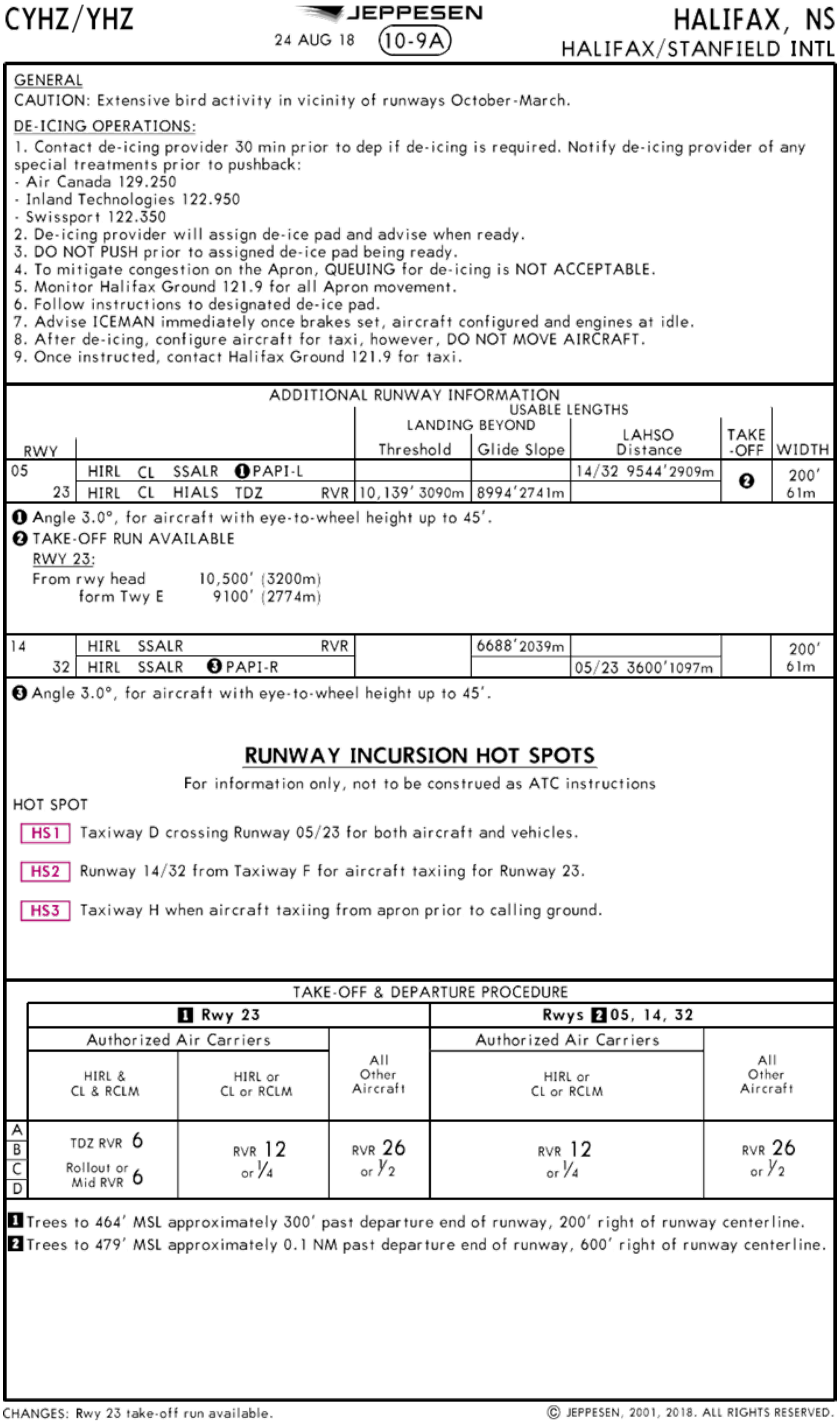
RUNWAY INCURSION HOT SPOTS
HS1
See 10-9A for description of Hot Spots

PARKING SPOT COORDINATES

SPOT NO.	COORDINATES
2A, 2B, 2C, 2D, 2E	N44 53.0 W063 30.9
3	N44 53.1 W063 30.9
5, 6, 7, 8, 9, 12, 14	N44 53.1 W063 30.8
15, 16, 18, 20	N44 53.2 W063 30.8
22/52, 23/53, 24/54	N44 53.3 W063 30.9
26/56, 27A/57A, 27/57	N44 53.3 W063 30.9
28/58	N44 53.3 W063 31.0
34, 36, 38	N44 53.4 W063 31.0
40	N44 53.4 W063 30.9
42, 42A	N44 53.4 W063 31.0
44	N44 53.4 W063 30.9
46, 46A	N44 53.4 W063 31.0

CHANGES: Note.

Source: Jeppesen



CYHZ/YHZ

JEPPESEN

24 AUG 18 (10-9A)

HALIFAX, NS

HALIFAX/STANFIELD INTL

GENERAL

CAUTION: Extensive bird activity in vicinity of runways October-March.

DE-ICING OPERATIONS:

1. Contact de-icing provider 30 min prior to dep if de-icing is required. Notify de-icing provider of any special treatments prior to pushback:
- Air Canada 129.250
- Inland Technologies 122.950
- Swissport 122.350
2. De-icing provider will assign de-ice pad and advise when ready.
3. DO NOT PUSH prior to assigned de-ice pad being ready.
4. To mitigate congestion on the Apron, QUEUING for de-icing is NOT ACCEPTABLE.
5. Monitor Halifax Ground 121.9 for all Apron movement.
6. Follow instructions to designated de-ice pad.
7. Advise ICEMAN immediately once brakes set, aircraft configured and engines at idle.
8. After de-icing, configure aircraft for taxi, however, DO NOT MOVE AIRCRAFT.
9. Once instructed, contact Halifax Ground 121.9 for taxi.

ADDITIONAL RUNWAY INFORMATION

		USABLE LENGTHS				
		LANDING BEYOND				
RWY		Threshold	Glide Slope	LAHSO Distance	TAKE-OFF	WIDTH
05	HIRL CL SSALR ❶PAPI-L			14/32 9544'2909m	❷	200' 61m
23	HIRL CL HIALS TDZ RVR	10,139' 3090m	8994'2741m			

❶ Angle 3.0°, for aircraft with eye-to-wheel height up to 45'.

❷ TAKE-OFF RUN AVAILABLE

RWY 23:

From rwy head 10,500' (3200m)

form Twy E 9100' (2774m)

RWY		Threshold	Glide Slope	LAHSO Distance	TAKE-OFF	WIDTH
14	HIRL SSALR RVR		6688'2039m			200' 61m
32	HIRL SSALR ❸PAPI-R			05/23 3600'1097m		

❸ Angle 3.0°, for aircraft with eye-to-wheel height up to 45'.

RUNWAY INCURSION HOT SPOTS

For information only, not to be construed as ATC instructions

HOT SPOT	
HS1	Taxiway D crossing Runway 05/23 for both aircraft and vehicles.
HS2	Runway 14/32 from Taxiway F for aircraft taxiing for Runway 23.
HS3	Taxiway H when aircraft taxiing from apron prior to calling ground.

TAKE-OFF & DEPARTURE PROCEDURE

	1 Rwy 23			Rwys **2** 05, 14, 32	
	Authorized Air Carriers		All Other Aircraft	Authorized Air Carriers	All Other Aircraft
	HIRL & CL & RCLM	HIRL or CL or RCLM		HIRL or CL or RCLM	
A B C D	TDZ RVR 6 Rollout or Mid RVR 6	RVR 12 or 1/4	RVR 26 or 1/2	RVR 12 or 1/4	RVR 26 or 1/2

1 Trees to 464' MSL approximately 300' past departure end of runway, 200' right of runway centerline.

2 Trees to 479' MSL approximately 0.1 NM past departure end of runway, 600' right of runway centerline.

CHANGES: Rwy 23 take-off run available.

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Source: Jeppesen

Appendix F – Significant events on approach and landing

Table F1. Significant events on approach and landing

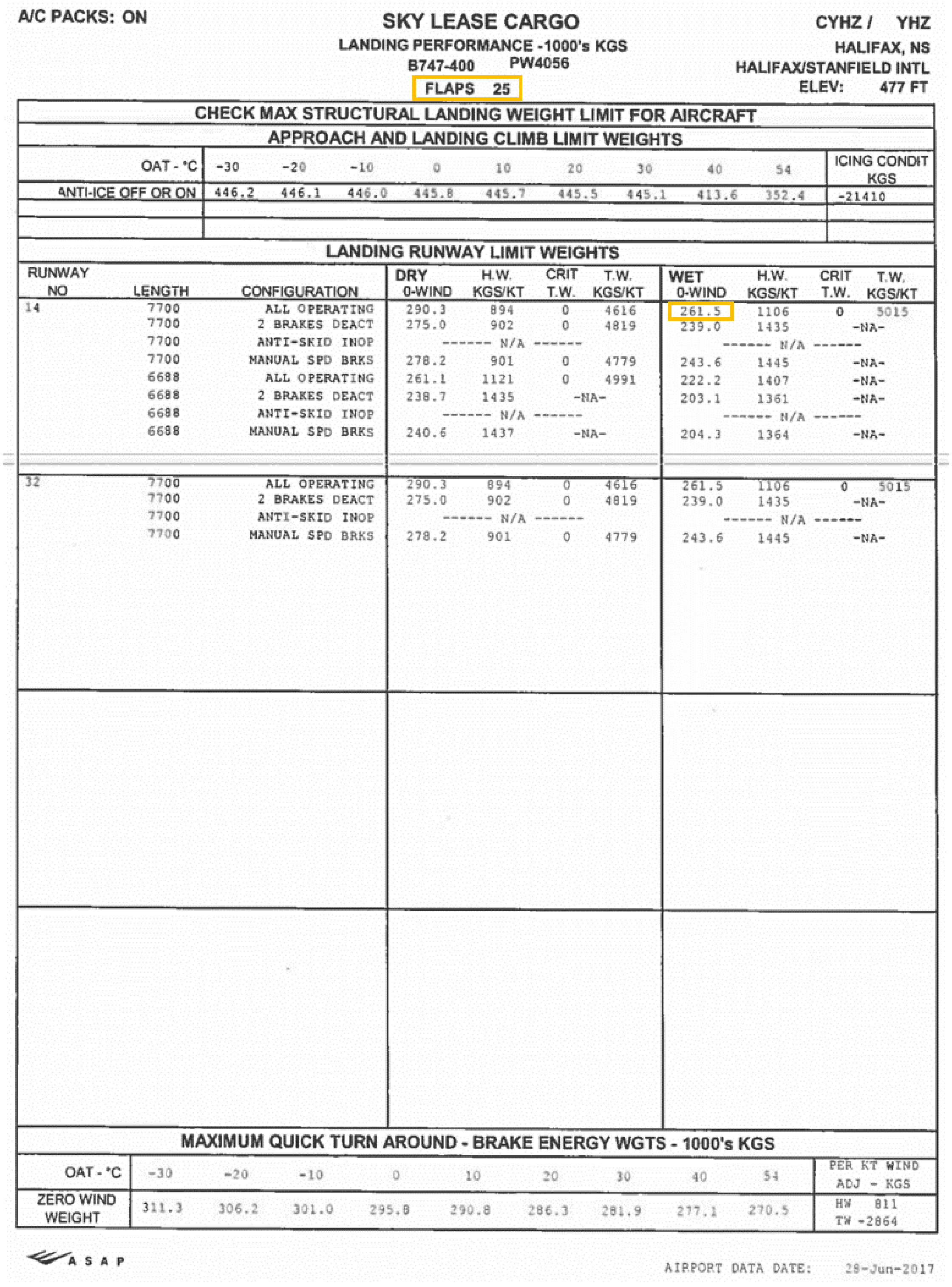
Time	Event	Wind direction and speed	Ground speed (knots)	Altitude (feet AGL)	Distance from runway threshold (NM)	Elapsed time to threshold
0400:00	Weather in ATIS S	230° 10 knots	583	FL370	562	1:05:34
0430:00	Approach preparation and briefing	N/A	596	FL370	265	0:35:34
0443:00	Aircraft begins descent (at FL370)	230° 10 knots	566	36 857	153.4	0:22:34
0454:00	Tower informs ACC that active runway has been switched to Runway 23	N/A	455	15 000	57	0:11:34
0457:09	Aircraft leaves 10 000 feet	N/A	330	10161	34.8	0:08:25
0458:00	ATIS T issued	230° 10 knots	340	9000	30.3	0:07:34
0458:19	ACC cleared for ILS RWY14	N/A	340	8481	28.6	0:07:15
0458:47	ATC cleared aircraft to TETAR (17 NM from runway threshold)	N/A	333	7774	26.1	0:06:47
0459:16	Flaps 1 called	N/A	324	6740	23.4	0:06:18
0459:40	Flaps 5 called	N/A	310	6567	21.4	0:05:54
0500:10	Flaps 10 called	N/A	287	6036	18.9	0:05:24
0500:20	Glideslope captured	N/A	279	5871	18.2	0:05:14
0501:02	ACC hands over aircraft to tower	N/A	259	5242	15.3	0:04:32
0501:22	Crew contacts tower, receives wind check: winds at 260° and 15 knots per ATIS T	260° 15 knots	257	4889	14.0	0:04:12
0501:33	PM acknowledges ATIS T	N/A	256	4630	13.3	0:04:01
0502:15	Localiser captured (aircraft is on glideslope)	N/A	264	3114	10.5	0:03:19
0502:29	GPWS callout: aircraft at 2500 feet AGL	N/A	245	2980	9.7	0:03:05

0502:46	Tower contacts aircraft to confirm Runway 14 still acceptable	260° 16 knots, gusting to 21 knots	212	3008	8.6	0:02:48
0503:05	PM confirms that Runway 14 still acceptable	N/A	195	2921	7.5	0:02:29
0502:58	Tower clears aircraft to land	N/A	198	2976	7.9	0:02:36
0503:30	Crew confirms V_{REF}	N/A	188	2457	6.2	0:02:04
0503:37	Crew starts landing check	N/A	184	2345	5.8	0:01:57
0504:03	Crew completes landing check	N/A	184	1930	4.5	0:01:31
0504:10	Aircraft reaches final approach fix IMANO	N/A	185	1817	4.1	0:01:24
0504:13	Crew confirms presence of tailwind	N/A	185	1300	4.0	0:01:21
0504:46	Crew reviews go-around items	N/A	179	800	2.3	0:00:48
0504:58	Tower provides crew with wind information	250° 15 knots, gusting to 21 knots	176	600	1.7	0:00:36
0505:11	Crew disconnects autopilot	N/A	174	400	1.1	0:00:23
0505:34	Aircraft at threshold of Runway 14	N/A	179	62	0	0:00:00

Table F2. Sequence of events on landing, showing ground speed and amount of runway remaining

Time	Event	Ground speed (knots)	Runway remaining (feet)	Elapsed time from touchdown
0505:34	Aircraft at threshold of Runway 14	179	7700	−00:00:04
0505:38	Touchdown	179	6349	0:00:00
0505:40	Reverse thrust for engines 2, 3, and 4 selected	177	5944	+0:00:02
0505:46	Manual braking	152	3596	+0:00:08
0505:50	Maximum lateral deviation	144	3069	+0:00:12
0505:53	Maximum braking called	130	**2500**	+0:00:15
0506:01	Maximum braking applied	100	**800**	+0:00:23
0506:06	End of runway	77	0	+0:00:28

Appendix G – Pre-departure landing limitations – runway analysis charts



A/C PACKS: ON

SKY LEASE CARGO
LANDING PERFORMANCE -1000's KGS
B747-400 PW4056
FLAPS 25

CYHZ / YHZ
HALIFAX, NS
HALIFAX/STANFIELD INTL
ELEV: 477 FT

CHECK MAX STRUCTURAL LANDING WEIGHT LIMIT FOR AIRCRAFT

APPROACH AND LANDING CLIMB LIMIT WEIGHTS

OAT - °C	-30	-20	-10	0	10	20	30	40	54	ICING CONDIT KGS
ANTI-ICE OFF OR ON	446.2	446.1	446.0	445.8	445.7	445.5	445.1	413.6	352.4	-21410

LANDING RUNWAY LIMIT WEIGHTS

RUNWAY NO	LENGTH	CONFIGURATION	DRY 0-WIND	H.W. KGS/KT	CRIT T.W.	T.W. KGS/KT	WET 0-WIND	H.W. KGS/KT	CRIT T.W.	T.W. KGS/KT
14	7700	ALL OPERATING	290.3	894	0	4616	261.5	1106	0	5015
	7700	2 BRAKES DEACT	275.0	902	0	4819	239.0	1435	-NA-	
	7700	ANTI-SKID INOP	------ N/A ------				------ N/A ------			
	7700	MANUAL SPD BRKS	278.2	901	0	4779	243.6	1445	-NA-	
	6688	ALL OPERATING	261.1	1121	0	4991	222.2	1407	-NA-	
	6688	2 BRAKES DEACT	238.7	1435	-NA-		203.1	1361	-NA-	
	6688	ANTI-SKID INOP	------ N/A ------				------ N/A ------			
	6688	MANUAL SPD BRKS	240.6	1437	-NA-		204.3	1364	-NA-	
32	7700	ALL OPERATING	290.3	894	0	4616	261.5	1106	0	5015
	7700	2 BRAKES DEACT	275.0	902	0	4819	239.0	1435	-NA-	
	7700	ANTI-SKID INOP	------ N/A ------				------ N/A ------			
	7700	MANUAL SPD BRKS	278.2	901	0	4779	243.6	1445	-NA-	

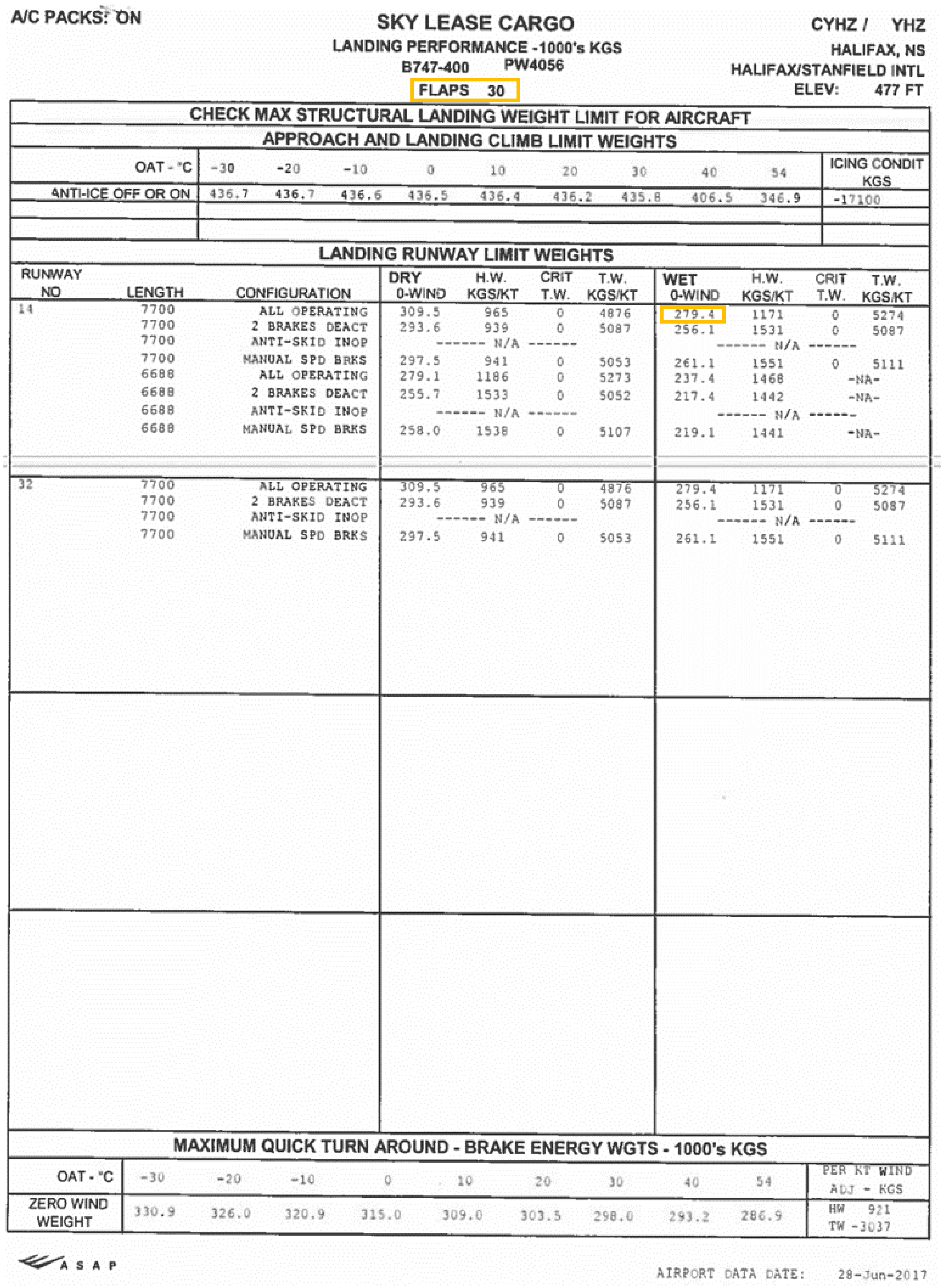
MAXIMUM QUICK TURN AROUND - BRAKE ENERGY WGTS - 1000's KGS

OAT - °C	-30	-20	-10	0	10	20	30	40	54	PER KT WIND ADJ - KGS
ZERO WIND WEIGHT	311.3	306.2	301.0	295.8	290.8	286.3	281.9	277.1	270.5	HW 811 TW -2864

ASAP

AIRPORT DATA DATE: 29-Jun-2017

Source: Sky Lease Cargo



A/C PACKS: ON

SKY LEASE CARGO
LANDING PERFORMANCE -1000's KGS
B747-400 PW4056
FLAPS 30

CYHZ / YHZ
HALIFAX, NS
HALIFAX/STANFIELD INTL
ELEV: 477 FT

CHECK MAX STRUCTURAL LANDING WEIGHT LIMIT FOR AIRCRAFT

APPROACH AND LANDING CLIMB LIMIT WEIGHTS

OAT - °C	-30	-20	-10	0	10	20	30	40	54	ICING CONDIT KGS
ANTI-ICE OFF OR ON	436.7	436.7	436.6	436.5	436.4	436.2	435.8	406.5	346.9	-17100

LANDING RUNWAY LIMIT WEIGHTS

RUNWAY NO	LENGTH	CONFIGURATION	DRY 0-WIND	H.W. KGS/KT	CRIT T.W.	T.W. KGS/KT	WET 0-WIND	H.W. KGS/KT	CRIT T.W.	T.W. KGS/KT
14	7700	ALL OPERATING	309.5	965	0	4876	279.4	1171	0	5274
	7700	2 BRAKES DEACT	293.6	939	0	5087	256.1	1531	0	5087
	7700	ANTI-SKID INOP	------ N/A ------				------ N/A ------			
	7700	MANUAL SPD BRKS	297.5	941	0	5053	261.1	1551	0	5111
	6688	ALL OPERATING	279.1	1186	0	5273	237.4	1468	-NA-	
	6688	2 BRAKES DEACT	255.7	1533	0	5052	217.4	1442	-NA-	
	6688	ANTI-SKID INOP	------ N/A ------				------ N/A ------			
	6688	MANUAL SPD BRKS	258.0	1538	0	5107	219.1	1441	-NA-	
32	7700	ALL OPERATING	309.5	965	0	4876	279.4	1171	0	5274
	7700	2 BRAKES DEACT	293.6	939	0	5087	256.1	1531	0	5087
	7700	ANTI-SKID INOP	------ N/A ------				------ N/A ------			
	7700	MANUAL SPD BRKS	297.5	941	0	5053	261.1	1551	0	5111

MAXIMUM QUICK TURN AROUND - BRAKE ENERGY WGTS - 1000's KGS

OAT - °C	-30	-20	-10	0	10	20	30	40	54	PER KT WIND ADJ - KGS
ZERO WIND WEIGHT	330.9	326.0	320.9	315.0	309.0	303.5	298.0	293.2	286.9	HW 921 TW -3037

ASAP

AIRPORT DATA DATE: 28-Jun-2017

Source: Sky Lease Cargo

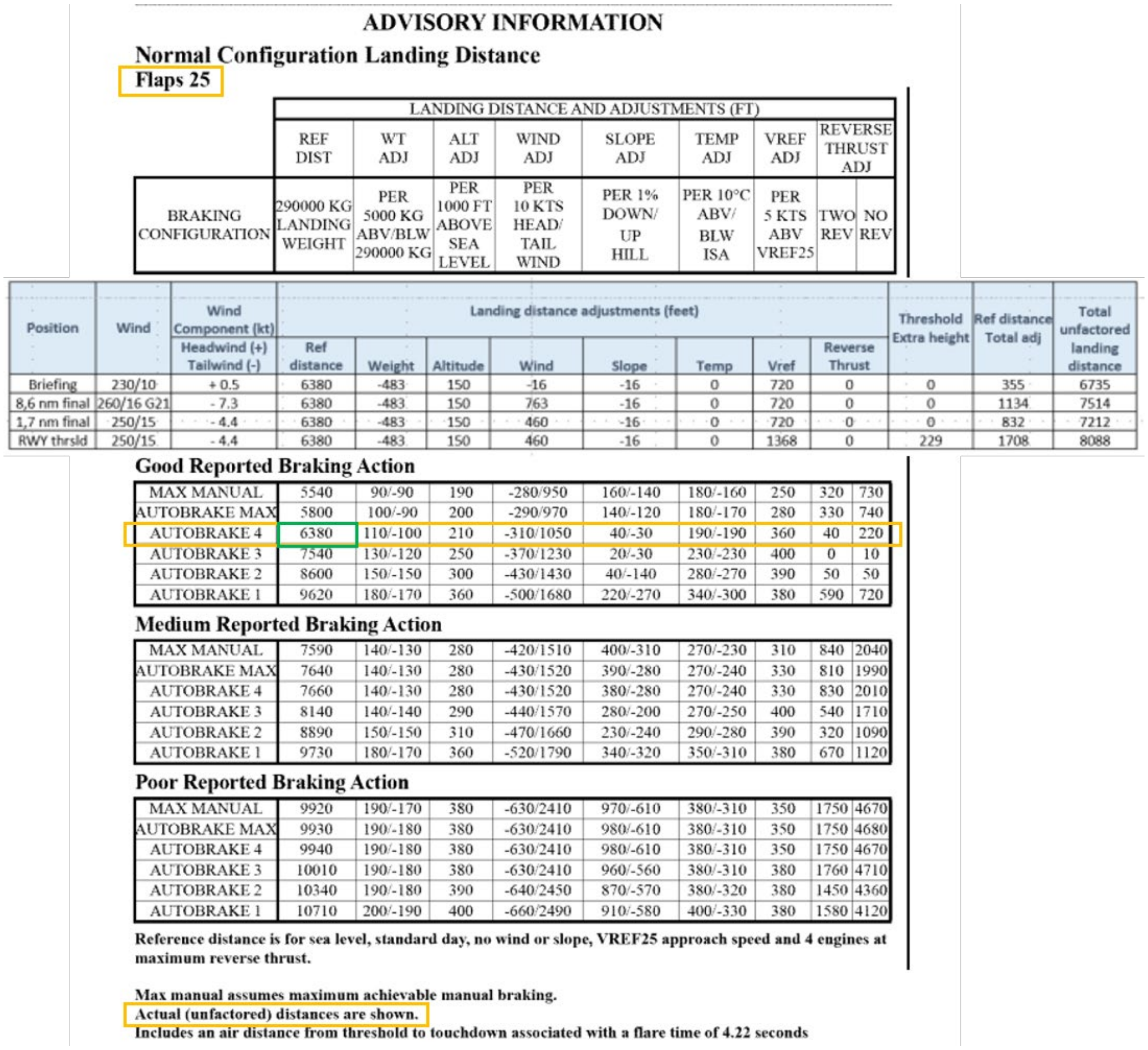
Appendix H – Actual (unfactored) landing distance charts

Table H1. Reference values used by the TSB for the landing distance adjustments

Weight	Pressure altitude	Wind	Slope	Temp	V_{REF}	Reverse thrust	Extra height at the threshold
265 852 kg	716 feet	See chart below (Position)	+0.54°	15 °C	+5 knots*	All operative	+12 feet

* V_{REF} + 14 knots (actual indicated airspeed) is used at the position "Runway threshold"

Figure H1. Advisory landing distance information (Source: Sky Lease Cargo, 747 Flight Crew Operations Manual: 747 Quick Reference Handbook, Revision 01 (01 May 2017), with TSB annotations)



ADVISORY INFORMATION

Normal Configuration Landing Distance

Flaps 25

BRAKING CONFIGURATION	LANDING DISTANCE AND ADJUSTMENTS (FT)								
	REF DIST	WT ADJ	ALT ADJ	WIND ADJ	SLOPE ADJ	TEMP ADJ	VREF ADJ	REVERSE THRUST ADJ	
	290000 KG LANDING WEIGHT	PER 5000 KG ABV/BLW 290000 KG	PER 1000 FT ABOVE SEA LEVEL	PER 10 KTS HEAD/ TAIL WIND	PER 1% DOWN/ UP HILL	PER 10°C ABV/ BLW ISA	PER 5 KTS ABV VREF25	TWO REV	NO REV

Position	Wind	Wind Component (kt)	Landing distance adjustments (feet)								Threshold Extra height	Ref distance Total adj	Total unfactored landing distance
		Headwind (+) Tailwind (-)	Ref distance	Weight	Altitude	Wind	Slope	Temp	Vref	Reverse Thrust			
Briefing	230/10	+ 0.5	6380	-483	150	-16	-16	0	720	0	0	355	6735
8,6 nm final	260/16 G21	- 7.3	6380	-483	150	763	-16	0	720	0	0	1134	7514
1,7 nm final	250/15	- 4.4	6380	-483	150	460	-16	0	720	0	0	832	7212
RWY thrsld	250/15	- 4.4	6380	-483	150	460	-16	0	1368	0	229	1708	8088

Good Reported Braking Action

MAX MANUAL	5540	90/-90	190	-280/950	160/-140	180/-160	250	320	730
AUTOBRAKE MAX	5800	100/-90	200	-290/970	140/-120	180/-170	280	330	740
AUTOBRAKE 4	6380	110/-100	210	-310/1050	40/-30	190/-190	360	40	220
AUTOBRAKE 3	7540	130/-120	250	-370/1230	20/-30	230/-230	400	0	10
AUTOBRAKE 2	8600	150/-150	300	-430/1430	40/-140	280/-270	390	50	50
AUTOBRAKE 1	9620	180/-170	360	-500/1680	220/-270	340/-300	380	590	720

Medium Reported Braking Action

MAX MANUAL	7590	140/-130	280	-420/1510	400/-310	270/-230	310	840	2040
AUTOBRAKE MAX	7640	140/-130	280	-430/1520	390/-280	270/-240	330	810	1990
AUTOBRAKE 4	7660	140/-130	280	-430/1520	380/-280	270/-240	330	830	2010
AUTOBRAKE 3	8140	140/-140	290	-440/1570	280/-200	270/-250	400	540	1710
AUTOBRAKE 2	8890	150/-150	310	-470/1660	230/-240	290/-280	390	320	1090
AUTOBRAKE 1	9730	180/-170	360	-520/1790	340/-320	350/-310	380	670	1120

Poor Reported Braking Action

MAX MANUAL	9920	190/-170	380	-630/2410	970/-610	380/-310	350	1750	4670
AUTOBRAKE MAX	9930	190/-180	380	-630/2410	980/-610	380/-310	350	1750	4680
AUTOBRAKE 4	9940	190/-180	380	-630/2410	980/-610	380/-310	350	1750	4670
AUTOBRAKE 3	10010	190/-180	380	-630/2410	960/-560	380/-310	380	1760	4710
AUTOBRAKE 2	10340	190/-180	390	-640/2450	870/-570	380/-320	380	1450	4360
AUTOBRAKE 1	10710	200/-190	400	-660/2490	910/-580	400/-330	380	1580	4120

Reference distance is for sea level, standard day, no wind or slope, VREF25 approach speed and 4 engines at maximum reverse thrust.

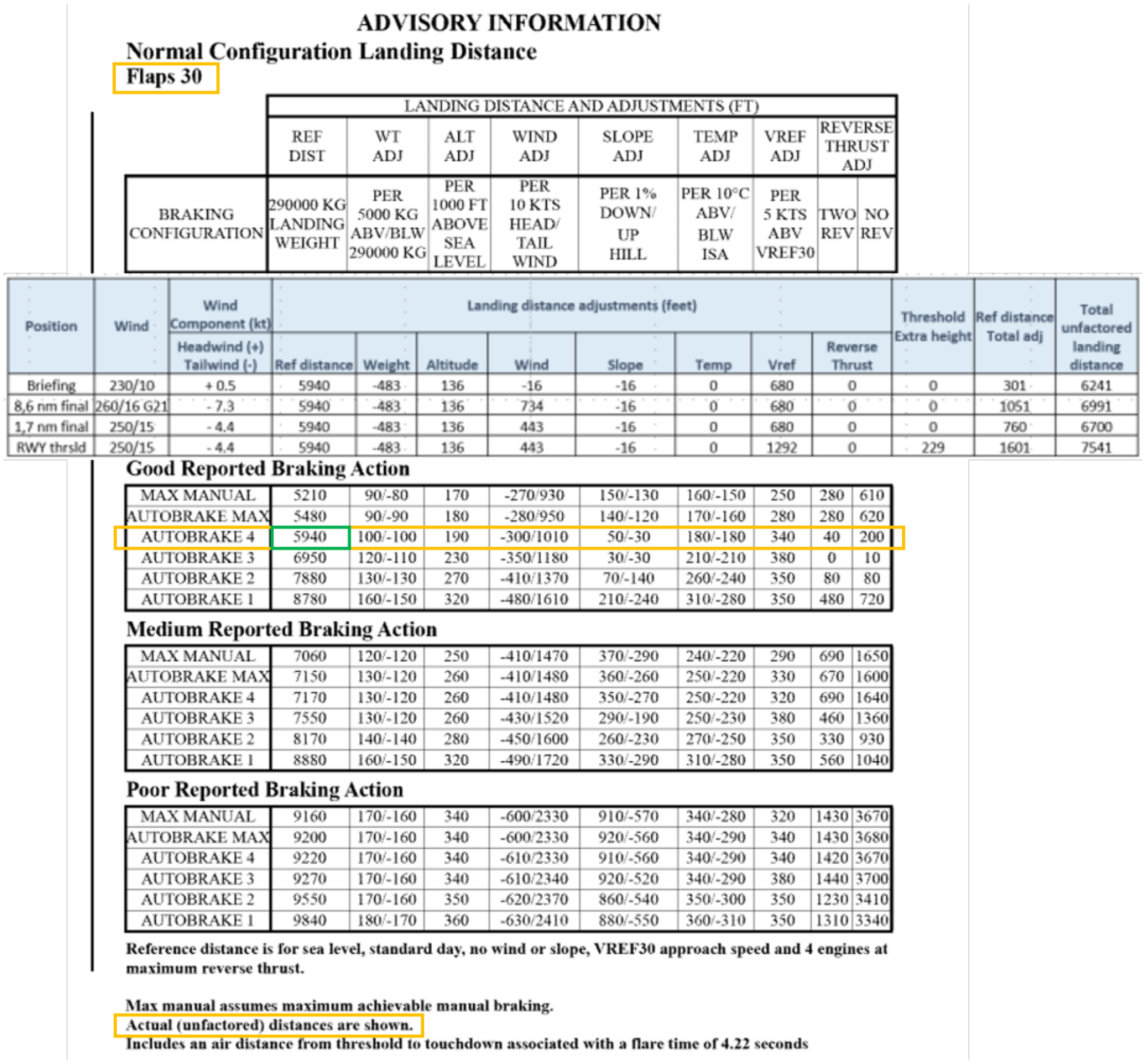
Max manual assumes maximum achievable manual braking.
Actual (unfactored) distances are shown.
Includes an air distance from threshold to touchdown associated with a flare time of 4.22 seconds

Table H2. Reference values used by the TSB for the landing distance adjustments

Weight	Pressure altitude	Wind	Slope	Temp	V_{REF}	Reverse thrust	Extra height at the threshold
265 852 kg	716 feet	See chart below (Position)	+0,54°	15 °C	+5 knots*	0	+12 feet

* V_{REF} + 14 knots (actual indicated airspeed) is used at the position "Runway threshold"

Figure H2. Advisory landing distance information (Source: Sky Lease Cargo, 747 Flight Crew Operations Manual: 747 Quick Reference Handbook, Revision 01 [01 May 2017] with TSB annotations)



ADVISORY INFORMATION

Normal Configuration Landing Distance

Flaps 30

	LANDING DISTANCE AND ADJUSTMENTS (FT)								
	REF DIST	WT ADJ	ALT ADJ	WIND ADJ	SLOPE ADJ	TEMP ADJ	VREF ADJ	REVERSE THRUST ADJ	
BRAKING CONFIGURATION	290000 KG LANDING WEIGHT	PER 5000 KG ABV/BLW 290000 KG	PER 1000 FT ABOVE SEA LEVEL	PER 10 KTS HEAD/ TAIL WIND	PER 1% DOWN/ UP HILL	PER 10°C ABV/ BLW ISA	PER 5 KTS ABV VREF30	TWO REV	NO REV

Position	Wind	Wind Component (kt)	Landing distance adjustments (feet)								Threshold Extra height	Ref distance Total adj	Total unfactored landing distance
		Headwind (+) Tailwind (-)	Ref distance	Weight	Altitude	Wind	Slope	Temp	Vref	Reverse Thrust			
Briefing	230/10	+ 0.5	5940	-483	136	-16	-16	0	680	0	0	301	6241
8,6 nm final	260/16 G21	- 7.3	5940	-483	136	734	-16	0	680	0	0	1051	6991
1,7 nm final	250/15	- 4.4	5940	-483	136	443	-16	0	680	0	0	760	6700
RWY thrsld	250/15	- 4.4	5940	-483	136	443	-16	0	1292	0	229	1601	7541

Good Reported Braking Action

MAX MANUAL	5210	90/-80	170	-270/930	150/-130	160/-150	250	280	610
AUTOBRAKE MAX	5480	90/-90	180	-280/950	140/-120	170/-160	280	280	620
AUTOBRAKE 4	5940	100/-100	190	-300/1010	50/-30	180/-180	340	40	200
AUTOBRAKE 3	6950	120/-110	230	-350/1180	30/-30	210/-210	380	0	10
AUTOBRAKE 2	7880	130/-130	270	-410/1370	70/-140	260/-240	350	80	80
AUTOBRAKE 1	8780	160/-150	320	-480/1610	210/-240	310/-280	350	480	720

Medium Reported Braking Action

MAX MANUAL	7060	120/-120	250	-410/1470	370/-290	240/-220	290	690	1650
AUTOBRAKE MAX	7150	130/-120	260	-410/1480	360/-260	250/-220	330	670	1600
AUTOBRAKE 4	7170	130/-120	260	-410/1480	350/-270	250/-220	320	690	1640
AUTOBRAKE 3	7550	130/-120	260	-430/1520	290/-190	250/-230	380	460	1360
AUTOBRAKE 2	8170	140/-140	280	-450/1600	260/-230	270/-250	350	330	930
AUTOBRAKE 1	8880	160/-150	320	-490/1720	330/-290	310/-280	350	560	1040

Poor Reported Braking Action

MAX MANUAL	9160	170/-160	340	-600/2330	910/-570	340/-280	320	1430	3670
AUTOBRAKE MAX	9200	170/-160	340	-600/2330	920/-560	340/-290	340	1430	3680
AUTOBRAKE 4	9220	170/-160	340	-610/2330	910/-560	340/-290	340	1420	3670
AUTOBRAKE 3	9270	170/-160	340	-610/2340	920/-520	340/-290	380	1440	3700
AUTOBRAKE 2	9550	170/-160	350	-620/2370	860/-540	350/-300	350	1230	3410
AUTOBRAKE 1	9840	180/-170	360	-630/2410	880/-550	360/-310	350	1310	3340

Reference distance is for sea level, standard day, no wind or slope, VREF30 approach speed and 4 engines at maximum reverse thrust.

Max manual assumes maximum achievable manual braking.
Actual (unfactored) distances are shown.
Includes an air distance from threshold to touchdown associated with a flare time of 4.22 seconds

GLOSSARY

ABC	aircraft braking coefficient
AC	advisory circular
ACARS	aircraft communication addressing and reporting system
ACC	area control centre
AGL	above ground level
ALS	approach lighting system
ALSF-2	approach lighting system with sequenced flashing lights for category II or III operations
ARFF	aircraft rescue and firefighting
ATC	air traffic control
ATIS	automatic terminal information service
ATPL	airline transport pilot licence
ATSB	Australian Transport Safety Bureau
CARs	*Canadian Aviation Regulations*
CRM	crew resource management
CYHZ	Halifax/Stanfield International Airport, Nova Scotia
CYYZ	Toronto/Lester B. Pearson International Airport, Ontario
CVR	cockpit voice recorder
EICAS	engine indicating and crew alerting system
FAA	U.S. Federal Aviation Administration
FARs	U.S. *Federal Aviation Regulations*
FAST	fatigue avoidance scheduling tool
FCTM	flight crew training manual
FDR	flight data recorder
FL	flight level
FO	first officer
FSF	Flight Safety Foundation
GNSS	global orbiting navigation satellite system
HIAA	Halifax International Airport Authority
IAS	indicated airspeed
ICAO	International Civil Aviation Organization
ILS	instrument landing system
inHg	inches of mercury
IRO	international relief officer
KBGR	Bangor International Airport, Maine, U.S.
KORD	Chicago/O'Hare International Airport, Illinois, U.S.
KSFO	San Francisco International Airport, California, U.S.

LNAV	lateral navigation
LPV	localizer performance with vertical guidance
M	magnetic
METAR	aerodrome routine meteorological report
NDB	non-directional beacon
NM	nautical mile
NPA	notice of proposed amendment
NTSB	U.S. National Transportation Safety Board
NVM	non-volatile memory
PANC	Ted Stevens Anchorage International Airport
PAPI	precision approach path indicator
PF	pilot flying
PIREP	pilot report
PM	pilot monitoring
QRH	*Quick Reference Handbook*
RCLL	runway centreline lights
RESA	runway end safety area
REV	annunciator when the related reverser is unlocked or moving
RNAV	area navigation
RNP	required navigation performance
RTHL	runway threshold lights
RTZL	runway touchdown lights
SAFO	Safety Alert for Operators
SM	statute mile
SOCC	System Operations Control Center
SOP	standard operating procedure
SPECI	aerodrome special meteorological report
SSALR	simplified short-approach lighting system with runway alignment indicator lights
T	true
TAF	aerodrome forecast
TC	Transport Canada
TP 312	*Aerodrome Standards and Recommended Practices*
UOM	Unit Operations Manual
VNAV	vertical navigation

V_{REF}	reference speed
ZGHA	Changsha/Huanghua Airport, Hunan, China