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

AIR TRANSPORTATION SAFETY INVESTIGATION REPORT A19O0117

RUNWAY INCURSION

Air Georgian Limited
Bombardier CRJ 200, C-GKEJ
Toronto/Lester B. Pearson International Airport, Ontario
09 August 2019

Canada

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Summary

On 09 August 2019, the Air Georgian Limited Bombardier CRJ 200 aircraft (registration C-GKEJ, serial number 7269) was preparing to conduct flight GGN7339 from Toronto/Lester B. Pearson International Airport, Ontario, to John Glenn Columbus International Airport, Ohio, United States. The Air Canada Boeing 777-300 aircraft (registration C-FIUR, serial number 35242) was completing flight ACA883 from Kobenhavn/Kastrup Airport, Copenhagen, Denmark, to Toronto/Lester B. Pearson International Airport, Ontario.

At 1240 Eastern Daylight Time, the flight crew of the CRJ 200 began taxiing and approximately 3 minutes later, was instructed by the tower controller to line up on Runway 33R. At approximately the same time, the Boeing 777 landed on Runway 33L and taxied onto Taxiway H. The north ground controller instructed the flight crew of the Boeing 777 to cross Runway 33R, and while the Boeing 777 was crossing the runway, the crew of the CRJ 200 began its take-off roll, without clearance. When the flight crew of the CRJ 200 saw the Boeing 777 over the crest of the runway, they aborted the takeoff and exited the runway via Taxiway B2. The occurrence took place during day visual meteorological conditions. There were no injuries. There was no aircraft damage.

1.0 FACTUAL INFORMATION

1.1 History of the flight

On 09 August 2019, the Air Georgian Limited Bombardier CRJ 200 aircraft (registration C-GKEJ, serial number 7269) with 45 crew and passengers onboard, was preparing to conduct flight GGN7339, an instrument flight rules (IFR) flight from Toronto/Lester B. Pearson International Airport (CYYZ), Ontario, to John Glenn Columbus International Air port (KCMH), Ohio, United States (U.S.). At 1240,[1] the flight crew of the CRJ 200 began taxiing from the Terminal 1 gate area to Runway 33R, via Taxiway DR and Taxiway D, for departure. While on Taxiway D, the captain asked the first officer (FO) to action the taxi checklist. In addition to completing the checklist, the FO was responsible for monitoring and responding to air traffic control (ATC) communications.

As the CRJ 200 was taxiing along Taxiway D, and approaching the intersection with Taxiway B, the captain's attention was focused on an aircraft approaching from the right, which was taxiing along Taxiway B for a departure on Runway 33R.

At approximately the same time, the Air Canada Boeing 777-300 aircraft (registration C-FIUR, serial number 35242) with 390 crew and passengers onboard, operating as flight ACA883, an IFR flight from Kobenhavn/Kastrup Airport (EKCH), Copenhagen, Denmark, to CYYZ, landed on Runway 33L. The flight crew of the Boeing 777 was instructed to taxi onto Taxiway F4 and Taxiway H,[2] and to contact the north ground controller. The north ground controller instructed the flight crew to hold short of Runway 33R.

At approximately 1242:30, a de Havilland DHC-8 aircraft was cleared to take off from the intersection of Runway 33R and Taxiway B3.[3] After the DHC-8 departed, the CRJ 200 was the next aircraft in sequence to depart Runway 33R.

At 1242:38, the FO of the CRJ 200 had finished the taxi checklist and was continuing with the line-up checklist, when the tower controller instructed the flight crew to line up on Runway 33R. With this instruction, the tower controller included an amendment to the altitude and heading for the standard instrument departure (SID) clearance to ensure adequate separation with the DHC-8 that had just departed.

After reading back the instructions correctly, the FO changed the altitude selector and then returned to the next item on the line-up checklist. After hearing the correct readback from the FO of the CRJ 200, the tower controller, who was also actively controlling arrivals on Runway 33L, turned to observe another de Havilland DHC-8 aircraft that was on approach for landing on Runway 33L.

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1 All times are Eastern Daylight Time (Coordinated Universal Time minus 4 hours).

2 Taxiway H intersects Runway 33R at the northern end of the runway.

3 Taxiway B3 is a rapid exit taxiway for Runway 15L that can also be used to access Runway 33R.

As the CRJ 200 taxied to line up on Runway 33R, the Boeing 777 was approaching the Runway 33R hold short line on Taxiway H. At 1243:16, the north ground controller, who had coordinated runway activity with the tower controller, instructed the flight crew of the Boeing 777 to cross Runway 33R without delay.

As the flight crew of the CRJ 200 lined up in position on Runway 33R and the FO finished the line-up checklist, the captain asked the FO if they had received a take-off clearance. The FO stated that they had.

At 1243:30, as the Boeing 777 crossed the runway holding position for Runway 33R, the crew of the CRJ 200 began the take-off roll. The crew had not received take-off clearance from the tower controller.

The CRJ 200 began to accelerate. As the aircraft approached the peak of the elevated hump in the runway, the captain saw the Boeing 777 approximately 5400 feet ahead and immediately rejected the takeoff. At that time, the flight crew realized that they had likely not received a take-off clearance.

At 1243:46, the runway incursion monitoring and conflict alert system (RIMCAS)[4] issued a visual alert and audible alarm in the tower. The tower controller, who had been focused on the arriving DHC-8 aircraft on Runway 33L, instantly shifted his attention to the conflict on Runway 33R.

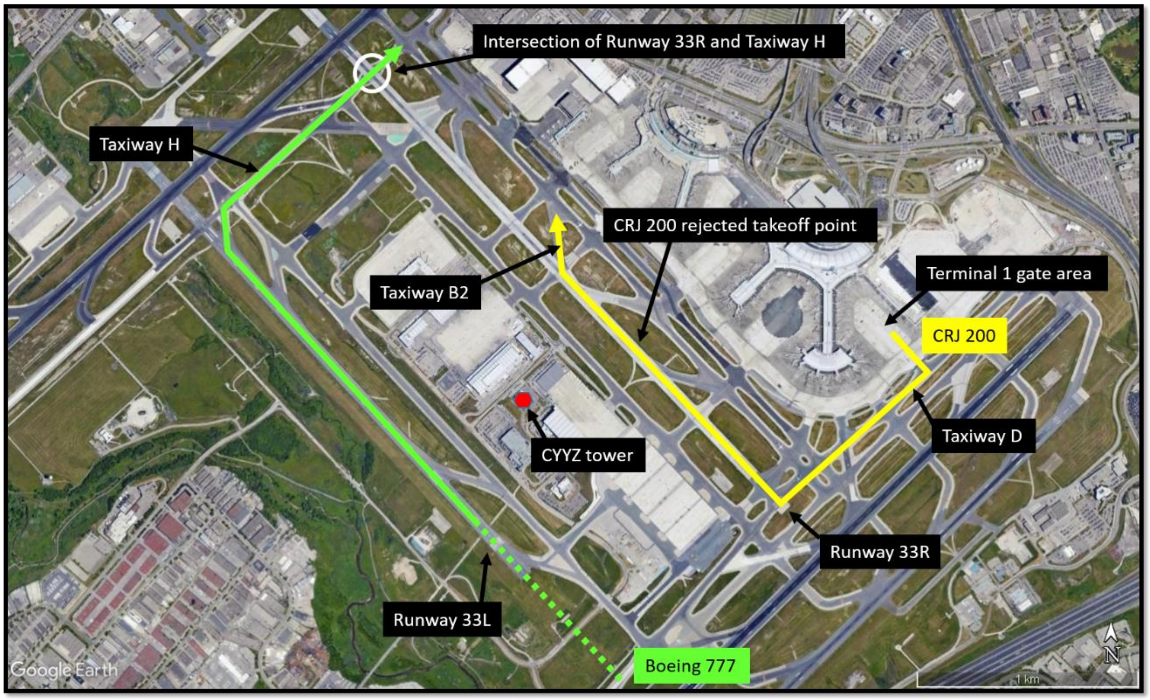
At 1243:53, the tower controller quickly assessed the situation, determined that there was no risk of collision, and immediately issued a take-off clearance to the crew of the CRJ 200, who had already initiated a rejected takeoff. The crew of the CRJ 200 made a radio call to inform the tower controller that they were rejecting the takeoff. The tower controller then instructed the CRJ 200 to exit Runway 33R on Taxiway B2 (Figure 1).

The CRJ 200 slowed and exited the runway via Taxiway B2.[5] The CRJ 200 had reached a maximum groundspeed of 99 knots during the take-off run.

4 Runway incursion monitoring and conflict alert system (RIMCAS) is described in section 1.10.3.

5 Taxiway B2 is a rapid exit taxiway along Runway 33R.

Figure 1. Depiction of the CRJ 200's route and the Boeing 777's approach path (dotted line) and taxi route (solid line) (Source: Google Earth, with TSB annotations)



After clearing the runway and stopping briefly on Taxiway B2 to complete the applicable checklist items, the flight crew of the CRJ 200 received taxi instructions to reposition the aircraft and prepare for another departure on Runway 33R. The CRJ 200 departed CYYZ at 1252. After landing at KCMH, the captain and FO both submitted an Air Safety Report[6] regarding the rejected takeoff at CYYZ, in accordance with the Air Georgian Company Operations Manual.

The flight crew of the Boeing 777 was unaware of the conflict because they had been monitoring the north ground frequency.

1.2 Injuries to persons

None of the 42 passengers and 3 crew members of the CRJ 200 were injured.

None of the 378 passengers and 12 crew members of the Boeing 777 were injured.

1.3 Damage to aircraft

There was no damage to either aircraft.

1.4 Other damage

There was no other damage.

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6 Air Georgian Limited, *CARs* [Canadian Aviation Regulations] *705 Company Operations Manual*, Issue 2 (February 2018), section 3.2.7 Safety Management System Reports, Air Safety Report (ASR), p. 3-6.

1.5 Personnel information

1.5.1 Flight crew of the CRJ 200

The CRJ 200 flight crew were certified and qualified for the flight in accordance with existing regulations (Table 1).

Table 1. Personnel information

	Captain	First officer
Pilot licence	Airline transport pilot licence (ATPL)	Commercial pilot licence (CPL)
Medical expiry date	01 December 2019	01 May 2020
Total flying hours	3394	2445
Flight hours on type	1331	995
Flight hours in the 7 days before the occurrence	28	30
Flight hours in the 30 days before the occurrence	82	51
Flight hours in the 90 days before the occurrence	199	245
Flight hours on type in the 90 days before the occurrence	199	245

1.5.2 Tower controller

The tower controller was certified and qualified for operational duty in accordance with existing regulations (Table 2).

Table 2. Controller information

Controller position	CYYZ tower controller
Locations licenced for	Calgary International Airport (CYYC), CYYZ
Medical expiry date	24 September 2020
Experience as a controller	24 years
Experience in present unit	7 years
Hours on duty prior to the occurrence	6 hours

1.6 Aircraft information

Records indicate that the aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures. The weight and centre of gravity were within the prescribed limits at the time of the occurrence (Table 3).

Table 3. Aircraft information

Manufacturer	Bombardier
Type, model and registration	CL-600-2B19, CRJ 200, C-GKEJ
Year of manufacture	1998

Serial number	7269
Certificate of airworthiness / flight permit issue date	2002-05-03
Total airframe time	46 784.6
Engine type (number of engines)	General Electric CF34-3B1 (2)
Maximum allowable take-off weight	52 888 lb (24 040.4 kg)

1.7 Meteorological information

The aerodrome routine meteorological report (METAR) for CYYZ at 1200, 43 minutes before the occurrence, indicated the following:

- winds 280° true (T) at 18 knots, gusting to 24 knots, variable from 250°T to 310°T
- visibility 15 statute miles
- scattered clouds at 5200 feet above ground level (AGL)
- broken ceiling at 6100 feet AGL
- temperature 24 °C; dew point 11 °C
- altimeter setting 29.80 inches of mercury

The winds for landing and take-off operations at CYYZ were favouring the use of runways 33L and 33R at the time of the occurrence. Weather was not considered a factor in this occurrence.

1.8 Aids to navigation

1.8.1 Standard instrument departure

A standard instrument departure (SID) is "[a] preplanned IFR departure procedure requiring ATC clearance and published for pilot/controller use to provide obstacle clearance and a transition from an aerodrome to the appropriate en-route structure."[7] In this occurrence, the CRJ 200 was sequenced to depart after a de Havilland DHC-8 aircraft. Because the CRJ 200 is a faster aircraft type than the DHC-8, ATC amended the CRJ 200's SID clearance to ensure adequate separation between the 2 aircraft.

The FO had previously received SID clearance amendments at CYYZ, but the amendments were typically provided while the aircraft was taxiing or included with the take-off clearance. When the SID clearance amendments had been included with the take-off clearance, they usually involved a change in altitude or a change in heading, not both. The FO had never received a SID amendment during a line-up instruction.

7 Transport Canada, Advisory Circular (AC) No. 100-001: *Glossary for Pilots and Air Traffic Services Personnel* (effective 2019-09-26), at https://www.tc.gc.ca/en/services/aviation/reference-centre/advisory-circulars/ac-100-001.html (last accessed on 03 July 2020).

1.9 Communications

1.9.1 Air traffic controller phraseology

Air traffic controllers at the CYYZ control tower follow the communication and phraseology guidance set out in NAV CANADA's *Manual of Air Traffic Services* (MATS)[8] and the *Toronto Control Tower Unit Operations Manual*.[9] ATC phraseology is also described in the NAV CANADA learning tool and reference guide, *IFR Phraseology.*[10,11] Each controller receives training regarding the content of these manuals.

As stated in the MATS, controllers should:

> Use standard phraseology contained in this manual whenever possible. Use standard phraseology in preference to plain language. If phraseology is not provided, use clear and concise plain language.[12]

The following are the controller phraseology requirements from the MATS that are associated with the occurrence flight:

Table 4. Examples of NAV CANADA's MATS controller phraseology (Source: NAV CANADA, *Manual of Air Traffic Services – Tower*, version 2.1 [effective 28 March 2019])

Action	Instruction to controller	Phraseology to be used in communication with aircraft	Page in source
Line-up instructions	When no delay is anticipated, instruct an aircraft to line up as follows:	LINE UP (runway identification)	93
SID	You may issue an altitude different from the altitude specified in the SID, provided you:	State the amended altitude Obtain a readback prior to departure	70
Amending an altitude in a previously issued SID departure clearance	No instruction provided.	FLIGHT NUMBER…, AMENDMENT TO YOUR SID ALTITUDE; CLIMB TO…	71
Successive IFR departures: same runway	Immediately after takeoff, departure tracks diverge by 30° or more. Either or both aircraft may turn.	FLY (heading), [altitude restriction]" or "TURN (LEFT/RIGHT)(heading), [(altitude restriction)]	182

8 NAV CANADA, *Manual of Air Traffic Services – Tower*, version 2.1 (28 March 2019).

9 NAV CANADA, *Toronto Control Tower Unit Operations Manual*, version 39 (05 June 2019).

10 NAV CANADA, *IFR Phraseology*, version 1 (03 May 2019).

11 *IFR Phraseology* is a guide for personnel, such as pilots and ground vehicle operators, working with NAV CANADA controllers.

12 NAV CANADA, *Manual of Air Traffic Services – Tower*, version 2.1 (28 March 2019), p. 220.

The purpose of standard phraseology in aviation is to remove any ambiguity. Standard phraseology reduces the risk that a message will be misunderstood and aids the readback/hearback process so that any error is quickly detected.[13]

1.9.1.1 Readback/hearback

The *Canadian Aviation Regulations* (CARs)[14] require that flight crew comply with and acknowledge all air traffic control instructions.

The following guidance for readback/hearback is provided to pilots in NAV CANADA's *IFR Phraseology*:

> ATS [air traffic services] personnel are required to confirm that the readbacks of all IFR clearances are correct; this is known as the hearback. As a pilot you can assist in this process by promptly reading back all IFR clearances and instructions using standard phraseology and as much as possible in the same order/format as issued.
>
> Readback/hearback errors are frequently identified as contributing to the occurrence of aviation safety events. Eliminating unnecessary radio calls and using only clear and concise phraseology can help reduce the occurrence of readback/hearback errors.[15]

The following guidance is provided to controllers in NAV CANADA's MATS:

> An ATC clearance or instruction constitutes authority for an aircraft to proceed only as far as known air traffic is concerned and is based solely on the need to safely separate and expedite air traffic.[172]
>
> 172 Pilots are required to comply with ATC clearances that they accept, and with ATC instructions that they acknowledge, subject to a pilot's final responsibility for safety of the aircraft.[16]

1.9.2 Delayed takeoff

When issuing instructions or clearances, and if there is a requirement to delay an aircraft due to traffic or for separation reasons, the air traffic controller may choose to instruct the flight crew to "wait" after the line-up instruction. The reason to delay the takeoff may not be apparent to the flight crew. According to NAV CANADA's MATS, "Delays may be caused by preceding landing/departing traffic, IFR delays or CRDA [converging runway display aid] positioning. For example, you are not expected to inform a pilot when the reason for delay is a preceding aircraft waiting for takeoff, or a visible aircraft on final approach."[17]

In this occurrence, as part of managing the traffic, the tower controller planned a short delay to allow the preceding departing aircraft to climb out on a diverging heading as well

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13 SKYbrary, "Standard Phraseology", at https://www.skybrary.aero/index.php/Standard_Phraseology (last accessed 04 December 2020).

14 Transport Canada, SOR/96-433, *Canadian Aviation Regulations*, subsection 602.31(1).

15 NAV CANADA, *IFR Phraseology*, version 1 (03 May 2019), p. 15.

16 NAV CANADA, *Manual of Air Traffic Services – Tower*, version 2.1 (28 March 2019), p. 67.

17 Ibid., p. 94.

as to allow time for the Boeing 777 to clear Runway 33R at Taxiway H. This planned short delay also gave the tower controller the opportunity to focus his attention on the landing aircraft approaching Runway 33L. Because the anticipated delay was short, and the controller believed the CRJ 200 crew was aware of the preceding departure, the controller chose not to inform the flight crew of the CRJ 200 of a delay or issue an instruction to "wait" after issuing the line-up instruction.

1.9.3 Take-off clearance

NAV CANADA's MATS provides guidance to controllers and the format to be used when issuing a take-off clearance to an aircraft.[18] The Manual also includes guidance to be followed when cancelling a take-off clearance. If the take-off clearance is being cancelled after the aircraft has started to roll, the controller will issue an instruction to "abort takeoff" and provide the reason for cancelling the clearance.[19]

In this occurrence, a take-off clearance was not issued to the CRJ 200 crew.

1.9.3.1 Safety-critical phraseology

In the event of a serious runway incursion, a controller may decide that the safest course of action is to issue an instruction to a departing aircraft to abort takeoff, or to issue an instruction to an aircraft on approach to pull up and go around. Such instructions, particularly with respect to aborting a takeoff, are not common but are considered only as a last resort option. The guidance in the MATS states:

> Aborting a takeoff is an emergency procedure used when continuing would present a grave hazard to the aircraft. A controller-initiated aborted takeoff is an extreme measure used only where no clear alternative exists.[20]

1.10 Aerodrome information

1.10.1 Toronto / Lester B. Pearson International Airport

CYYZ is operated by the Greater Toronto Airports Authority and has a total of 5 runways: 05/23, 06L/24R, 06R/24L, 15L/33R and 15R/33L.

1.10.1.1 Runways 15L/33R and 15R/33L

At the time of the occurrence, runways 33R and 33L were being used in order to gather runway occupancy time (ROT) data.[21] Runway 33R was being used for departing aircraft and Runway 33L for arriving aircraft. The distance required to taxi from the Terminal 1 gate

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18 Ibid., p. 96.

19 Ibid., p. 98.

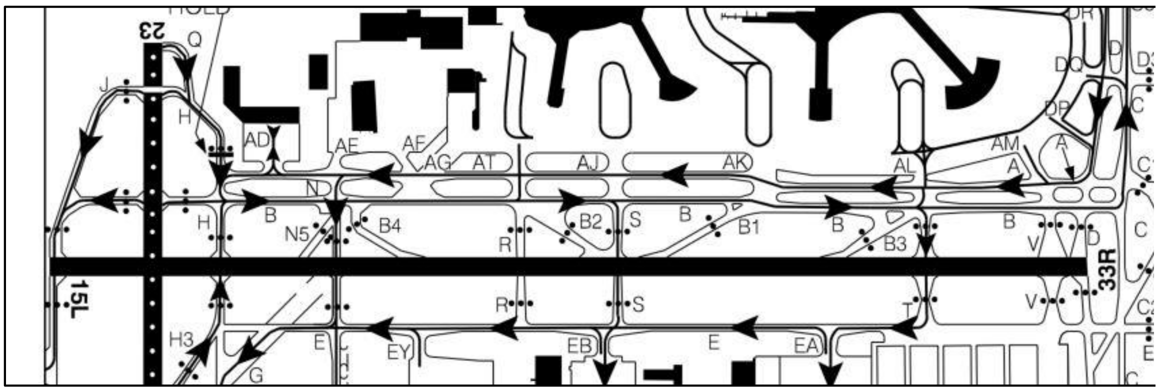
20 Ibid., p. 98.

21 In accordance with NAV CANADA's *Air Traffic Services Administration and Management Manual* (ATSAMM), section 313 ATS Surveillance separation between successive IFR arrivals, runway occupancy time (ROT) data must be revalidated every 3 years.

area to Runway 33R can be described as a short taxi distance. In this occurrence, the measured distance from the gate area from where the CRJ 200 started the taxi to the hold short line at Runway 33R is approximately 1000 m (3280 feet).

At CYYZ, Runways 15L/33R and 15R/33L are used for approximately 5% of all movements. Runway 15L/33R has 8 crossing taxiways (Figure 2) that are used to facilitate aircraft movements at CYYZ.

Figure 2. Schematic of Runway 15L/33R showing all intersecting taxiways (indicated by letters) (Source: NAV CANADA, Canada Air Pilot Vol. 4, p. 721)



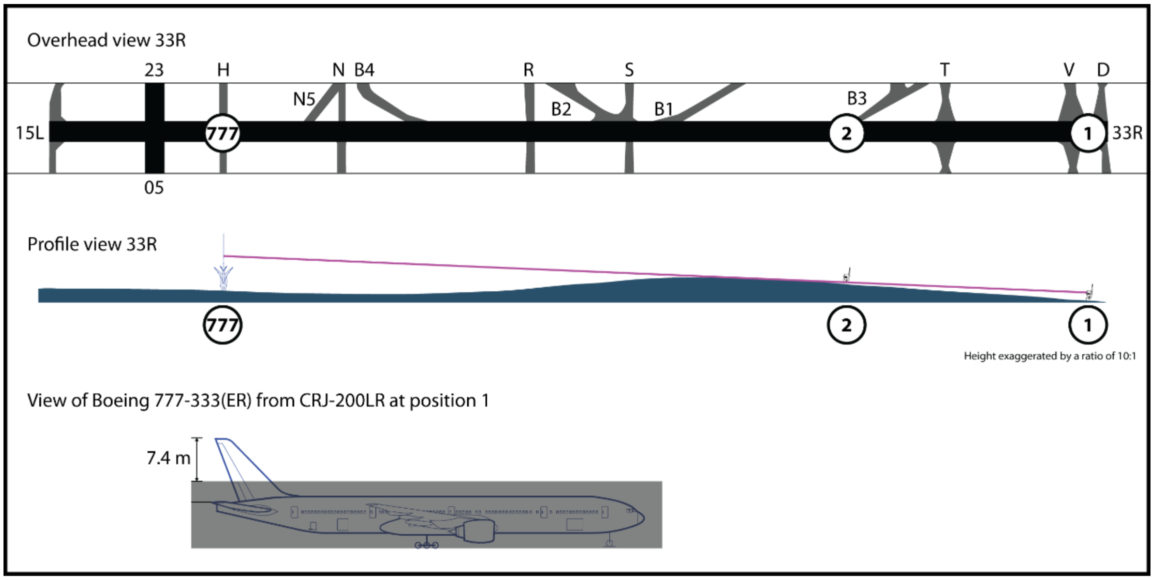
1.10.1.2 Runway 15L/33R and line-of-sight calculations

Runway 33R, the occurrence runway, is 11 050 feet long and 200 feet wide. The runway surface elevation increases from the threshold of Runway 33R and peaks at an elevation of 23 feet above the threshold elevation, creating a hump approximately 3600 feet down the runway. The elevation then decreases and flattens out for the remainder of the runway length.

The investigation calculated the amount of the Boeing 777 surface area that the flight crew of the CRJ 200 would have been able to see at specific points along Runway 33R. The calculations were based on the line of sight from the flight crew's seated position in the cockpit of the CRJ 200 and included the grade profile of the runway and the position of the Boeing 777 as it crossed Runway 33R, at Taxiway H.

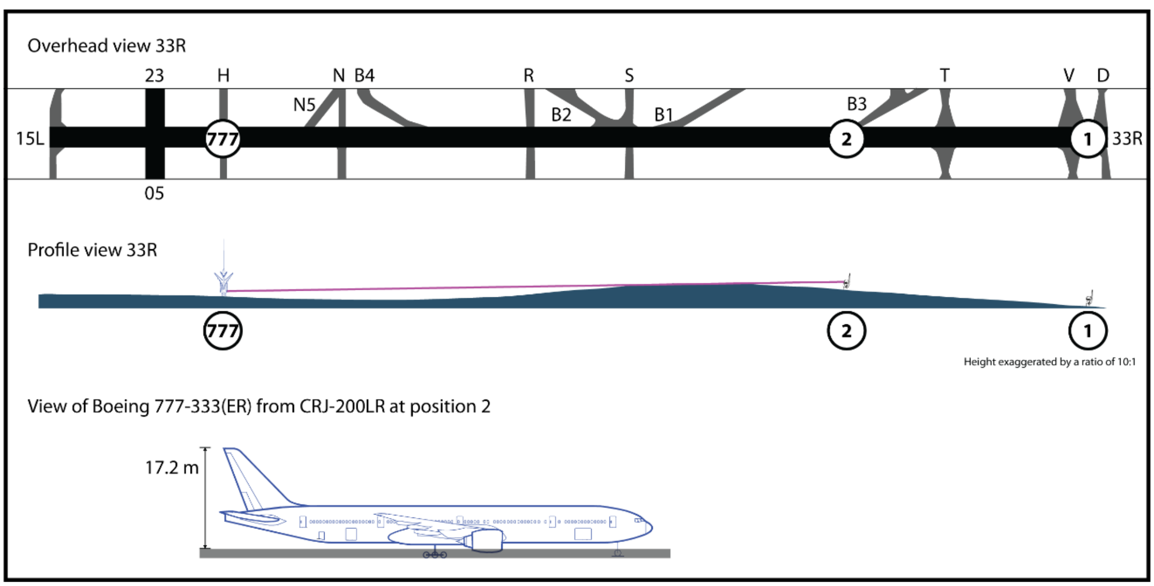
At the start of the take-off roll from the threshold of Runway 33R, the 7.4 m (24.28 feet) of the top of the Boeing 777's vertical stabilizer would have been visible approximately 8900 feet ahead (Figure 3).

Figure 3. Overhead and profile views of Runway 33R, illustrating the sightline of the CRJ 200 flight crew and their view of the Boeing 777 at the start of the take-off roll (position 1 in the figure) (Source: TSB)



As the aircraft continued along Runway 33R and approached the crest of the hump in the runway, the entire aircraft fuselage, or the top 17.2 m (56.43 feet) of the Boeing 777, would have been visible crossing Runway 33R, at Taxiway H, approximately 6400 feet ahead (Figure 4).

Figure 4. Overhead and profile views of Runway 33R, illustrating the sightline of the CRJ 200 flight crew and their view of the Boeing 777 at the crest of the hump in the runway (position 2 in the figure) (Source: TSB)



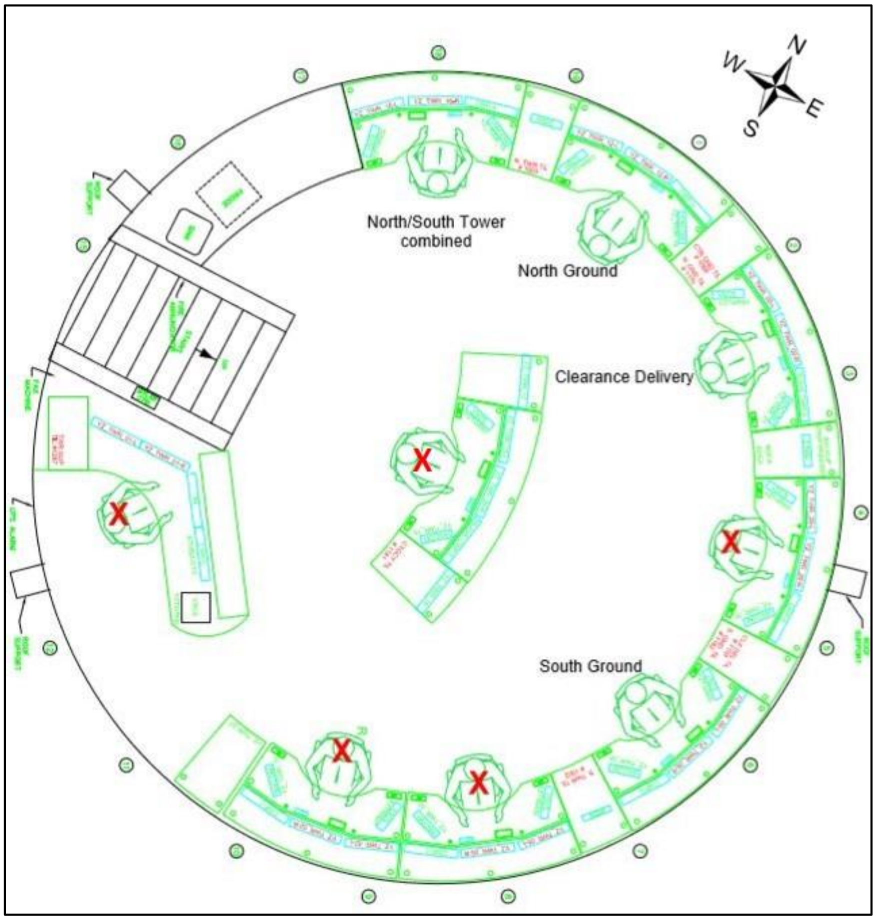
1.10.2 Toronto/Lester B. Pearson International Airport tower

1.10.2.1 General

At the time of the occurrence, 4 of the 9 positions (Figure 5) in the CYYZ tower were occupied:

- North/south tower (combined position). The occurrence controller was working this combined position.
- North ground
- Clearance delivery
- South ground

Figure 5. Staff positions in the Toronto/Lester B. Pearson International Airport tower. Positions not staffed at the time of the occurrence indicated by X. (Source: NAV CANADA)



1.10.2.2 North/south tower combined position

There are 2 airport tower controller positions in the CYYZ tower. The north tower controller is responsible for arriving and departing aircraft on Runway 05/23 and Runway 15L/33R. The south tower controller is responsible for arriving and departing aircraft on Runway 06L/24R, Runway 06R/24L and Runway 15R/33L.

The *Toronto Control Tower Unit Operations Manual* allows 1 tower controller to assume both the north and south tower responsibilities in a combined position during periods of light traffic at the airport, under the direction of the tower supervisor or senior controller on duty.[22] At the time of the occurrence, the traffic volume at CYYZ was considered light, which justified tower operations with 1 controller working the north/south tower combined position.

1.10.2.3 Visibility of the thresholds of Runway 33L and Runway 33R from the tower

The tower is located between runways 33L and 33R. The north/south tower combined workstation faces northwest. In order to observe the threshold of Runway 33R while seated or standing at this workstation, and facing this direction, the tower controller has to rotate their chair or body clockwise approximately 150°. Similarly, the tower controller must rotate counter-clockwise approximately 110° to observe the threshold of Runway 33L.

At the time of the occurrence, the tower controller was standing to observe an aircraft that was landing on Runway 33L; therefore, he could not monitor the threshold of Runway 33R or use the advanced surface movement guidance and control system (A-SMGCS) display at the workstation to confirm the position of the CRJ 200.

1.10.2.4 Controller workload

The tower controller described the workload at the time of the occurrence as moderate given the challenge of monitoring the thresholds of both Runway 33L and Runway 33R while working the combined position. The controller must also be vigilant for traffic crossing the active runway given the number of crossing taxiways along the length of Runway 33R. To manage this workload, the tower controller occasionally implemented short delays between line-up instructions and take-off clearances for departing aircraft. The short delay would give the tower controller time to monitor landing aircraft and to coordinate with the ground controller to ensure that aircraft that had to cross Runway 33R did so safely.

1.10.3 Advanced surface movement guidance and control system

The control tower at CYYZ is equipped with an A-SMGCS, or ground radar, that provides controllers with a real-time display of aircraft and vehicle traffic on the airport manoeuvring areas. The system receives input from both radar and multilateration antennas. Each control position in the tower is equipped with its own A-SMGCS display.

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22 NAV CANADA, *Toronto Control Tower Unit Operations Manual*, revision 39 (05 June 2019), Chapter C: Operational Positions, section C.1.3: Hours of Operation.

1.10.3.1 Runway incursion monitoring and conflict alert system

The RIMCAS is a sub-system within the A-SMGCS. RIMCAS monitors aircraft and vehicle traffic on the airport movement area and surrounding airspace to identify and alert air traffic controllers to possible conflict situations.[23]

Runway incursion monitoring is the main function of RIMCAS. When an aircraft is due to take off or land on a designated active runway, the system assesses the positions of radar targets and, within configurable parameters, identifies incursions onto that runway. When it detects a hazard, the system sends an alert message to the air traffic controller identifying the targets involved, their locations, and the severity of the hazard.

Alerts are generated in 2 stages. A stage 1 alert is a visual warning that appears on the A-SMGCS display advising the air traffic controller that a hazardous situation exists. A stage 2 alert is both visual and aural: a warning appears on the A-SMGCS display and a tower-wide alarm is sounded, indicating that the hazard is critical and an incursion may be imminent.

The MATS provides the following guidance for when a stage 1 alert progresses to stage 2:

> When a departure activates an alert, cancel take-off clearance or issue abort take-off instructions.[24]

RIMCAS-generated alerts and alarms are provided only to air traffic controllers and are intended to prompt controllers to issue alternative instructions to the aircraft or vehicles involved in the hazard. The system does not provide alerts directly to flight crews on board aircraft.

On the day of the occurrence, RIMCAS operated as designed and generated both a stage 1 and a stage 2 alert.

1.11 Flight recorders

The CRJ 200 was equipped with both a cockpit voice recorder (CVR) and a digital flight data recorder (DFDR), as required by regulation. The TSB requested that both recorders be secured for analysis.

1.11.1 Digital flight data recorder

Air Georgian did not secure the DFDR and it was therefore not available to the investigation.

1.11.2 Cockpit voice recorder

Air Georgian secured the CVR and provided it to the TSB. The CVR installed on the CRJ 200 was a Fairchild model A100S, which has a 30-minute recording time capacity. The occurrence communications were not recorded on the CVR because the CVR was not

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[23] Indra Navia AS, Sub-System Description – Runway Incursion Monitoring and Conflict Alert (RIMCAS), Revision 1.0 (18 December 2012), section 1.1, p. 1.

[24] NAV CANADA, *Manual of Air Traffic Services – Tower*, version 2.1 (28 March 2019), p. 125.

removed from service until after the aircraft had completed its flight to KCMH, approximately 60 minutes after departure from CYYZ.

The CARs Standard 625.34 states, in part:

> In this section, a reference to the date on which an aircraft is manufactured is a reference to the date on which the manufacturer has signed the statement of conformity certifying that the aircraft conforms to the approved type design.
>
> […]
>
> (2) A CVR installed on board an aircraft manufactured after December 31, 2002, shall retain all information recorded during the aircraft's operation, or all information recorded during the last two hours of the aircraft's operation, whichever is less.
>
> (3) A CVR installed on board any aircraft other than one referred to in subsection (2), shall retain all the information recorded during the aircraft's operation, or all the information recorded during the last 30 minutes of the aircraft's operation, whichever is less.[25]

To operate in the U.S., Canadian air operators are required to comply with specific parts of the U.S. *Federal Aviation Regulations* (FARs). In this case specifically, Air Georgian is required to comply with FAR Part 129.5(b), which states

> [e]ach foreign air carrier conducting operations within the United States must conduct its operations in accordance with the Standards contained in […], Annex 6 (Operation of Aircraft), […] to the Convention on International Civil Aviation.[26]

In its Annex 6 to the Convention on International Civil Aviation, the International Civil Aviation Organization (ICAO) requires that

> [a]ll aeroplanes of a maximum certificated take-off mass of over 5 700 kg for which the individual certificate of airworthiness is first issued on or after 1 January 1987 shall be equipped with a CVR.[27]

Annex 6 also requires that

> [a]ll CVRs shall retain the information recorded during at least the last 2 hours of their operation.[28]

This requirement for CVRs to be capable of retaining at least 2 hours was first published in ICAO's Annex 6 on 18 November 2010. It came into effect on 01 January 2016. Therefore, CVRs with 30-minute capacity are no longer permitted by international standards.

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25 Transport Canada, SOR/96-433, *Canadian Aviation Regulations,* Standard 625 - Aircraft Equipment and Maintenance Standard, section 625.34: Cockpit Voice Recorders (CVRs).

26 Federal Aviation Administration, *Code of Federal Regulation*s (CFR) Title 14: Aeronautics and Space, Part 129: Operations: Foreign Air Carriers and Foreign Operators of U.S.- Registered Aircraft Engaged in Common Carriage, Subpart A: General, section 129.5: Operations specifications.

27 International Civil Aviation Organization, Annex 6 to the Convention on International Civil Aviation: Operation of Aircraft, Part 1: International Commercial Air Transport – Aeroplanes, Eleventh Edition (July 2018), paragraph 6.3.2.1.3, p. 6-7.

28 Ibid., paragraph 6.3.2.3.1, p. 6-7.

In May 2019, Transport Canada published amendments to the *Canadian Aviation Regulations* that require CVRs to be capable of recording at least 2 hours; however, these requirements will only become effective on 29 May 2023. This implementation date will allow the continued use of 30-minute CVRs in Canada for more than 7 years beyond the ICAO deadline of January 2016.

The CRJ 200 was being operated in compliance with existing CARs for flight in Canada; however, it was not in compliance with the FAR or ICAO requirements for international flights.

1.11.3 Previous TSB recommendation on cockpit voice recorder duration

On 09 March 1999, the TSB issued Recommendation A99-02 as part of its investigation into an accident involving Swissair Flight 111, a McDonnell Douglas MD-11 aircraft that struck water near Peggy's Cove, Nova Scotia, after the crew diverted the flight to Halifax, Nova Scotia, because of smoke in the cockpit.[29]

One of the shortcomings identified during the investigation was the limited recording capacity of the aircraft's CVR. The CVR was able to record only 30 minutes, and therefore did not capture the timeframe critical for the investigation. Therefore, the Board recommended to Transport Canada (TC) that:

> As of 01 January 2005, all aircraft that require both an FDR and a CVR be required to be fitted with a CVR having a recording capacity of at least 2 hours.
>
> **TSB Recommendation A99-02**

In its latest response (dated October 2019), TC indicated that it agreed with Recommendation A99-02.

In May 2019, amendments to the CARs for flight data recorders (FDR) and CVRs were published in the *Canada Gazette*, Part II.[30] These amendments included the requirement for CVRs to be capable of recording at least 2 hours. The regulations will come into effect in May 2023.

The Board believes that these amendments will address the safety deficiency associated with this recommendation.

Therefore, the response to Recommendation A99-02 is assessed as **Fully Satisfactory**.

For further details relating to this recommendation, along with TC's responses to the recommendation and the TSB's assessment of these responses, visit https://www.tsb.gc.ca/eng/recommandations-recommendations/aviation/index.html.

29 TSB Aviation Investigation Report A98H0003.

30 Government of Canada, *Canada Gazette*, Part II, Volume 153, Number 11 (10 May 2019): Regulations Amending the Canadian Aviation Regulations (Parts I and VI – Flight Data Recorder and Cockpit Voice Recorder).

1.12 Wreckage and impact information

Not applicable.

1.13 Medical and pathological information

The investigation determined that there was nothing to indicate that the captain's or FO's performance was degraded by medical and pathological factors.

1.14 Fire

Not applicable.

1.15 Survival aspects

Not applicable.

1.16 Tests and research

1.16.1 TSB laboratory reports

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

- LP222/2019 – CVR Download
- LP273/2019 – Line of Sight Calculation

1.17 Organizational and management information

1.17.1 General

Both the Boeing 777 and the CRJ 200 were being operated under CARs Subpart 705 (Airline Operations).

1.17.2 Air Georgian Limited

1.17.2.1 General

At the time of the occurrence, the CRJ 200 was owned and operated by Air Georgian Limited, a subsidiary of Regional Express Aviation Ltd., which was formed in 1984. The company operated Beechcraft 1900D and Bombardier CL-600-2B19 (CRJ 100 and 200) series aircraft. Its head office was located in Toronto, Ontario.

1.17.2.2 Flight crew tasks during taxi

The Air Georgian company operations manual provides definitions and responsibilities for each flight crew member. The manual states that the captain is to ensure "that crew members perform their duties in a manner consistent with published Company policies and procedures during flight duty time."[31]

All flight crews must monitor each other, as their duties permit, to ensure consistency in all operations.

As stated in the standard operating procedures (SOPs), the taxi checklist is not to be performed while manoeuvring in high-traffic areas, such as around departure gates and aprons. The flight crew must be focused on the manoeuvring area around them.[32]

Each flight crew member is expected to monitor the other, cross-check all instrumentation, and keep the other informed of any deviations from SOPs. The SOPs also require that the captain and FO verbally confirm certain instructions and clearances with one another, such as all hold-short instructions, clearances onto active runways, and take-off clearances.[33]

1.17.2.2.1 Captain

During taxi, the captain is tasked with manoeuvering the aircraft safely to the runway, keeping a lookout for other ground traffic, monitoring the FO, and responding to any challenge-and-response items on the checklists as called by the FO.

1.17.2.2.2 First officer

During taxi, the FO is tasked with completing the required checklists, initiating any challenge-and-response items on the checklists, monitoring and responding to ATC communications, and keeping a lookout outside the aircraft.

1.18 Additional information

1.18.1 Expectations and mental models in operational environments

In real-world operational situations, people use their prior experience and knowledge to rapidly categorize the situation they are experiencing and select an appropriate course of action.[34] Therefore, in highly practised situations, attention and expectations are more often informed by one's existing mental model of the situation since previous experience will dictate what information is important and how the situation will unfold.

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[31] Air Georgian Limited, *CARs 705 Company Operations Manual*, Issue 2 (February 2018), section 1.4.6 Captain, p. 1-8.

[32] Air Georgian Limited, *705 Standard Operating Procedures*, Issue 4 (July 2018), section 3.1.12: Taxi Checklist, p. 3-7.

[33] Ibid., section 1.1.1: Monitoring and Cross-Checking, p. 1-3.

[34] G. Klein, "Naturalistic decision making", *Human Factors*, Vol. 50 No. 3 (June 2008), pp. 456–460.

Mental models are critical for effective performance in dynamic time-critical environments since they reduce the need for time-consuming evaluation of the situation and enable quick actions. However, they can also lead to errors in how information is perceived. When pilots receive information about the environment that they expect to receive, they tend to react quickly and without errors. However, when they receive information that is contrary to their expectations, their performance tends to be slow or inappropriate.[35]

1.18.2 Attention and workload

Workload is a function of the number of tasks that must be completed within a given amount of time. If the number of tasks that must be completed increases, or if the time available to complete them decreases, the workload increases. Task saturation occurs when the number of tasks to be completed in a given time exceeds a person's capacity to perform them, and some tasks must be abandoned or deferred as a result.[36]

A person's ability to divide their attention is limited, and increased workload can adversely affect their ability to perceive and evaluate information from the environment. Increased workload can lead to attention narrowing or tunnelling.[37] In some cases, people may unintentionally focus on the information they believe is most important. In other cases, people may fixate on certain information. Either situation can result in their situational awareness being inaccurate.[38]

1.18.3 Factors affecting flight crew attention and workload

On the day of the occurrence, while taxiing to Runway 33R, the captain was focused on an aircraft that was taxiing toward them, on Taxiway B, and therefore, was unable to monitor the FO while she completed her duties.

It could take up to 6 minutes to conduct and visually verify the items in the taxi and line-up checklists, if accomplished without any time constraint pressure.[39] However, if the flight crew receives a radio call from ATC while a checklist is being completed, the person completing the checklist must stop what they are doing, note the items on the checklist that had not yet been completed, and then listen to the ATC instructions received, take notes (if applicable), and read back the instructions. Each radio communication with ATC can delay the completion of a checklist by 10 to 30 seconds, or longer depending on the content of the

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35 M. R. Endsley, "Situation awareness in aviation systems," *Handbook of Aviation Human Factors,* 2nd edition, (CRC Press, 2010) pp. 12-1 to 12-22.

36 C.D. Wickens, "Multiple resources and performance prediction", *Theoretical Issues in Ergonomic Science*, Vol. 3, No. 2 (2002), pp. 159–177.

37 C. D. Wickens, R. S. Gutswiller., and A. Santamaria, "Discrete task switching in overload: A meta-analyses and a model", *International Journal of Human Computer Studies,* Vol. 79 (July 2015), pp. 79–84.

38 M. R. Endsley, B. Bolté, and D. G. Jones, *Designing for Situation Awareness: An Approach to User-Centered Design* (Taylor and Francis, 2003).

39 The total amount of time to conduct, visually verify, and process the action for each of the items in the taxi and line-up checklists, is an approximation based on a task analysis conducted with the first officer.

communication. At the time of the occurrence, the flight crew of the CRJ 200 had received 2 instructions from the south ground controller and 1 instruction from the tower controller while they were taxiing from the gate apron to Runway 33R.

The elapsed time from when the CRJ 200 started to taxi from the gate area to the time it started the take-off roll was 3 minutes and 22 seconds.

1.18.4 Fatigue

Sleep-related fatigue may result from 1 or more of the following 6 risk factors:

- acute sleep disruption;
- chronic sleep disruption;
- continuous wakefulness;
- circadian rhythm effects;
- sleep disorders; and
- medical and psychological conditions, illnesses and drugs.

Performance impairments associated with fatigue are significant risk factors and predictors of occupational accidents and injuries,[40] motor vehicle accidents,[41] and aviation occurrences.

There are numerous biological rhythms in humans that follow a circadian (daily) pattern. Many circadian rhythms are interdependent and synchronized both to each other and to the time of day. Fatigue and sleep propensity also follow a circadian pattern and increase significantly at night.[42] Optimal human performance occurs when all circadian rhythms are synchronized to each other as well as to external time cues.

Shift schedules that rotate forward—that is, from day, to afternoon, to night—facilitate circadian rhythm adjustment and lessen the risk of fatigue compared to backward-rotating scheduling systems.[43] Changing sleep-wake patterns too quickly can cause circadian rhythms to desynchronize, which can lead to performance impairments. Research shows that, compared to workers who work regular shift schedules, workers who work variable shifts get, on average, less sleep, and are more likely to experience sleep disturbance,

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40 D. Dawson and K. Reid, "Fatigue, alcohol and performance impairment", *Nature*, Vol. 388, Issue 6639 (17 July 1997), p. 235.

41 Traffic Injury Research Foundation, *Fatigue-Related Fatal Collisions in Canada, 2000-2016* (March 2020), at https://tirf.ca/Fatigue_Related_Fatal_Collisions_Canada_2000_2016 (last accessed on 13 July 2020).

42 D.F. Dinges, "The influence of the human circadian timekeeping system on sleep", in: M. H. Kryger, T. Roth, and W. C. Dement (eds.), *Principles and Practice of Sleep Medicine* (Philadelphia: W. B. Saunders Company, 1989), pp. 153–162.

43 T.R. Driscoll, R.R. Grunstein, and N.L. Rogers, "A systematic review of the neurobehavioral and physiological effects of shiftwork systems", *Sleep Medicine Reviews*, Vol. 11, No. 3 (2007), pp. 179–194.

excessive sleepiness, and disrupted circadian rhythms.[44,45] The desynchronization will also make it more difficult to obtain sufficient restorative sleep before the new early-morning shift because the body is not yet synchronized to sleep in the early night.

Research also shows that circadian rhythms adapt at a rate of between 1 and 1.5 hours per day, depending on the direction of the time change. To reduce the risks of circadian rhythm desynchronization and fatigue, a good rule of thumb is to allow people 1 day of adaptation for every hour of counter-clockwise change in sleep-wake pattern (i.e., where bedtime is earlier than usual).[46]

1.18.4.1 Air Georgian Fatigue Management Policy

Air Georgian developed its fatigue management program with an understanding of the risk posed to medium and short-haul pilots. Fatigue management was covered at length during ground school training, which included the IMSAFE checklist[47] and awareness training regarding how to identify fatigue, the reporting process, and how those reports were actioned.

In addition, in early 2019, as part of Air Georgian's fatigue management program, the company engaged a third party to assist in further developing strategies to help reduce risk, improve productivity, and optimize human performance through the science of sleep. Air Georgian also used a software program that managed and optimized crew scheduling by applying the standards for flight time and duty time limitations that were in force at the time of the occurrence.

The Air Georgian *Corporate Policy and Procedures Manual*[48] contains the company's Fatigue Management Policy, which provides information on the causes of fatigue, some mitigating steps to avoid fatigue, guidance should a crew member feel fatigued at work, and flight

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44 M.M. Ohayo, P. Lemoine, V. Arnaude-Briant, V., and M. Dreyfus, "Prevalence and consequences of sleep disorders in a shift worker population", *Journal of Psychosomatic Research*, Vol. 53, No. 1 (2002), pp. 577–583.

45 K. Pati, A. Chandrawanshi and A. Reinberg, "Shift work: Consequences and management", *Current Science*, Vol. 81, No. 1, (2001), pp. 32–52.

46 K. Klein, and H. Wegmann, "Significance of circadian rhythms in aerospace operations", NATO AGARD-AG-247 (Neuilly sur Seine, France: NATO AGARD, 1980).

47 The IMSAFE checklist is used to help mitigate risk by prompting the pilot to assess their physical and mental readiness for the flight. The checklist cues pilots to check for the following common risk factors: illness, medication, stress, alcohol, fatigue, and emotion. (Source: Federal Aviation Administration, FAA-H-8083-25B, *Pilot's Handbook of Aeronautical Knowledge* [2016], Chapter 2: Aeronautical Decision Making, Mitigating Risk, p. 2-8, at https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/pilot_handbook.pdf [last accessed 26 November 2020])

48 Air Georgian Limited, *Corporate Policy and Procedures Manual,* Issue 12, Amendment 1 (16 October 2018).

operation fatigue policies. The manual does not mention the impact of rotating shift schedule direction on an individual's circadian rhythm and level of fatigue.

Fatigue training for pilots at Air Georgian focused on elements of the *Corporate Policy and Procedures Manual*, including the Fatigue Management Policy. At the time of the occurrence, the captain and FO were aware of the Fatigue Management Policy and had received training concerning fatigue.

1.18.4.2 Typical crew scheduling at Air Georgian

In the 2 months leading up to the occurrence, the crew worked a rotating evening to day shift schedule. The crew flight duty and rest periods were in accordance with regulations.[49] Evening shifts typically began between 1300 and 1430 and ended between 2230 and 2330. During early morning shifts, the crew would typically report in the early morning between 0500 and 0655 and be released from duty between 1300 and 1600.

Both the captain and the FO reported regularly feeling fatigued when working an evening shift schedule rotation. On those nights, the captain and the FO went to bed about 2 to 4 hours later than their normal bedtime of 2200 because of the time the late evening shift ended and a 2-hour time commuting home from the airport gate. Following evening shifts, the captain and the FO reported normally waking up at their usual time in the morning (around 0700), then attempting to go back to sleep. Neither the captain nor the FO took naps on their days off.

During the 2 months leading up to the occurrence, the crew received between 1 to 6 days of rest between backward-rotating evening-to-day shift schedules. During their days off, the captain and the FO attempted to maintain their normal sleep/wake pattern (going to sleep at approximately 2200 and waking at approximately 0700).

1.18.4.3 Crew sleep-wake history

1.18.4.3.1 Captain

On the day of the occurrence, the captain woke up at 0415 and began his duty day at 0530. Although he had obtained 7 hours of good-quality sleep the night before, he felt fatigued on the day of the occurrence.

The captain had worked a backward-rotating shift schedule in the 6 days leading to the occurrence. Following a 4-day evening shift schedule, the captain had 1 day off to rest before beginning an early morning shift schedule, with a start time of 0715. The captain did not take a nap during his day off. The occurrence took place on the captain's 2nd day of working the early morning shift schedule. The captain was at risk of some circadian rhythm desynchronization as he would have required at least 3 days between shift rotations to adapt to the new early morning schedule (he had an early wake time of 0400 rather than his

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[49] Transport Canada, SOR/96-433, *Canadian Aviation Regulations*, subsections 700.13 to 700.23. These (700.13 - 700.23) were in effect at the time of the occurrence and have since been superceded by 700.19 - Division III — Flight Crew Member Fatigue Management.

normal 0700). The captain experienced acute sleep disruption because the early morning shifts required earlier start times than what he was used to. The late evening shift end times in the 4 work days leading up to the occurrence meant that the captain was unable to get a full 8 hours of restorative sleep on any of those nights due to waking up at his usual wake time, and he was building a chronic sleep debt caused by regularly occurring, reduced-quantity sleep. Although the captain was experiencing some fatigue at the time of the occurrence, the investigation could not determine whether the performance effects of fatigue contributed to the runway incursion.

1.18.4.3.2 First officer

In the 6 days leading up to the occurrence, the FO worked a regular early morning shift schedule, reporting to work between 0500 and 0530, and completing the duty day between 1244 and 1619. The FO obtained an average of 7.5 to 9 hours of good quality nighttime sleep during this time. On the morning of the occurrence, the FO woke at approximately 0400 following a 7.75-hour period of good-quality sleep. The FO's duty day began at 0530. The FO was on the 6th shift of an 8-day shift schedule. The FO did not feel fatigued on the day of the occurrence. The investigation determined that fatigue was not a factor for the FO.

1.18.5 TSB Watchlist

The TSB Watchlist identifies the key safety issues that need to be addressed to make Canada's transportation system even safer. The TSB publishes the Watchlist to focus the attention of industry and regulators on the problems that need to be addressed today.

1.18.5.1 Risk of collisions

Risk of collisions from runway incursions is a **Watchlist 2020 issue**.

Since this issue was added to the Watchlist in 2010, the TSB has completed 18 investigations[50] into runway incursions, including a safety issue investigation focused on the south complex parallel runways at CYYZ.[51] Although there has not been a recent accident as a result of a runway incursion in Canada, the potential consequences of such a collision could be catastrophic.[52] Therefore, the Board is concerned that the rate of runway incursions in Canada and the associated risks of collision will remain elevated until effective defences created to address identified hazards are implemented at airports and in aircraft, vehicles, and air traffic service facilities across Canada.

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50 TSB aviation investigation reports A10W0040, A10O0089, A11Q0170, A13H0003, A13O0045, A13O0049, A13O0014, A14C0112, A14H0002, A14W0046, A14W0127, A16O0016, A16W0170, A17O0038, A18P0177, A19O0006, A19Q0015 and A19O0117.

51 TSB Air Transportation Safety Issue Investigation Report A17O0038.

52 On 11 February 1978, 42 people on board Pacific Western Airlines flight 314 were killed as a result of an incursion accident at Cranbrook/Canadian Rockies International Airport, British Columbia.

ACTIONS REQUIRED

- This issue will remain on the TSB Watchlist until the rate of runway incursions, particularly the number of high-risk incursions, demonstrates a sustained reduction; or new technology is implemented that improves safety defences.
- There is no single solution that can address the incursion risk nationwide. Individual solutions to previously identified hazards, in combination with wider-reaching technological advancements such as in-cockpit situational awareness aids and runway status lights, will likely be most effective.

1.19 Useful or effective investigation techniques

Not applicable.

2.0 ANALYSIS

The runway incursion occurred during daylight hours in visual meteorological conditions. The actions of the flight crew of the Boeing 777 were not considered to have contributed to this occurrence.

Records indicate that all personnel responsible for the operation of CRJ 200 aircraft and air traffic control (ATC) involved in this occurrence were certified and qualified in accordance with existing regulations and/or applicable directives. The aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures.

The analysis will focus on the formation of the CRJ 200 flight crew's mental model of the evolving situation, and how the flight crew's expectations and workload, combined with the sequence of the ATC instructions provided by the tower controller, likely contributed to the flight crew's misunderstanding of the line-up instructions. The analysis will also focus on fatigue risks and the recording capacity of the cockpit voice recorder.

2.1 Flight crew workload, expectations, and mental model

During the short taxi distance, the flight crew had to complete a number of pre-departure tasks, such as manoeuvring the aircraft, completing checklist items, communicating with ATC, and monitoring the area around the aircraft, including keeping watch for other aircraft and their movements. In preparation for departure, the captain's attention was focused on safely manoeuvring the aircraft, while the first officer's (FO's) attention was focused on completing the checklists and communicating with ATC.

During normal operations, without any time constraints, the taxi and line-up checklists could take up to 6 minutes to complete. Due to the lack of CVR data, the actual time it took the flight crew to complete the checklist items could not be determined. However, the elapsed time from when the aircraft started to taxi from the gate area to the time it started the take-off roll on Runway 33R was 3 minutes and 22 seconds. Given that the flight crew completed the required checklists and also responded to ATC instructions, the number of pre-departure tasks the flight crew was required to complete within a short amount of time increased their workload.

As the CRJ 200 approached Runway 33R, the flight crew was expecting to receive immediate authorization to take off. Although the FO read back the ATC instructions correctly, she had limited attentional resources to evaluate the content of the instructions as her focus was on completing the line-up checklist. The FO's workload was further elevated as she focused on the heading and altitude change of the standard instrument departure (SID) amendment, which, at the time, she believed was most important in the line-up instruction.

The SID amendment reinforced the FO's expectation that they would soon receive authorization to take off. It is important to note that the FO was accustomed to receiving a SID amendment followed by a take-off clearance. In this occurrence, when the FO received and read back the line-up instruction with the SID amendment, she had misinterpreted that ATC communication as a clearance for takeoff. During this time, the captain was focused on another aircraft while manoeuvring the aircraft to position. Therefore, he had reduced attentional resources to attend to ATC instructions and clearances and supervise the FO, and, as a result, did not focus on the ATC instruction.

When the CRJ 200 entered Runway 33R, a de Havilland DHC-8 aircraft had departed and was likely no longer visible to the crew. There was no other aircraft on the runway directly in front of them.

When the captain asked the FO if they had received clearance to take off, the FO, who had misinterpreted the tower controller line-up and SID amendment instructions as clearance to take off, replied that they had received take-off clearance. This interpretation matched the crew's mental model of the situation that they would be taking off shortly after lining up on Runway 33R.

The increased workload, the expectation to receive a take-off clearance without delay, and the misinterpretation of the line-up instructions led the crew to initiate the take-off roll without a take-off clearance.

Based on TSB calculations, the fuselage of the Boeing 777 would not have been visible to the CRJ 200 crew at the start of the take-off roll because of the grade profile of Runway 33R; therefore, the crew had no visual indication that it was unsafe to initiate the take-off roll on Runway 33R. The flight crew would have only been able to see the top portion of the Boeing 777's vertical stabilizer at Taxiway H, over 8900 feet away. The distance between the CRJ 200 and the Boeing 777, in addition to the speed at which the Boeing 777 was taxiing and the surrounding features on the horizon, would have made it difficult for the flight crew to identify the top portion of the vertical stabilizer.

The crew only detected the Boeing 777 after reaching the crest of the hump of Runway 33R. The captain immediately rejected the takeoff. At that time, the flight crew realized that they had likely not received a take-off clearance.

2.2 Air traffic control instructions

On the day of the occurrence, the tower controller was working a combined north/south position, and was controlling both departing aircraft on Runway 33R and landing aircraft on Runway 33L. Due to the physical location of the tower, the tower controller cannot observe the threshold of both Runway 33L and Runway 33R at the same time. In addition, while the tower controller is observing aircraft at either threshold, the controller cannot monitor displays on the workstation and must rely instead on audible alarms to alert them to runway conflicts. Because there are 8 crossings on Runway 33R, which increases the risk of incursion, the controller must also be vigilant for traffic crossing the active runway. The tower controller was experiencing a moderate level of workload at the time of the occurrence due to the challenge in monitoring both Runway 33 thresholds and workstation displays, all at the same time.

The tower controller managed the workload by occasionally implementing short delays between line-up and take-off clearances for departing aircraft. This short delay would give the tower controller time to monitor landing aircraft and to coordinate with the ground controller to ensure that aircraft that have to cross Runway 33R do so safely.

The tower controller had planned for a short delay after issuing the line-up instruction to the CRJ 200. The tower controller intended to provide the take-off clearance as soon as his attention was no longer required for the landing aircraft on Runway 33L, and after confirming that the Boeing 777 was clear of Runway 33R. Although NAV CANADA's *Manual of Air Traffic Services* (MATS) requires a controller to instruct an aircraft to "wait" if a delay is expected following a line-up instruction, the tower controller did not believe that the delay would be long and believed that the CRJ 200 crew was aware of the preceding departure; therefore, he did not issue an instruction to "wait".

After the tower controller provided the CRJ 200 flight crew with line-up instructions, and heard the correct readback, he expected the flight crew to comply with the instruction. He then turned to focus his attention on the aircraft that was landing on Runway 33L and, therefore, could not monitor the threshold of Runway 33R or the advanced surface movement guidance and control system (A-SMGCS) display to confirm the position of the CRJ 200 or the Boeing 777 crossing Runway 33R.

The CRJ 200 began the take-off roll as the Boeing 777 crossed the runway holding position for Runway 33R. Shortly after, the tower controller received a stage 2 audible alarm from the runway incursion monitoring and conflict alert system (RIMCAS) and his attention was drawn back to Runway 33R. He observed the CRJ 200 accelerating along the runway and then noticed the Boeing 777 clearing the runway. Given the speed and position of both aircraft, he quickly assessed that there was no risk of collision and issued a take-off clearance to the CRJ 200. At the same time, the flight crew of the CRJ 200 observed the Boeing 777 still crossing the runway and initiated a rejected takeoff. The flight crew of the CRJ 200 heard the ATC take-off clearance, but informed the controller that they were rejecting the takeoff.

The guidance in the MATS states that the controller must cancel the take-off clearance or issue an instruction to abort takeoff when a RIMCAS stage 2 alert is activated. The MATS also states that "[a] controller-initiated aborted takeoff is an extreme measure used only where no clear alternative exists."[53] In this occurrence, although the MATS requires an abort-takeoff instruction to be issued when the stage 2 alert is triggered, the tower controller chose not to issue an abort-takeoff instruction, but rather issued a take-off clearance because he assessed that there was no risk of collision.

53 NAV CANADA, *Manual of Air Traffic Services – Tower*, version 2.1 (28 March 2019), p. 98.

2.3 Fatigue risk from backward-rotating shift schedules and circadian rhythm disruptions

A thorough fatigue analysis of the flight crew was conducted, including consideration of the flight crew's work schedule, their sleep history, and circadian rhythm timing. The investigation did not identify fatigue as a factor for the FO at the time of the occurrence.

Three fatigue risk factors were present for the captain at the time of the occurrence: acute sleep disruption, chronic sleep disruption, and circadian rhythm disruption. Although the captain was experiencing some fatigue at the time of the occurrence, the investigation could not determine whether the performance effects of fatigue contributed to the runway incursion.

However, flight crew members are at risk of fatigue when working early morning shifts following evening shifts without having had a sufficient number of days of rest to adapt to the new early morning schedule.

Shift schedules that rotate from nights (or late evenings, as in this case) to early mornings are referred to as backward-rotating shift schedules. This type of shift schedule makes it difficult for the body's circadian rhythm to resynchronize to the new schedule. The desynchronization will also make it more difficult to obtain sufficient restorative sleep before the first early-morning shift because the body is not synchronized to sleep in the early night (a counter-clockwise change). A good rule of thumb is to allow people 1 day of adaptation for every hour of counter-clockwise change in sleep-wake pattern.[54]

Although the investigation did not determine that fatigue affected performance in this occurrence, backward-rotating shift schedules cause circadian rhythm desynchronization, which increases the risk of fatigue in crew members who do not receive sufficient time off to adapt their sleep-wake pattern when working these schedules.

A review of the Air Georgian Limited *Corporate Policy and Procedures Manual* found that, while the Fatigue Management Policy identifies several causes of fatigue and some mitigating steps, there is no mention of the impact of shift schedule rotation on an individual's circadian rhythm and level of fatigue.

If airlines do not inform crew members of the risk of fatigue due to the direction of shift schedule rotation, there is an increased risk that crew members will operate an aircraft while fatigued.

2.4 Cockpit voice recorder

The cockpit voice recorder (CVR) installed on the CRJ 200 had a 30-minute recording capacity and was certified for use in Canada according to existing Canadian regulations. The CRJ 200 eventually departed for its scheduled flight to John Glenn Columbus International

54 K. Klein and H. Wegmann, "Significance of circadian rhythms in aerospace operations", NATO AGARD-AG-247 (Neuilly sur Seine, France: NATO AGARD, 1980).

Airport (KCMH), Ohio, United States (U.S.). However, Part 129 of the U.S. *Federal Aviation Regulations* (FAR) requires foreign air operators to conduct operations in accordance with the International Civil Aviation Organization's (ICAO's) Annex 6 to the *Convention on International Civil Aviation*. Annex 6 specifically states the requirement for all CVRs to have a recording capacity of at least 2 hours.

The use of CVRs with 30-minute recording capacity is no longer permitted by international standards. Therefore, any Canadian aircraft currently equipped with a CVR with a 30-minute recording capacity, such as the occurrence aircraft, that is operating outside Canada, does not comply with the U.S. and ICAO requirements.

ICAO standards regarding CVRs were amended in 2010 and stated that, as of January 2016, all CVRs must be capable of retaining the information recorded during at least the last 2 hours of their operation. In May 2019, Transport Canada published amendments to the *Canadian Aviation Regulations* that require CVRs to be capable of recording at least 2 hours; however, these requirements will only become effective on 29 May 2023. This implementation date will allow the continued use of 30-minute CVRs for more than 7 years beyond the ICAO deadline of January 2016.

If CVRs that have a reduced recording capacity remain in service, there is an increased risk that data relevant to an occurrence will not be available to an investigation, precluding the identification and communication of safety deficiencies to advance transportation safety.

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 number of pre-departure tasks the flight crew was required to complete within a short amount of time increased their workload.

2. The first officer's workload was further elevated as she focused on the heading and altitude change of the standard instrument departure amendment, which, at the time, she believed was most important in the line-up instruction.

3. When the first officer received and read back the line-up instruction with the standard instrument departure amendment she had misinterpreted that air traffic control communication as a clearance for takeoff.

4. The increased workload, the expectation to receive a take-off clearance without delay, and the misinterpretation of the line-up instructions, led the crew to initiate the take-off roll without a take-off clearance.

5. The fuselage of the Boeing 777 would not have been visible to the CRJ 200 crew at the start of the take-off roll because of the grade profile of Runway 33R; therefore, the crew had no visual indication that it was unsafe to initiate the take-off roll on Runway 33R.

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. Backward-rotating shift schedules cause circadian rhythm desynchronization, which increases the risk of fatigue in crew members who do not receive sufficient time off to adapt their sleep-wake pattern when working these schedules.

2. If airlines do not inform crew members of the risk of fatigue due to the direction of shift schedule rotation, there is an increased risk that crew members will operate an aircraft while fatigued.

3. If cockpit voice recorders that have a reduced recording capacity remain in service, there is an increased risk that data relevant to an occurrence will not be available to an investigation, precluding the identification and communication of safety deficiencies to advance transportation safety.

3.3 Other findings

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

1. Although the *Manual of Air Traffic Services* requires an abort-takeoff instruction to be issued when the stage 2 alert is triggered, the tower controller chose not to issue an abort-takeoff instruction, but rather issued a take-off clearance because he assessed that there was no risk of collision.

4.0 SAFETY ACTION

4.1 Safety action taken

4.1.1 NAV CANADA

As a result of this investigation, NAV CANADA issued Operations Directive YYZ-OD-2020-488, reminding tower controllers that, as stated in the *Manual of Air Traffic Services*, when runway incursion monitoring and conflict alert system stage 2 alerts are activated by departing aircraft, they must cancel the take-off clearance or issue an instruction to abort takeoff.

4.1.2 Air Georgian Limited

Air Georgian Limited is no longer a corporate entity.

However, following the occurrence, Air Georgian conducted an internal safety investigation in accordance with the company's safety management system. In addition, as a result of this occurrence, Air Georgian reported that they had amended their standard operating procedures to mandate an air traffic control (ATC) query if one of the two crew members was unaware of the content of an ATC clearance or instruction.

This report concludes the Transportation Safety Board of Canada's investigation into this occurrence. The Board authorized the release of this report on 16 December 2020. It was officially released on 15 January 2021.