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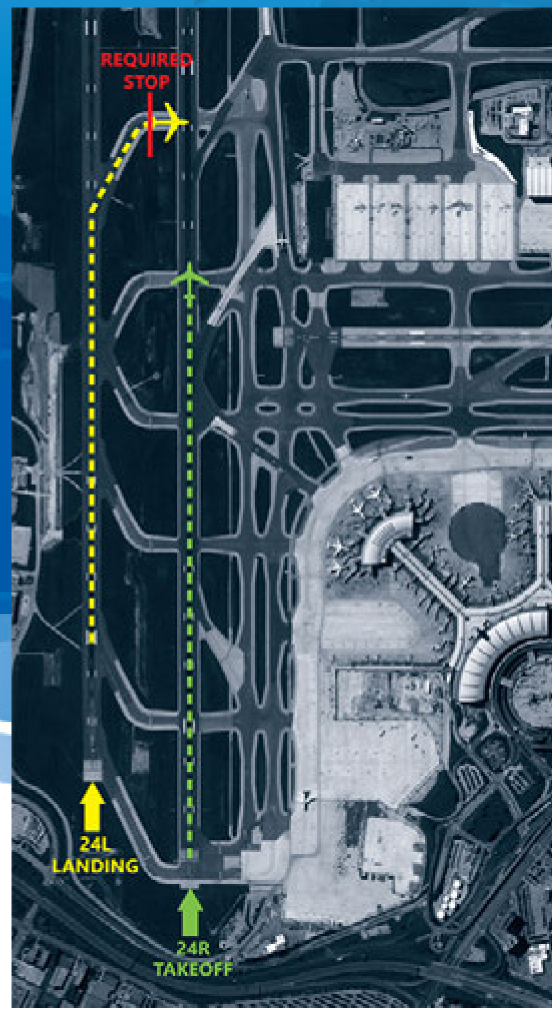

AIR TRANSPORTATION SAFETY ISSUE INVESTIGATION REPORT A17O0038

Runway Incursions Between the Parallel Runways at Toronto/Lester B. Pearson International Airport, Ontario

Released 31 January 2019

Canada

ABOUT THIS INVESTIGATION REPORT

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

This report is the result of an investigation into a class 1 occurrence. For more information, see the Occurrence Classification Policy at www.tsb.gc.ca

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Transportation Safety Board of Canada
Place du Centre
200 Promenade du Portage, 4th floor
Gatineau QC K1A 1K8
819-994-3741
1-800-387-3557
www.tsb.gc.ca
communications@tsb.gc.ca

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Cover image: South complex runways and rapid exit taxiways at Toronto/Lester B. Pearson International Airport (Source: Google Earth, with TSB annotations)

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Runway Incursions Between the Parallel Runways at Toronto/Lester B. Pearson International Airport, Ontario

Summary

This investigation examined 27 runway incursions that occurred between June 2012 and November 2017 at 2 closely spaced parallel runways known as the "south complex" at Toronto/Lester B. Pearson International Airport (CYYZ), Ontario. The 27 cases studied were not the only incursions at CYYZ during that period. However, their number and similarity raised concern and led the TSB to examine them more closely as a group, in order to determine their systemic underlying causes and contributing factors and to assess the degree of ongoing risk.

All of the incursions occurred on the inner runway (Runway 06L/24R) after the flight crews involved had landed on the outer runway (Runway 06R/24L), had been instructed by air traffic control (ATC) to hold short of Runway 06L/24R, and, despite intending to stop, had missed the visual cues depicting the runway holding positions.

The taxiway layout between the runways has several characteristics that are uncommon compared to those at other airports, both within North America and internationally. The runways are spaced a relatively short distance (305 m [1000 feet]) apart, and the rapid exit taxiways (RETs) provide direct access to the adjacent runway without first progressing to another transitional surface. The runway holding positions are located immediately following a 65° curve and are situated at greater distances from the protected inner runway than they are at other airports.

Regional airlines that are based in the United States and that operate regional jets were involved in a disproportionate number of the incursions, both in total and in terms of the rate of incursions per landing. This was likely due to foreign flight crews being unfamiliar

with the uncommon taxiway layout between the parallel runways at CYYZ and to the increased speed at which their smaller aircraft types often approached the runway holding positions.

It is for these reasons that some foreign flight crews did not anticipate the location of the stopping position on each RET and so did not direct their attention outside the aircraft at the required time to identify the visual cues indicating the runway holding positions.

Most of the flight crews were aware of the south complex areas at increased risk for runway incursions because they are designated as “hot spots” on the airport charts supplied to crews. However, that guidance, together with limitations in operators’ requirements for taxi briefings, did not bring crews’ attention to specific strategies to mitigate the risk of incursion. Instead, the crews followed their usual routines after exiting the landing runway and proceeded with their post-landing checks. The timing of those tasks distracted them at a point when limited time was available to recognize the visual cues requiring them to stop, and contributed to their overlooking those cues.

In the occurrences examined in this study, ATC recognized the incursions quickly and took appropriate actions that either caused the incurring aircraft to stop or reduced the severity of the consequences. As a result, most of the aircraft did not reach the inner runway surface. Of the 3 that did reach the surface, 2 were at an intersection beyond the point at which the departing aircraft presented a risk of collision. In the 3rd case, ATC cancelled the takeoff clearance for the departing aircraft before it began its take-off roll.

In another occurrence, ATC instructed the incurring aircraft to stop before it had reached the runway surface, then immediately told the departing aircraft to abort its takeoff. The crew of the departing flight did not recognize the instruction to abort because the phraseology was unfamiliar and because it was not repeated as they were used to; as a result, they continued their departure. The incurring aircraft stopped before reaching the runway surface, and the departing aircraft overflew the intersection without further event.

International guidance for the prevention of runway incursions recommends that, once areas presenting a hazard of incursion have been identified, strategies to manage or mitigate that risk should be implemented and should include awareness campaigns, additional visual aids, alternate routings, or, ultimately, the construction of new taxiways.

Various awareness campaigns and advisories have been issued since 2012, and visual aids have undergone progressive but significant improvements. Those strategies have likely resulted in periodic, but not permanent, reductions in the incidence of incursions.

Revising the post-landing procedures of flight crews may lead to increased vigilance and reduced distraction, but it is unlikely to eliminate crews’ expectations that visual cues will be situated in common locations or induce crews to reduce their taxiing speeds so that they have more time to recognize the cues.

All but one of the applicable strategies recommended by international guidance have been implemented on the south complex; the remaining strategy is to make physical changes to the taxiway layout. A change of this scale may be required to increase the distance and taxiing time between runway holding positions, reduce the taxiing speeds of aircraft approaching hold-short locations, and prevent direct access to adjacent runways from RETs. Among the possible reconfigurations for achieving these objectives is the addition of an intermediate taxiway between the runways and parallel to them, as found at numerous airports with parallel runways, and the re-situating of visual cues in common locations.

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1.0 FACTUAL INFORMATION

1.1 Purpose

1.1.1 What is a safety issue investigation?

In its mission to advance transportation safety, the Transportation Safety Board of Canada (TSB) investigates occurrences to determine their causes and contributing factors, identifies safety deficiencies, and makes recommendations to reduce or eliminate those deficiencies.

When there have been a number of occurrences with common characteristics under similar circumstances, this may indicate that their underlying causes or contributing factors are systemic in nature. Such occurrences can be combined in a single investigation rather than examined in separate investigations.

The TSB's Policy on Occurrence Classification refers to this type of investigation as a safety issue investigation (SII), which is initiated when a TSB assessment indicates a significant safety issue that is systemic in nature.

1.1.2 Runway incursions

According to the International Civil Aviation Organization (ICAO), a runway incursion is "[a]ny occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and takeoff of aircraft."[1]

ICAO uses a system with 5 categories to classify the severity of runway incursions (Table 1).

---

1 International Civil Aviation Organization, Doc 9870 AN/463, *Manual on the Prevention of Runway Incursions*, First Edition (2007), Chapter 1, Section 1.1, p. 1-1.

Table 1. ICAO classification of the severity of runway incursions (Source: International Civil Aviation Organization, Doc 9870 AN/463, Manual on the Prevention of Runway Incursions, First Edition [2007], Chapter 6, Table 6-1)

Severity classification	Description*
A	A serious incident in which a collision is narrowly avoided.
B	An incident in which separation decreases and there is significant potential for collision, which may result in a time-critical corrective/evasive response to avoid a collision.
C	An incident characterized by ample time and/or distance to avoid a collision.
D	An incident that meets the definition of runway incursion, such as the incorrect presence of a single vehicle, person, or aircraft on the protected area of a surface designated for the landing and takeoff of aircraft but with no immediate safety consequences.
E	Insufficient information or inconclusive or conflicting evidence precludes a severity assessment.

* Refer to ICAO Annex 13 to the Convention on International Civil Aviation for ICAO's definition of "incident" and "serious incident."

1.1.3 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.

The risk of collisions from runway incursions is a 2018 Watchlist issue, and the TSB has completed 10 investigations[2] into runway incursions since this issue was first added to the Watchlist in 2010. 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.

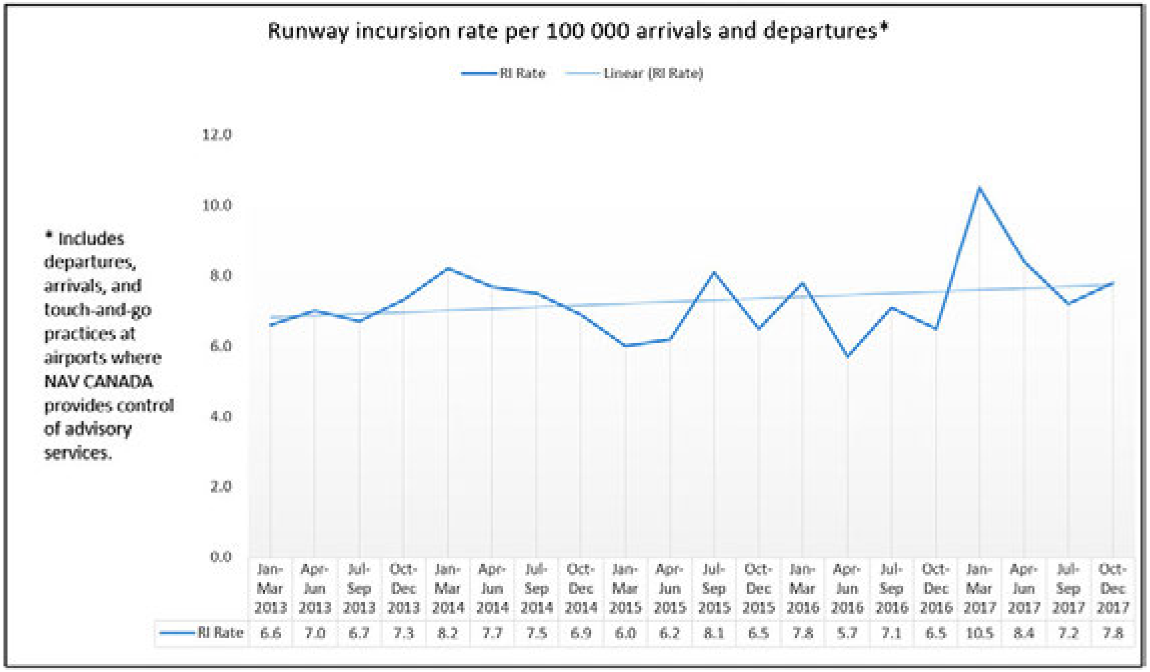
Risk of collisions from runway incursions will remain on the TSB Watchlist until

- the rate of runway incursions, particularly the most severe ones, demonstrates a sustained reduction;
- Transport Canada and all sectors of the aviation industry continue to collaborate and develop tailored solutions to identified hazards at Canadian airports (e.g., improvements in air traffic control procedures, surveillance and warning systems, runway and taxiway designs, holding position visual aids, and flight crew training and procedures); and
- modern technical solutions, such as in-cockpit electronic situational awareness aids, and direct-to-pilot warnings, such as runway status lights, are implemented.

From 2013 to 2017, NAV CANADA recorded an average of 445 runway incursions in Canada each year (Figure 1). The incursion rate gradually increased from 6.6 to 7.8 incursions per 100 000 arrivals and departures over this period.

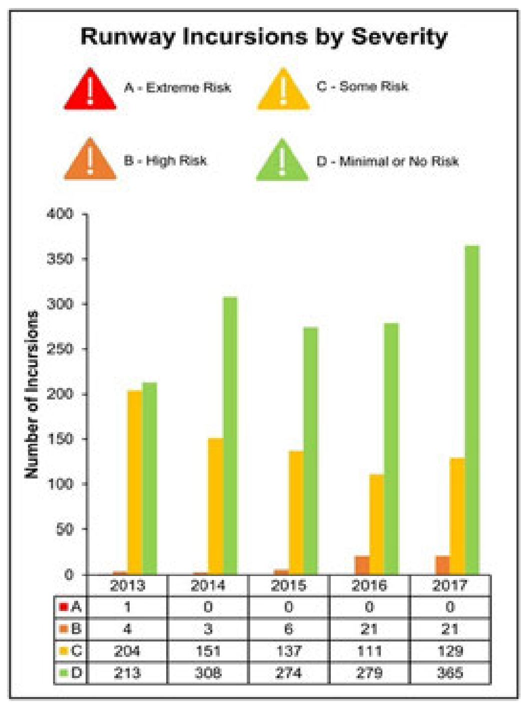
[2] TSB aviation investigation reports A10W0040, A11Q0170, A13H0003, A13O0045, A13O0049, A14C0112, A14H0002, A14W0046, A16O0016, and A16W0170.

Figure 1. Runway incursion per aircraft movement in Canada, defined as arrivals, departures, and touch-and-go practices at airports where NAV CANADA provides control or advisory services (Source: NAV CANADA)



While the majority of these incursions posed little to no risk, there were 21 high-severity (Category B) events in each of the past 2 years (Figure 2). These could have led to a collision with other aircraft, damage, injuries, or death.

Figure 2. Runway incursions in Canada from 2013 to 2017, categorized classified by according to severity (Source: NAV CANADA)



Runway incursions are also a global concern. ICAO's 2017 Global Runway Safety Action Plan notes that "[a]lthough the number of runway incursion accidents reported between the period of 2008 to 2016 is very low, the number of runway incursion incidents remains high […]."[3]

The aviation industry has started addressing factors that can lead to runway incursions by implementing incremental improvements to policies, procedures, technologies, and infrastructure. For example, in Canada, in-cockpit aids to increase situational awareness, such as electronic flight bags with moving

3 International Civil Aviation Organization, *Runway Safety Programme – Global Runway Safety Action Plan*, First Edition (November 2017), p. 3.

maps, are becoming more prevalent. Despite these improvements, there has been an 18% increase in the overall rate of runway incursions from 2013 to 2017.

The Board is concerned that the rate of runway incursions in Canada and the associated risks of collision will remain until effective defences tailored to address previously identified hazards are implemented at airports and in aircraft, vehicles, and air traffic service facilities across Canada.

Transport Canada (TC) and all sectors of the aviation industry must continue to collaborate to identify these hazards and tailor specific solutions. These solutions could include improvements in air traffic control (ATC) procedures, surveillance and warning systems, runway and taxiway designs, holding-position visual aids, automated direct-to-pilot warnings, and flight crew training and procedures.

This issue will remain on the TSB Watchlist until the rate of runway incursions, particularly the most severe ones, demonstrates a sustained reduction.

1.2 Scope

In May 2017, the TSB identified the high incidence of incursions between 2 parallel runways on the south complex at Toronto/Lester B. Pearson International Airport (CYYZ), Ontario, as a source of concern. It initiated this investigation to identify the factors that have led to those incursions and to analyze current and potential new defences to prevent such occurrences.

The investigation was concerned solely with aircraft that landed on the outer runway, exited on one of the rapid exit taxiways (RETs), and did not hold short of the inner runway at the designated holding position. These incursions were deemed to pose the highest risk of collision between aircraft. Data from June 2012 to November 2017 were examined.[4] Runway incursions by anything other than aircraft, and those involving any other locations on the airfield, were excluded.

This report is intended for the aviation industry as a whole and, in particular, for those involved in operations at CYYZ.

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[4] It was decided to use June 2012 as the starting point for this investigation because the incursions that occurred before that date had been the subject of investigations conducted by outside organizations.

1.3 Background

1.3.1 Previous studies

1.3.1.1 Greater Toronto Airports Authority investigation in 2012

In March 2012, following a runway incursion[5] in November 2011, the Greater Toronto Airports Authority (GTAA) completed a safety management system (SMS) investigation report.[6] The scope of the investigation included root-cause analysis of several runway incursions on the south complex at CYYZ by aircraft operated by regional airlines based in the U.S.

The GTAA report identified several causal factors related to disparities among Canadian, U.S., and international guidance, including differences in recommended ground markings and signage, and the recommended displacement distance of runway holding positions from the runway edge. The report also concluded that the likelihood of incursions was increased by the absence of an intermediate taxiway between the parallel runways—a feature at most U.S. airports with similar runways.

The report made several recommendations to modify the lights, marking, and signage to increase the conspicuity of these defences, and to change airport charts to alert crews to the hazard.

1.3.1.2 NAV CANADA operations safety investigation in 2012

Following the November 2011 runway incursion and a similar incident[7] in December 2011, NAV CANADA began its own safety investigation into the issue. Its operations safety investigation report[8] on that study, published in June 2012, reviewed the history of runway incursions on the south complex at CYYZ since the parallel runways became operational.

The report identified 40 occurrences that had taken place between 01 September 2002 and 13 January 2012 and that fell into one of 5 categories:

- The failure of an aircraft to hold short of the inner runway after landing on the outer runway (incursion of inner runway).

---

5 TSB Aviation Occurrence A11O0218.

6 Greater Toronto Airports Authority, South Complex Runway Incursions – Level 3 – SMS Investigation (Toronto: 31 March 2012).

7 This event was not recorded in the TSB database, as it did not meet the TSB's definition of a reportable incident.

8 NAV CANADA, Operations Safety Investigation Report: Report of the Safety Investigation on Runway Incursions Involving the Toronto/Lester B. Pearson International Airport South Complex (June 2012).

> - The failure of an aircraft to exit the outer landing runway on [*sic*] a timely manner due to possible traffic congestion between the two runways (blocking outer runway); and. [*sic*]
> - ATC failure to protect the runway protected area of the inner runway, following the landing of an aircraft on the outer runway (inner runway not protected).
>
>   […]
> - "Other South Complex": Do not meet the criteria described, but involve operations on the 24/06s.
> - "Rolling inner runway without clearance:" Although there was only one instance, a separate category was created since it did not meet the definition of "incursion of inner runway" but resulted in the same outcome (i.e. an aircraft crossing with an aircraft on the takeoff roll).[9]

Half of those 40 occurrences fell into the 1st category, involving incursion of the inner runway. Of those 20, 14 involved U.S. regional carriers, 3 involved Canadian regional carriers, and 3 involved U.S. mainline carriers. The investigation report concluded with numerous findings that were specific to the regulator, air operators, the airport operator, or NAV CANADA itself.

The report noted that TC's *Aerodrome Standards and Recommended Practices*[10] (TP 312) recommends that frequently used runway holding positions be located 115 m (377 feet) from the runway centreline, which is not the common placement of hold lines in the U.S. The report also noted that the guidance allows for lighting and signage that differ from those used in the U.S. It found that air operators were unfamiliar with stop-bar usage in good weather conditions and did not have procedures in place to review hot spots[11] during briefings or tools for remembering hold-short instructions. NAV CANADA also found that ground radar alerts were ineffective and that warnings indicated on airport charts and broadcast on the automatic terminal information service (ATIS)[12] were insufficient.

With regard to the GTAA, NAV CANADA found that some visual cues in the form of ground markings and lit signage, although compliant with TP 312, had contributed to the occurrences. It also found the following:

> The configuration of the high speed taxiways has been identified as a contributing factor to runway incursions on 06L/24R. The high speed taxiways consisted of a straight section at an oblique angle to both runways, followed by a turn to place the aircraft perpendicular to the runway. As such, an aircraft exiting the south runway was not aligned with the hold short lighting and markings until they made the turn

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9 Ibid., p. 10.

10 Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 4th Edition (revised March 2005).

11 A hot spot is a "location on an airport movement area with a history of potential risk of collision or runway incursion, and where heightened attention by pilots/drivers is necessary." (Source: International Civil Aviation Organization, Doc 9870 AN/463, *Manual on the Prevention of Runway Incursions*, First Edition [2007], Glossary.)

12 See section 1.6.5.3 for more information on the automatic terminal information system (ATIS).

> at which time they were very close to the Stop Bar. In the event the crews were not anticipating the location of the stop line, they may not have had time to stop by the time the markings were observed.
>
> The oblique angle was identified by the GTAA as a possible issue increasing the pilot's challenge in seeing the Runway Guard Lights and Stop Bars from the outer runway exit perspective. As a result, the GTAA has reoriented the Runway Guard Light direction to make them more visible from the outer runway exit; however, Stop Bar positions remained unchanged. In addition, the oblique angle can also result in aircraft holding short of the inner runway in a position that is not perpendicular to the runway, which may have increased difficulty for pilots to observe departing traffic from the inner runway.[13]

1.3.1.3 Changes implemented as a result of previous studies

In response to the findings of its own investigation and that of NAV CANADA, the GTAA developed an action plan for addressing the safety issues identified. Under this plan, it undertook numerous physical and administrative enhancements aimed at risk mitigation. Those improvements, implemented in 2012 and 2013, included

- enhanced taxiway centreline markings;
- enhanced runway holding position markings that extend into the taxiway shoulders;
- painted mandatory hold signs;
- reorientation of the runway guard lights;
- addition to airport charts of a page dedicated to south complex hot spots;
- distribution of advisories to all applicable carriers regarding the hazard of incursions in the area;
- improvements to internal incursion investigation protocols; and
- continued development of the local runway safety team (LRST),[14] with participation from third parties.

At the same time, NAV CANADA began to modernize its ground surveillance system and associated alerts and alarms. Although these upgrades did not result solely from the south complex runway incursions, they were considered an effective means of addressing the risks specific to ATC identified by NAV CANADA.

For a 20-month period following the implementation of the full range of changes in 2013, the number of runway incursions on the south complex decreased; however, this decrease was not permanent, and in 2015 the number began to increase again.

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13 NAV CANADA, Operations Safety Investigation Report: Report of the Safety Investigation on Runway Incursions Involving the Toronto/Lester B. Pearson International Airport South Complex (June 2012), p. 34.

14 ICAO defines a local runway safety team as a "team comprised of representatives from aerodrome operations, air traffic services providers, airlines or aircraft operators, pilot and air traffic controllers associations and any other group with a direct involvement in runway operations that advise the appropriate management on the potential runway incursion issues and recommend mitigation strategies." (Source: International Civil Aviation Organization, Doc 9870 AN/463, *Manual on the Prevention of Runway Incursions*, First Edition (2007), Glossary.)

1.4 Incursions examined in this investigation

Data were gathered from the TSB's Aviation Safety Information System (ASIS), TC's Civil Aviation Daily Occurrence Reporting System (CADORS), NAV CANADA's Aviation Occurrence Reporting System, and the SMS records of several air operators for the period encompassed by this investigation (12 June 2012 to 12 November 2017). This period was selected to include all relevant events between the date of the last incursion studied by the previous 2 external investigations and the drafting of this investigation report. It was determined that, during this period, there were 107 runway incursions in total at CYYZ. Of these incursions, 27 occurred between the parallel runways on the south complex and are the focus of this SII (Table 2).

Table 2. Runway incursions examined in this investigation

Date	Day or night	Intersection	Aircraft type	Country of operator
2012-06-12	Day	D4	B737-700	Canada
2012-07-12	Day	Uncertain*	B737-800	U.S.
2012-07	Uncertain	D4	CRJ-100/200	U.S.
2012-08	Night	D3	CRJ-900	U.S.
2012-11-27	Night	D2	CRJ-100/200	U.S.
2012-11-29	Night	D4	DHC-8-400	Canada
2012-12-19	Night	D4	A320	U.S.
2013-03-27	Day	D4	CRJ-700	U.S.
2013-04-02	Day	D6	CRJ-900	U.S.
2013-06-03	Day	D4	CRJ-100/200	U.S.
2013-06	Uncertain	D4	CRJ-100/200	U.S.
2013-07-25	Day	D6	B767-300	Canada
2013-09-02	Day	D6	CRJ-700	U.S.
2013-12-13	Night	D5	CRJ-900	Canada
2014-07	Uncertain	D4	CRJ-100/200	U.S.
2015-07	Uncertain	D4	CRJ-900	U.S.
2015-08-02	Day	D4	CRJ-900	U.S.
2015-12-04	Night	D4	ERJ-145	U.S.
2016-05-09	Day	D6	CRJ-900	U.S.
2016-06-13	Day	D5	CRJ-900	U.S.
2016-08-16	Day	D4	CRJ-900	U.S.
2017-03-22	Day	D3	CRJ-700	U.S.
2017-04-20	Day	D3	ERJ-145	U.S.
2017-06-20	Day	D4	ERJ-170	U.S.
2017-08-08	Day	D4	ERJ-175	U.S.

Date	Day or night	Intersection	Aircraft type	Country of operator
2017-08-14	Day	D6	ERJ-170	U.S.
2017-11-17	Night	D6	B767-300	Canada

* Some specific details of individual occurrences remain uncertain because they were not recorded during the initial investigation of those occurrences and they could not be determined with certainty after the fact.

1.4.1 Available data and common characteristics

The extent of available data on the 27 occurrences varied considerably. Some events had not been initially reported to the TSB. Others had been reported through other systems but were not recorded in the TSB database because they were assessed as non-reportable. Some that were reported and recorded had only limited data because they were initially assessed as Class 5 occurrences.[15]

Since an occurrence involving a CRJ-900 aircraft on 02 August 2015, significantly more data on each occurrence has been gathered. As a result, the SII had substantial data on the 11 events that occurred after that date, and limited or variable data for the 16 preceding events.

An analysis was conducted to identify common characteristics from the data available on all occurrences.

1.4.1.1 Known data: All occurrences

A review of the available data on all 27 occurrences established the following common characteristics:

- The majority of the air operators (20) involved were U.S.-based regional carriers.
- The majority of the aircraft involved were regional jets:
  - 16 were Bombardier CRJ 100/200/700/900 aircraft, and
  - 5 were Embraer ERJ 170/175[16] or ERJ 135/145 aircraft.
- The majority of the events (16) occurred during daylight hours.
- The most common location (14) of the incursions was RET D4.

1.4.1.2 Known data: 11 most recent occurrences

The data available to this investigation for the 11 most recent occurrences were more complete, and included information gathered from ATC radar and audio recordings, personnel interviews, and, in some cases, cockpit voice recorders or flight data recorders.

Unless otherwise stated, the remainder of this report focuses on these 11 most recent occurrences.

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15 A Class 5 occurrence is limited to data gathering, and the data are recorded for statistical reporting and future analysis.

16 ERJ 170/175 aircraft are often used in both mainline and regional operations; in the occurrences considered here, they were operated in a regional role.

A review of this subset of data determined that the following factors were common to most or all of the 11 occurrences:

- **Most of the occurrences involved U.S.-based regional jets**. Ten of the 11 occurrences involved a U.S.-based regional carrier, flying regional jets such as CRJs and ERJs.
- **The visibility was good.** In all cases, the visibility at the time of the occurrence was equal to or greater than 15 statute miles.
- **Hold-short instructions were issued and acknowledged.** During the landing roll in each case, ATC issued clear instructions to the flight crew involved to hold short of the inner runway, and the flight crew read back the instructions correctly.
- **The flight crews were aware that they were approaching a runway and needed to stop.** In all cases, both crew members understood exactly which exit they were on and that the aircraft was approaching an active runway and had to stop.
- **The attention of 1 or both of the flight crew members was briefly diverted.** In 10 of the 11 cases, the attention of at least 1 crew member was partially diverted when approaching the runway holding position, usually while completing post-landing tasks or checklists. For the most part, the first officer began the post-landing tasks once clear of the landing runway.
- **The flight crews did not recognize the runway holding position.** In 10 of the 11 cases, the flight crew reported that they had crossed a painted line but thought that the line they had crossed was the runway holding position for exiting the landing runway. None of the crews that crossed the line believed that they had been cleared to cross the runway.
- **The stop-bar lights were illuminated.** On the ground radar video recordings, the status of the stop-bar lights was recorded as a displayed red line. The recordings showed that, in every case, the lights had been on.
- **None of the crews recalled seeing the lit stop-bar lights.** Although the lights had been on in each case, no crews recalled seeing the stop-bar lights, and most crews were not aware that stop-bar lights were installed at these locations.[17]
- **Once the aircraft had crossed the line, ATC ordered the aircraft to stop.** In 9 of the 11 cases, ATC instructed the incurring aircraft to stop. In the other 2 cases, controllers considered that the departing aircraft was no longer a threat, so no instruction to stop was issued.
- **The stop-bar overrun alarm sounded in the tower.** In 10 of the 11 cases, the stop-bar overrun alarm sounded in the tower. In the other case, the aircraft did not travel far enough across the line to trigger the alarm.
- **Most aircraft stopped before entering the runway surface.** In 8 of the 11 cases, the taxiing aircraft that had incurred on the runway protected area stopped after

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[17] The stop bars are graphically depicted on the low-visibility taxi chart in flight crew chart publications; however, flight crews do not usually include this particular chart in briefings during operations in good visibility.

being instructed by ATC to do so and before the nose of the aircraft entered the main runway surface.

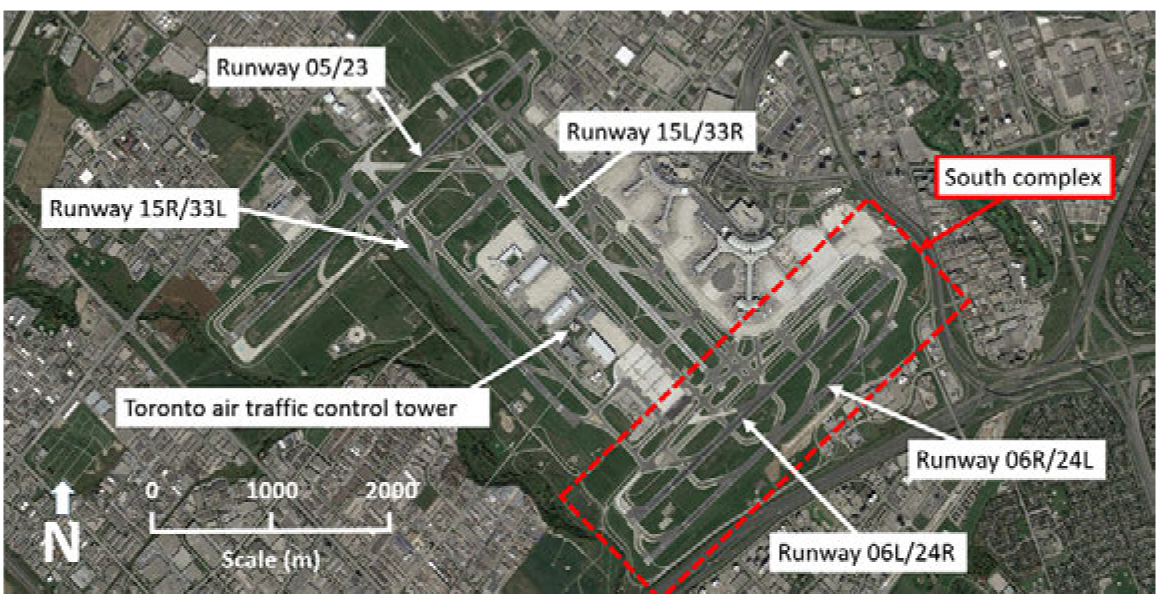
The review of the 11 events also revealed some rare, but significant, incidents:

- **Some aircraft entered the runway surface.** In 3 cases, the taxiing aircraft entered the runway surface before coming to a stop—twice at the intersection with RET D4 and once at RET D3.
- **One departing aircraft was instructed to abort takeoff.** The aircraft, which was accelerating through 80 knots, was issued an abort-takeoff instruction by ATC. The ATC instruction was not actioned by the flight crew.
- **One departing aircraft's take-off clearance was cancelled.** The crew, who had previously been issued a clearance to take off, were instructed to stop before beginning the take-off roll.
- **One arriving aircraft executed a missed approach.** The aircraft was on final approach to the inner runway (Runway 24R) when an aircraft that had landed on Runway 24L incurred on Runway 24R. ATC instructed the arriving aircraft to perform a side-step manoeuvre to Runway 24L, but the crew performed a go-around instead.

1.5 Aerodrome

CYYZ has 5 runways: 2 oriented north–south and 3, east–west. The preferred runways are the east–west parallel runways, which include Runway 05/23, located on the north side of the airport, and runways 06L/24R and 06R/24L, located on the south side. The 2 runways on the south side, together with the nearby taxiways, are referred to as the "south complex" (Figure 3).

Figure 3. Aerial view of CYYZ and the south complex (Source: Google Earth, with TSB annotations)



The south complex runways are spaced 305 m (1000 feet) apart, from centreline to centreline. Each is served by multiple RETs. The acute-angled RETs allow landing aircraft to exit these runways at greater speeds than do perpendicular exits, which in turn reduces runway occupancy times.

Certified in 2002, Runway 06L/24R was designed following the requirements laid out in the edition of TP 312 that was current at the time (4th edition, 01 March 1993). TP 312 was significantly updated in 2015 and re-issued as the 5th edition. In accordance with TC's Advisory Circular No. 302-018 on grandfathering at airports pursuant to *Canadian Aviation Regulations* section 302.07, Runway 06L/24R is required to maintain only those standards set out in the 4th edition, unless major modifications are required, such as reconstruction of the runway or replacement of lighting systems.[18]

1.5.1 High-capacity operations

During periods of high-volume traffic, all 3 east–west runways are used; this is referred to as triple-runway operations. Runways 05/23 and 06R/24L are used for arrivals at these times, and runways 05/23 and 06L/24R, for departures. Aircraft landing on Runway 06R/24L are required to exit the runway via one of the RETs (D1 through D7) and to hold short of the inner runway (06L/24R) (Figure 4).

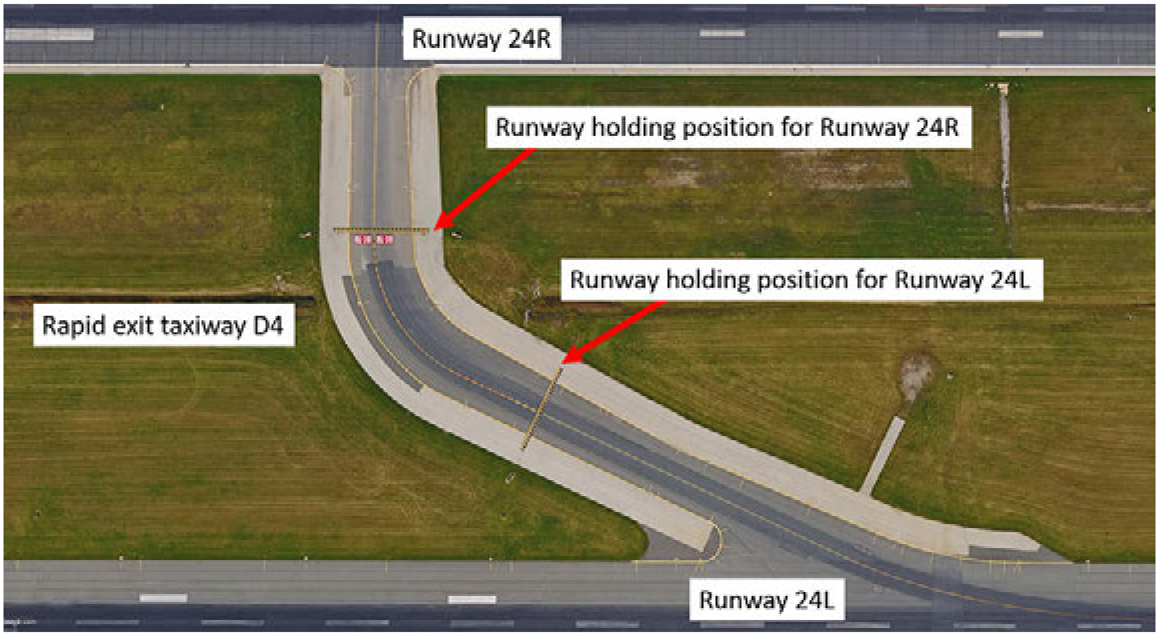
18 Transport Canada, Advisory Circular No. 302-18, Grandfathering at Airports Pursuant to *Canadian Aviation Regulation* (CAR) 302.07 (Issue 01: 27 November 2014).

Figure 4. CYYZ's south complex runways and rapid exit taxiways (Source: Google Earth, with TSB annotations)

1.5.2 Rapid exit taxiway geometry

Each RET between the parallel runways has 2 runway holding positions: 1 designating the protected area for Runway 06R/24L (normally the landing runway) and 1 for the protected area for Runway 06L/24R (normally the departure runway). Each position is designated by markings, lighting, and signage (Figure 5).

Figure 5. The runway holding positions on rapid exit taxiway D4 (Source: Google Earth, with TSB annotations)



1.5.2.1 Initial turn and straight section

The RETs used to exit Runway 06R/24L are at a 25° angle to the runway, then curve a further 65° to intersect the adjacent parallel runway at a 90° angle. Because aircraft can round shallower curves at higher speeds, the acute angle and large radius of the initial turn theoretically allow initial exit speeds of up to 50 knots.

Following the initial turn onto the RET, there is a straight section intended to enable the aircraft to reduce speed. This section is approximately 219 m (720 feet) long on RETs D1, D2, D3, D4, and D5, and 134 m (440 feet) long on RET D6. RET D7 is not commonly used.

The 4th edition of TP 312 recommended the following:

> A rapid exit taxiway should include a straight distance after the turn–off curve sufficient for an exiting aircraft to come to a full stop clear of any intersecting taxiway.[19]

Although TP 312 does not specify the distance that is considered sufficient, the ICAO *Aerodrome Design Manual* recommends a minimum of 75 m (246 feet) for this type of RET.[20]

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19 Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 4th Edition (revised March 2005), section 3.4.5.3.

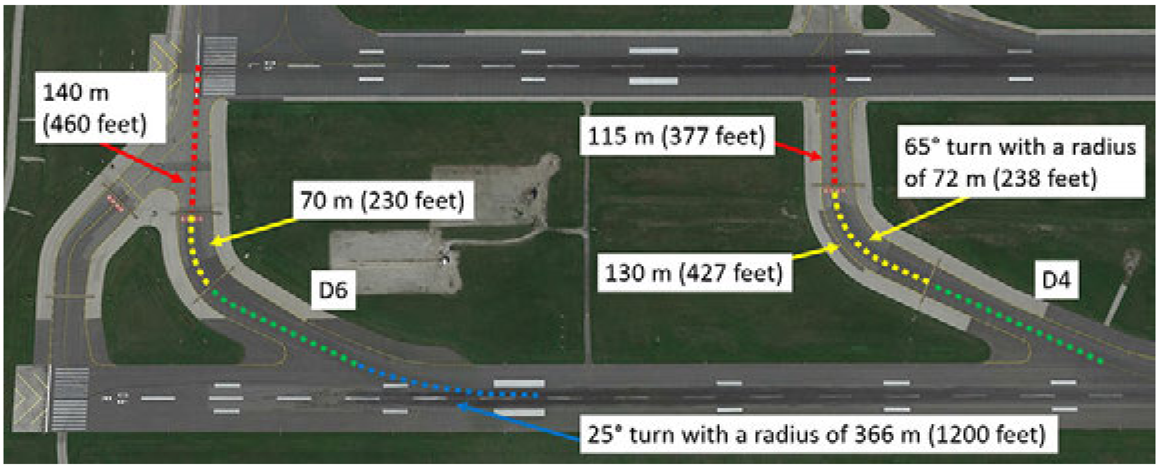
20 International Civil Aviation Organization, Doc 9157 AN/901, *Aerodrome Design Manual*, Part 2 – Taxiways, Aprons and Holding Bays, Fourth Edition (2005), section 1.3.19.

1.5.2.2 Direct access following the 2nd turn

Following the straight section of each RET is a 65° curve with a radius of 72 m (238 feet). On each RET, except D7, the runway holding position for Runway 06L/24R is situated immediately following the completion of that curve.

The overall distance from the exiting runway holding position (for Runway 06R/24L) to the runway holding position for the adjacent runway (Runway 06L/24R) is 130 m (427 feet) on RETs D1, D2, D3, D4, and D5, but is reduced to 70 m (230 feet) on RET D6 (Figure 6).

Figure 6. Distances on the rapid exit taxiways of Runway 06L/24R that have direct access to the adjacent runway (Source: Google Earth, with TSB annotations)



Neither TP 312 nor ICAO's Annex 14 to the *Convention on International Civil Aviation*[21] provides restrictions or recommendations for a minimum distance between runway holding positions on RETs. Furthermore, neither document sets out any restriction on direct access from one runway to another without an intermediate, transitional taxiway. By contrast, a comparable document published by the U.S. Federal Aviation Administration (FAA) instructs as follows: "Do not provide direct access from a high speed exit [i.e., a RET] to another runway."[22]

In the November 2017 version of the *European Action Plan for the Prevention of Runway Incursions*, the European Organisation for the Safety of Air Navigation (EUROCONTROL)[23] makes a similar recommendation: "A RET should meet with a parallel taxiway, and never end directly onto another active runway (that is used for take-off/landing)."[24]

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21 International Civil Aviation Organization, Annex 14 to the Convention on International Civil Aviation, Volume I – *Aerodrome Design and Operations*, Seventh Edition (July 2016).

22 U.S. Federal Aviation Administration, Advisory Circular 150/5300-13A: Airport Design (26 February 2014), p. 143, paragraph 409 b.

23 The European Organisation for the Safety of Air Navigation (EUROCONTROL) is a civil–military organization that provides support to air traffic operations across Europe.

24 European Organisation for the Safety of Air Navigation, *European Action Plan for the Prevention of Runway Incursions*, Version 3.0 (20 November 2017), p. 123.

1.5.2.3 Runway holding position distance from runway

RETs D1, D2, D3, D4, and D5 have runway holding positions protecting Runway 06L/24R at a distance of 115 m (377 feet) from the centreline of the runway. The runway holding position on RET D6 is farther than the others, at 140 m (459 feet), and on RET D7, which is used infrequently, it is farther still, at 154 m (505 feet).

The runway holding position on RET D6 was situated at 140 m (459 feet) so that aircraft would not interfere with signal propagation of the glideslope that serves the category II/III instrument landing system approach to Runway 06L.

The 4th edition of TP 312, which outlined the standards for runway design when Runway 06L/24R was certified, provided both minimum standards and recommendations. While the standard required that the runway holding position be situated a minimum of 90 m (295 feet) from the runway centreline, the recommendation stated:

> Where a taxiway/runway intersection occurs at other than the runway threshold and aircraft hold for the purpose of crossing the runway on a frequent or recurring basis, the distance between the taxi-holding position and the centre line of the runway should be increased to be not less than the appropriate dimensions specified in Table 3–3.[25]

The minimum distance specified in Table 3-3, cited above, was 115 m (377 feet) for the type of aircraft operations at CYYZ.

In the 5th edition of TP 312, the recommendation of 115 m (377 feet), along with all other recommendations, was removed, as the document was adapted to be a standards-only resource. The newer standard calls for a minimum of 90 m (295 feet),[26] and that standard is reflected in ICAO's Annex 14.[27]

The U.S. standard requires[28] a minimum of 280 feet (85 m); for runways that accommodate only narrow-body and smaller aircraft, the minimum is 250 feet (76 m) (Figure 7).

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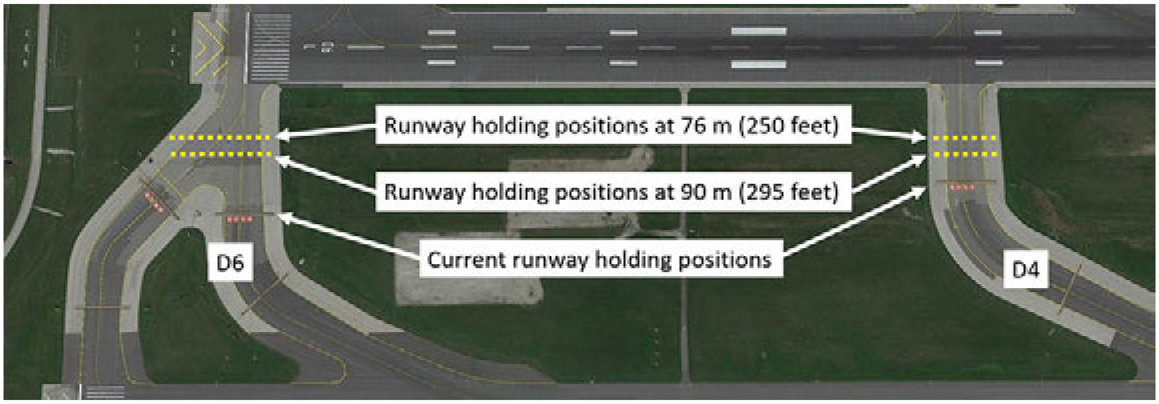
25 Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 4th Edition (revised March 2005), section 3.5.2.3.

26 Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 5th Edition (effective date 15 September 2015), section 3.6.1.3.

27 International Civil Aviation Organization, Annex 14 to the Convention on International Civil Aviation, Volume I – *Aerodrome Design and Operations*, Seventh Edition (July 2016), Table 3-2.

28 U.S. Federal Aviation Administration, Advisory Circular 150/5300-13A: Airport Design (26 February 2014), Table 3-5.

Figure 7. Comparison of the distances of the current runway holding positions from the Runway 06L/24R centreline with distances that correspond to the U.S. standard of 250 feet (76 m) and the standard in the 5th edition of TP 312 of 90 m (295 feet). (Source: Google Earth, with TSB annotations



As the taxiways are currently configured, 3 of the 11 aircraft in the 11 most recent occurrences reached the runway surface (Table 3, column 4). The TSB re-calculated the stopping position of the aircraft assuming that the holding positions were located at 90 m rather than the current 115 m and that the aircraft crews did not see the 90 m holding position. Given these assumptions, 6 of the 11 aircraft would have reached the runway surface (Table 3, column 5). Thus, the aircraft that incurred on the runway and were instructed to stop by ATC in fact stopped further from the inner runway surface than they might have if the holding position had been located at 90 m.

Table 3. Distance from runway edge, after stopping, of the aircraft in the 11 runway incursion occurrences examined by the TSB

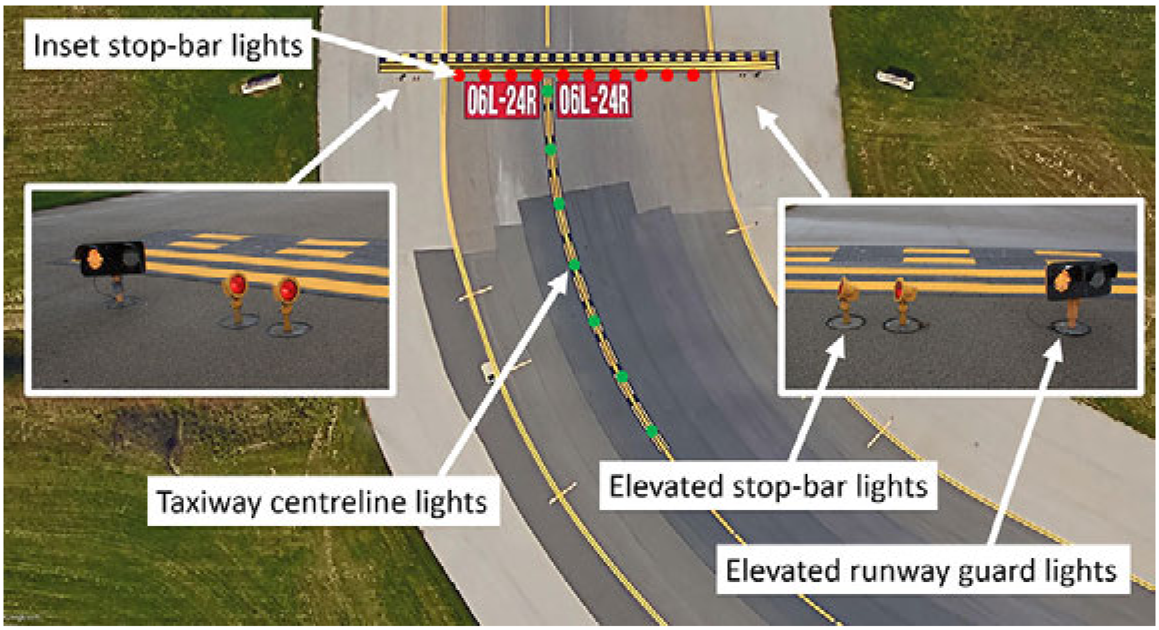
Date	RET	Runway surface	Actual stopped distance from runway edge (feet) with holding positions at current locations (115 m or 140 m)	Projected stop distance from runway edge (feet) with runway holding positions relocated to 90 m	Assessed severity*
2015-08-02	D4	No	160	78	B
2015-12-04	D4	Yes	−20	−102	C
2016-05-09	D6	No	150	−14	C
2016-06-13	D5	No	135	53	B
2016-08-16	D4	No	200	118	C
2017-03-22	D3	Yes	−80	−162	B
2017-04-20	D3	No	30	−52	B
2017-06-20	D4	Yes	0	−82	C
2017-08-08	D4	No	170	88	C
2017-08-14	D6	No	340	176	C
2017-11-17	D6	No	160	–4	C

* The TSB made these assessments using ICAO's severity classification system (see section 1.3.2).

1.5.3 Lighting

All of the RETs between the parallel runways and their associated runway holding positions are equipped with identical lighting. This lighting system is more complex than lighting systems used on a typical runway, as Runway 06L/24R is certified for category III operations in poor weather conditions. The lighting at each runway holding position consists of elevated runway guard lights, inset stop-bar lights, supplemental elevated stop-bar lights, and taxiway centreline lights (Figure 8). The purpose of these lights is to draw attention to the runway holding positions.

Figure 8. Current lighting at the runway holding positions of rapid exit taxiways at Runway 06L/24R (Source: Google Earth, with TSB annotations [green and red dots added for contrast])



1.5.3.1 Elevated runway guard lights

A set of elevated runway guard lights is located at each runway holding position. Commonly referred to as wig wags, these lights are composed of a raised unit on each side of the taxiway that contains 2 yellow, unidirectional lights side by side that illuminate alternately. Since modifications were made to the runway environment in 2012 and 2013, these runway guard lights have been pointed toward a position on the RET where they are visible to the flight crew while an aircraft is on the straight portion of the exit.

1.5.3.2 Stop-bar lighting

Each runway holding position has inset stop-bar lights—unidirectional red lights spaced evenly across the taxiway and set into the pavement. Supplemental elevated stop-bar lights, which are pairs of raised red lights, are located on each end. The spacing, beam spread, directional orientation, and intensity of the stop-bar lights meet the specifications set out in the 4th edition of TP 312.[29]

1.5.3.2.1 Spacing

The inset stop-bar light fixtures are evenly spaced 3 m (10 feet) apart across the taxiway just before the runway holding position markings. When they were originally installed, the standard in the 4th edition of TP 312 required that spacing be exactly 3 m (10 feet)[30]; however, the 5th edition has altered this, and now requires that "[s]top bars consist of lights spaced at uniform intervals not exceeding 3 m across the runway-holding position."[31]

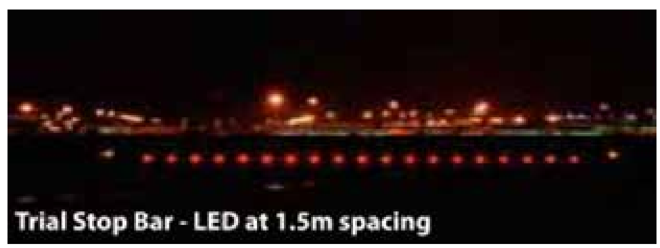
Changes to ICAO's Annex 14, which were first implemented in 2013 and have remained in subsequent editions, mirror this revision. The current version of Annex 14 states:

> Stop bars shall consist of lights spaced at uniform intervals of no more than 3 m across the taxiway […].
>
> *Note.—Where necessary to enhance conspicuity of an existing stop bar, extra lights are installed uniformly.*[32]

Some airports in other countries have adjusted to the newer guidance and have installed stop-bar lights spaced at intervals of 1.5 m (5 feet). This has safety advantages: "In conjunction with the increasing use of LED [light-emitting diode] filaments, a distance of 1.5m [5 feet] has been shown to greatly increase the visibility of the stop bars in all light conditions"[33] (Figure 9 and Figure 10).

Figure 9. ICAO standard stop-bar light spacing (Source: EUROCONTROL, Hindsight 19 [2014], p. 18)

Figure 10. Reduced stop-bar light spacing with LED lights (Source: EUROCONTROL, Hindsight 19 [2014], p. 18)



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[29] Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 4th Edition (revised March 2005).

[30] Ibid., section 5.3.18.5.

[31] Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 5th Edition (effective date 15 September 2015), section 5.3.23.9.

[32] International Civil Aviation Organization, Annex 14 to the Convention on International Civil Aviation, Volume I – *Aerodrome Design and Operations*, Seventh Edition (July 2016), section 5.3.20.6.

[33] European Organisation for the Safety of Air Navigation, "Request for support message: runway incursion prevention aerodrome stop bar operating policy," *Hindsight 19* (summer 2014), p. 18.

1.5.3.2.2 Beam spread and directional orientation

The 4th edition of TP 312 required that the main beam of the inset stop-bar lights produce a minimum average intensity of 200 candelas (cd), with a beam spread of at least 10° horizontally on either side of the centre.[34] In addition, it specified that "where the light units are installed on curve sections, they shall be toed-in 15.75 degrees with respect to the tangent of the curve."[35] However, at CYYZ, the stop bars on RETs D1 through D7 are aimed parallel to the taxiway centreline, as they are located on a straight section just beyond a curve. The 4th edition of TP 312 contains no specific guidance on directional orientation for lights in this position.

The 5th edition of TP 312 contains updated guidance for this type of installation, requiring that these inset stop-bar lights be

> normally aimed parallel with the taxi centreline. However, for certain applications angular aiming may be necessary depending upon site requirements to facilitate viewing from the aircraft, such as in a curve.[36]

The manual further describes that this angular aiming should be the same as the aiming of inset runway guard lights,[37] which are normally installed in similar locations and for similar purposes. These in-pavement lights are required to be aimed 60 m to 90 m (197 feet to 295 feet) down the approaching taxiway (Figure 11).

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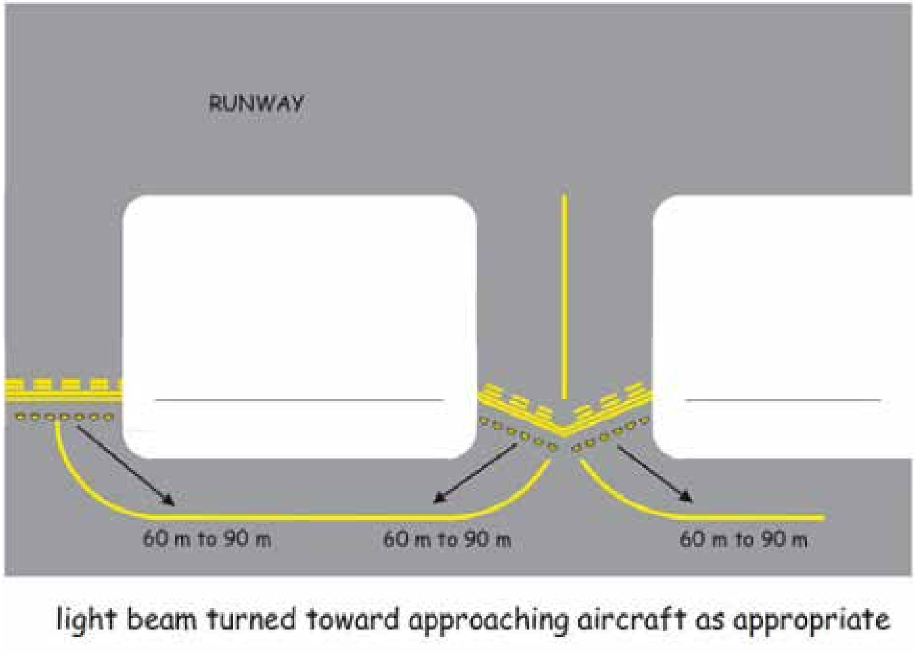
[34] Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 4th Edition (revised March 2005), Figure B-13.

[35] Ibid., section B.2.3.2.

[36] Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 5th Edition (effective date 15 September 2015), section 5.3.23.4.

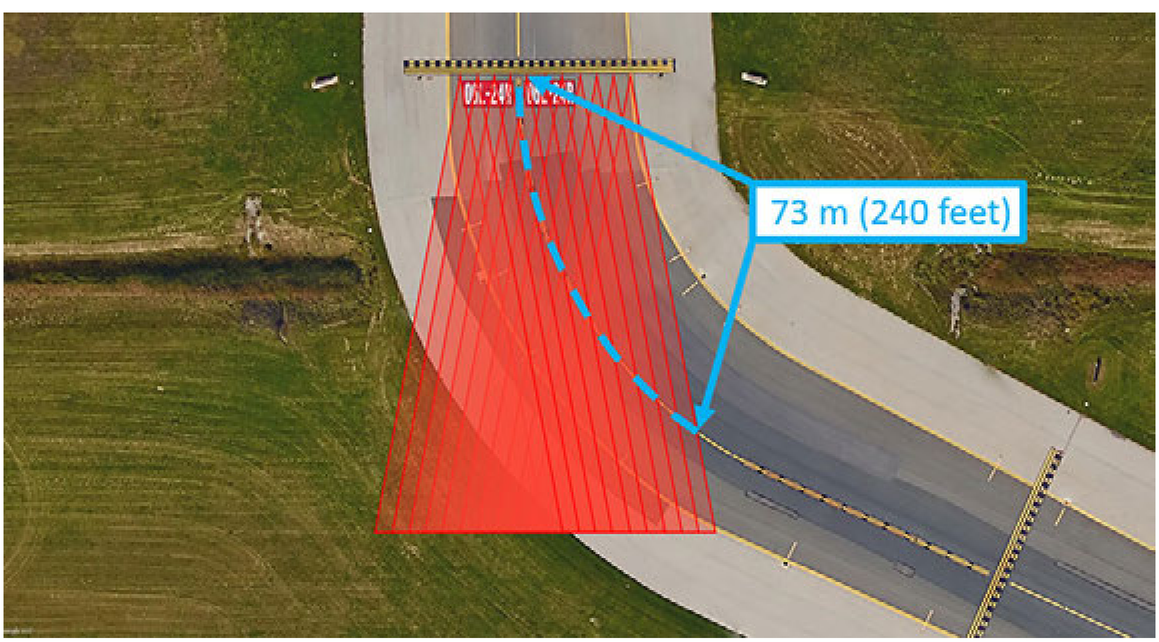
[37] Ibid., Figure 5-57.

Figure 11. Orientation of inset runway guard lights (Source: Transport Canada, TP 312, Aerodrome Standards and Recommended Practices, 5th Edition [effective date 15 September 2015], Figure 5-57)



Because the lights are angled relative to the taxiway, the inset stop-bar light located on the side closest to the inside of the turn, which is aimed parallel to the taxiway, would be the first stop-bar light to become visible to an approaching aircraft. In its current placement, if the light is operating at the minimum specification, the angular limitations mean that this main beam would become visible only when the aircraft is within 73 m (240 feet) of the stop-bar position. The main beam of the outer 3 inset stop-bar lights would not be visible to aircraft at any point on the taxiway centreline (Figure 12).

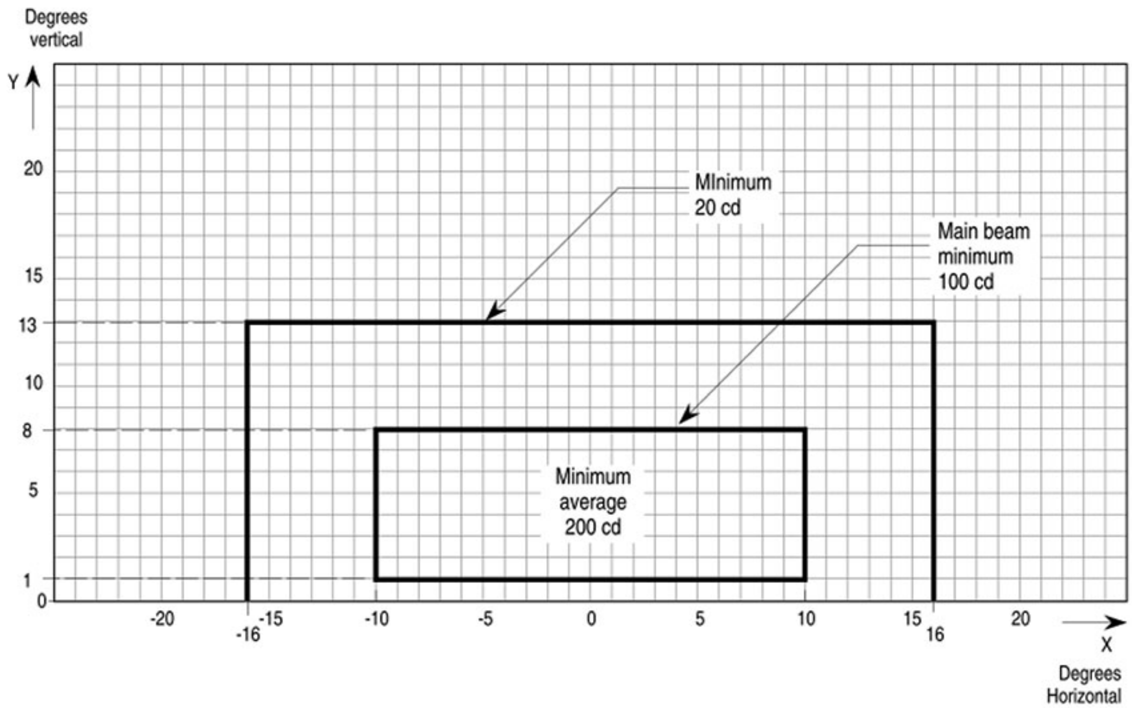
Figure 12. Angular orientation and main beam spread of individual inset stop-bar lights at rapid exit taxiways of Runway 06L/24R (Source: Google Earth, with TSB annotations)



1.5.3.2.3 Intensity

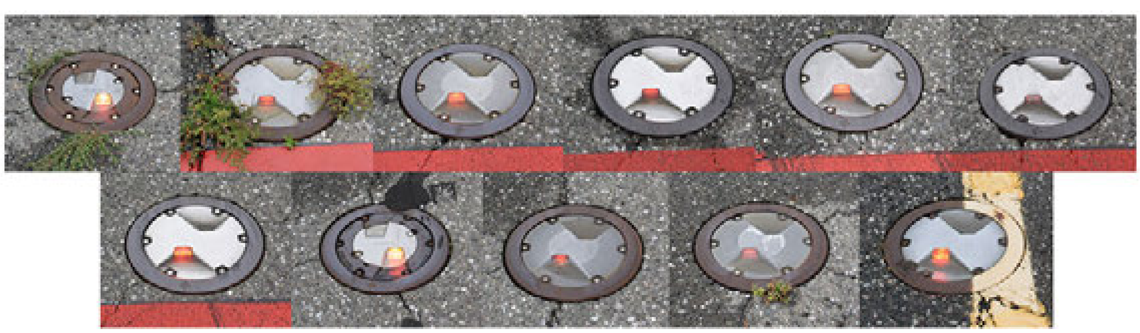
The requirements of the 4th edition of TP 312 for the intensity of the inset stop-bar lights are shown in Figure 13.

Figure 13. Requirements for intensity and beam spread of inset stop-bar lights (Source: Transport Canada, TP 312, Aerodrome Standards and Recommended Practices, 4th edition [revised March 2005], Figure B-13)



During this investigation, the inset stop-bar lights were examined and photographed on a few different occasions (Figure 14). It was noted that, to the naked eye, the strengths of the individual lights varied, and several different levels of intensity were often evident among lights within the same row. In addition, their fixtures occasionally differed and were mixed within the same row.

Figure 14. Composite image of inset stop-bar lights installed at rapid exit taxiway D4, showing varied intensities and differing fixtures



It was determined that light fixtures from 2 different manufacturers were installed interchangeably and often mixed within a single stop-bar location. Both types of fixtures met the minimum TP 312 specifications by design; however, the minimum average main-beam intensity of one unit type was 417 cd, with a beam spread of 48°, while that of the other was 247 cd, with a beam spread of 20°.

The basic light intensity requirements in TP 312 are similar to those set out in ICAO's Annex 14; however, ICAO recommends greater intensity for certain installations [emphasis in original]:

> **Recommendation.—** *Where stop bars are specified as components of an advanced surface movement guidance and control system and where, from an operational point of view, higher intensities are required to maintain ground movements at a certain speed in very low visibilities or in bright daytime conditions, the intensity in red light and beam spreads of stop bar lights should be in accordance with the specifications of Appendix 2, Figure A2-17, A2-18 or A2-19.*
>
> *Note.—High-intensity stop bars should only be used in case of an absolute necessity and following a specific study.*[38]

Figure A2-17, cited above, calls for a main beam intensity of 1800 cd.[39]

The FAA requirements for stop-bar lights also differ from those contained in TP 312. The FAA requirements call for a minimum average main-beam intensity of 300 cd and a main beam spread of 48°.[40]

1.5.3.2.4 Supplemental elevated stop-bar lights

In addition to the inset stop-bar lights, supplemental elevated stop-bar lights are installed on both sides of the taxiway near the runway guard lights and consist of a pair of elevated unidirectional red lights per side, for a total of 4 (Figure 8 and Figure 15).

The lights were originally installed in accordance with the standard set out in the 4th edition of TP 312, which stated that "these lights shall have the same characteristics as the lights in the stop bar, but shall be visible to approaching aircraft up to the stop bar position."[41]

To meet this standard, the unidirectional lights were aimed at a position consistent with the approximate position of an aircraft holding at the runway holding position, or roughly 3 m (10 feet) from the position. As a result, the pair of lights located closest to the inside of the curve on the RET were not visible to the approaching aircraft until it had nearly completed rounding the 65° curve, directly before the runway holding position.

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38 International Civil Aviation Organization, Annex 14 to the Convention on International Civil Aviation, Volume I – *Aerodrome Design and Operations*, Seventh Edition (July 2016), section 5.3.20.11.

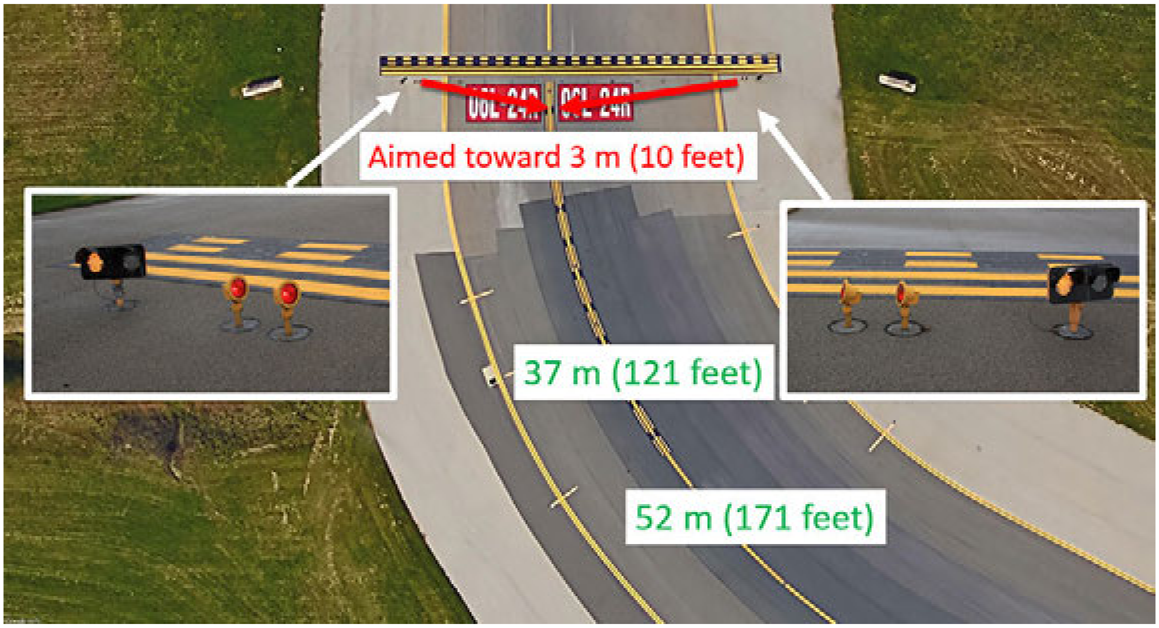
39 Ibid., Figure A2-17.

40 U.S. Federal Aviation Administration, Advisory Circular 150/5345-46E: Specification for Runway and Taxiway Light Fixtures (02 March 2016), Table 1.

41 Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 4th Edition (revised March 2005), section 5.3.18.8.

The standard for the angular aiming of these lights was changed in the 5th edition of TP 312, which now requires that "Supplemental stop bar lights are aimed toward the taxi centreline at a distance of between 37 m and 52 m from the runway-holding position."[42]

Figure 15. Current aim point of elevated stop-bar lights at rapid exit taxiways of Runway 06L/24R (Source: Google Earth, with TSB annotations)



1.5.3.2.5 Maintenance and inspection

The GTAA inspects all airport lighting regularly and makes repairs as necessary. General basic inspections are carried out daily, and more thorough low-visibility route inspections are conducted on a weekly rotation; the entire facility is inspected every month.

During the TSB's examination of the lights, it was observed that the stop-bar lights were sometimes partially obscured by vegetation, and, on a few occasions, different coloured lenses were installed and/or individual lightbulbs were non-functional. It was not determined why or for what duration these deficiencies were present (Figure 16).

Figure 16. Composite image showing obscured lights, incorrect lenses, and non-functioning bulbs at Runway 06L/24R

[42] Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 5th Edition (effective date 15 September 2015), section 5.3.23.7.

1.5.4 Marking and signage

The runway holding positions are equipped with signage and markings on the ground to provide flight crews with visual cues indicating their position and proximity to the runway. Since the changes made in 2013 to improve conspicuity, every runway holding position between the parallel runways that designates the point at which to hold short of Runway 06L/24R has included the following signs and markings:

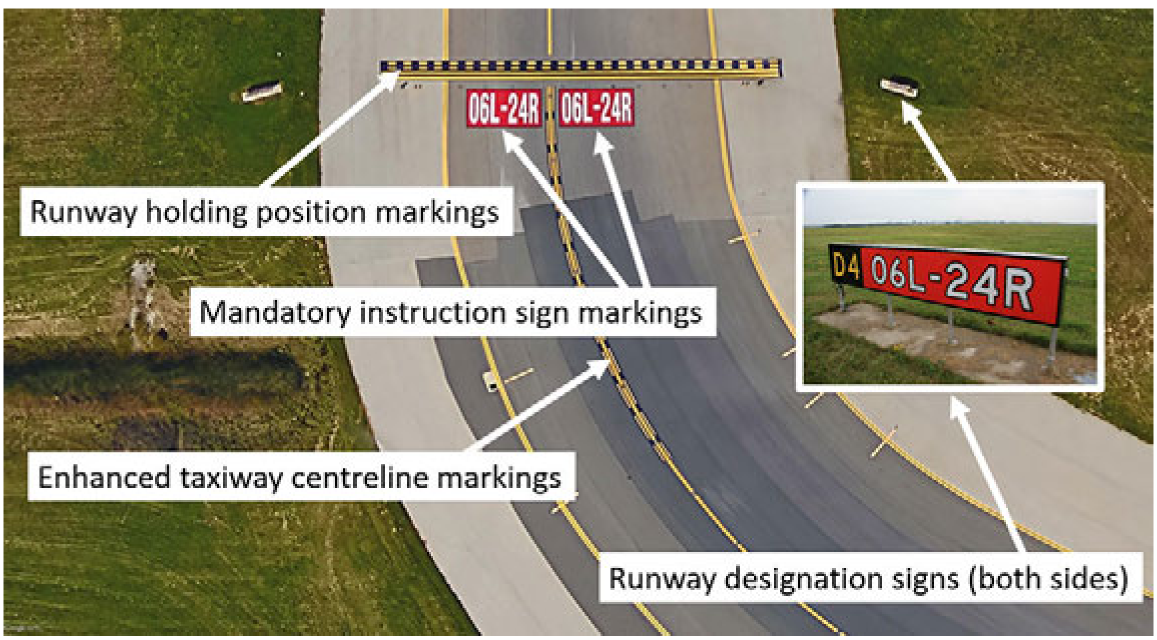
- enhanced taxiway centreline markings,
- runway holding position markings (often referred to as "hold lines"),
- mandatory instruction sign markings (often referred to as "runway boxes") installed in 2013, and
- runway designation signs.

The runway boxes are large, red ground markings that identify the designation of the runway ahead (Figure 17).

The enhanced taxiway centreline and runway holding position markings are highlighted with a black background to increase their conspicuity.

The runway designation signs, previously lit using individual fibre-optic points, were switched in 2013 to internal illumination, consistent with lit signage in the U.S. Both lighting methods are acceptable per TP 312.

Figure 17. Markings and signage on the rapid exit taxiways (Source: Google Earth, with TSB annotations)



1.5.4.1 Changes in 2017

During this investigation, the TSB noted some potential safety deficiencies with regard to markings; these were communicated directly to the GTAA and discussed in meetings of the local runway safety team (LRST). Following these discussions, the GTAA implemented some changes to address the deficiencies and reduce the continued risk of runway incursion.

During flight crew interviews, several crews had reported seeing only 1 of the 2 runway holding position markings (hold lines) on the taxiways between the parallel runways. Therefore, in consultation with the LRST, the GTAA decided to install runway boxes at these exiting positions. The purpose of the boxes was to increase the conspicuity of the markings that aircraft cross first after exiting Runway 06R/24L and to signal to flight crews that they will be required to stop at the next set of markings. The runway boxes were gradually added to all exits from October to December 2017. Those at RET D6 were added in October.

At the same time, some flight crews did not recognize the aircraft's proximity to the runway edge once they had passed the runway holding position. One of the ways flight crews can recognize this transition from taxiway to runway is through the use of runway side-stripe marking: a 90 cm–wide strip of white paint that runs down the full length of the side of the runway.

Neither the 4th edition of TP 312 nor previous or current ICAO standards[43] prescribed whether side-stripe marking should be continuous through intersections or broken. On Runway 06L/24R, the line was broken, or interrupted, at each intersection. The lack of prescription was rectified in the 5th edition of TP 312, which specifically calls for this line to be broken. In contrast, current FAA guidance[44] calls for the line to be continuous.

The GTAA, again in consultation with the LRST, determined that, given the flexibility allowed by the 4th edition of TP 312, a continuous line would provide a more obvious visual cue for the transition to the runway surface. As a result, the previously broken side-stripe marking on Runway 06L/24R was made continuous in October 2017.

Although these 2 improvements had both been completed on RET D6 before November 2017, another runway incursion occurred at this location shortly afterward, on 17 November.[45]

1.5.5 Examination of exit usage

In October 2017, with the assistance of the GTAA, the investigation examined ground radar data recorded from 2015 to 2017 in an effort to determine the frequency of usage of each RET during periods in which both runways in the south complex were in use.

During the period examined, 81 172 aircraft landed on the outer runway and exited on one of the RETs (Table 4). Of those aircraft, 24 760 landed on Runway 06R and 56 412 on Runway 24L. The RET most commonly used was D4.

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43 International Civil Aviation Organization, Annex 14 to the Convention on International Civil Aviation, Volume I – Aerodrome Design and Operations, Seventh Edition (July 2016), section 5.2.7.

44 U.S. Federal Aviation Administration, Advisory Circular 150/5340-1L: Standards for Airport Markings (27 September 2013), paragraph 2.8 e.(2), pp. 26–27.

45 Another similar incursion occurred in June 2018; however, this was outside the time frame examined in this study.

Table 4. Comparison of the frequency of exit usage versus number of incursions during the period examined

Rapid exit taxiway	Number of movements	Percentage of movements	Number of incursions	Percentage of incursions
D4	39 986	46%	14	52%
D2	15 357	19%	1	4%
D3	14 466	18%	3	11%
D5	5701	7%	2	7%
D1	4368	5%	0	0%
D6	4053	5%	6	22%
D7	241	0.3%	0	0%

The exit frequency during the entire investigation period (2012 to 2017) was considered similar to that during the examined period (2015 to 2017). Although RET D6 accounted for only 5% of the exiting traffic during the examined period, 6 out of 27 (or 22%) of the incursions examined in this investigation occurred at that location.

In a recently published safety alert for operators, the FAA detailed an examination of ground surveillance data recorded from 2014 to 2016 and stated that, a very high percentage of the time, the most serious runway incursions occur on the first two thirds of the runway length.[46]

On Runway 06L/24R, the most common crossing location (RET D4) is located slightly beyond the first two thirds of the runway. However, the intersections of RETs D1, D2, and D3 are located on the first two thirds of the respective runways they intersect and, together, currently account for 42% of the crossing traffic.

1.5.6 Comparison with other airports

The investigation compared the characteristics of the south complex at CYYZ with those of other high-volume airports that have closely spaced parallel runways. The TSB examined 130 airports worldwide, including the top 100 airports internationally and the top 60

46 U.S. Federal Aviation Administration, Safety Alert for Operators 17012: High Collision Risk During Runway Crossing (29 November 2017).

airports in the U.S. by passenger volume.[47] CYYZ had several uncommon characteristics when compared to those other layouts, including

- the absence of a parallel taxiway between the runways,
- the greater distance of its runway holding positions, and
- the location of its hold lines, immediately after a curve.

1.5.6.1 Prevalence of parallel taxiways

Of the 130 airports examined, including CYYZ, only 12 had parallel runways with no parallel taxiway between them. Eight of those 12 airports had runways spaced less than 305 m (1000 feet) apart, making the inclusion of an intermediate taxiway more difficult. Other than CYYZ, only 3 of the airports had parallel runways spaced 305 m (1000 feet) or more apart. CYYZ was the only airport identified in Canada or the U.S. with parallel runways spaced 305 m (1000 feet) or more apart without an intermediate parallel taxiway.

1.5.6.2 Runway holding position distance

The distance of the runway holding position, or hold line, from the runway centreline varies among airports in the U.S. and internationally, but is rarely farther than 90 m (295 feet) at its closest point. At most airports in the U.S., these positions are established at either 76 m (250 feet) or 85 m (280 feet), and at most other international locations, they are placed at 90 m (295 feet), in accordance with respective guidance documents. CYYZ was the only airport identified with runway holding positions on RETs at a distance of 115 m (377 feet) or greater from runway centrelines.

1.5.6.3 Runway holding position following a curve

At other locations around the world, RETs situated between 2 parallel runways generally follow 1 of 2 patterns. Either there is a parallel taxiway between the runways and the RETs terminate on the taxiway (Figure 18), or there is no parallel taxiway and the RETs continue with a relatively straight section before the holding position of the adjacent runway (Figure 19).

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[47] Of the 130 airports examined, 39 had closely spaced parallel runways, and 24 of those 39 had intermediate taxiways.

Figure 18. George Bush Intercontinental/Houston Airport (KIAH), Texas, U.S., provides an example of a common configuration of closely spaced parallel runways with a parallel taxiway in between. (Source: Google Earth, with TSB annotations)

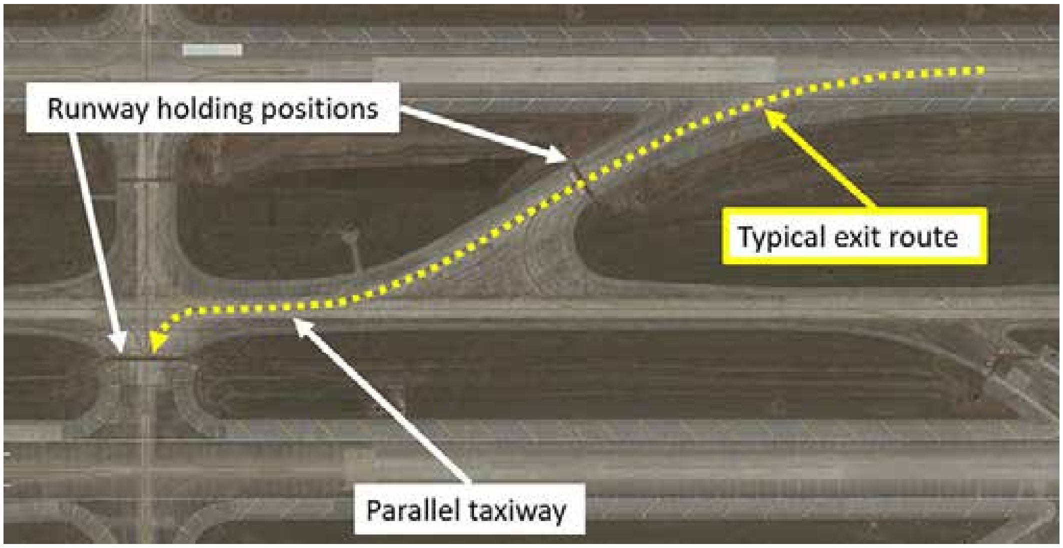
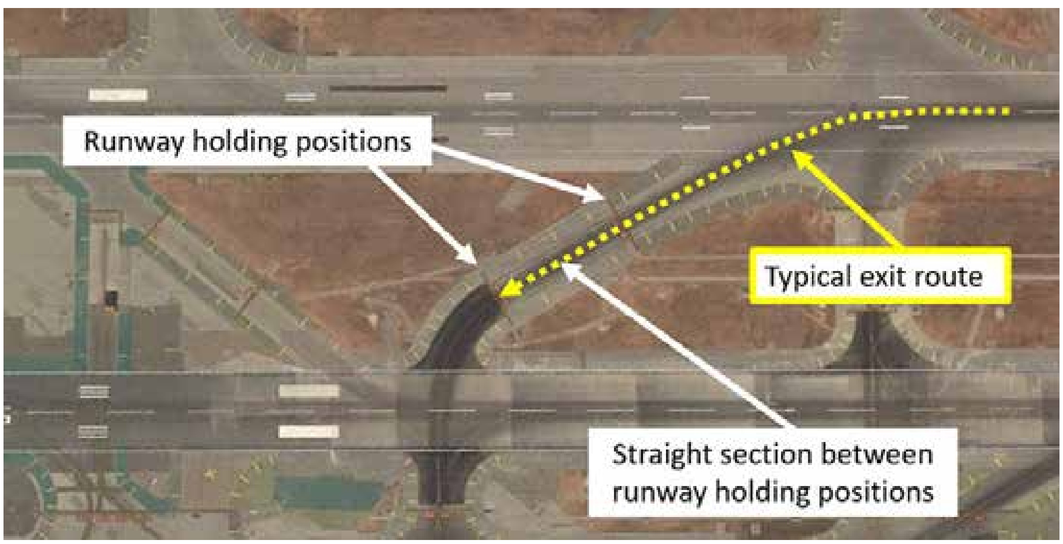
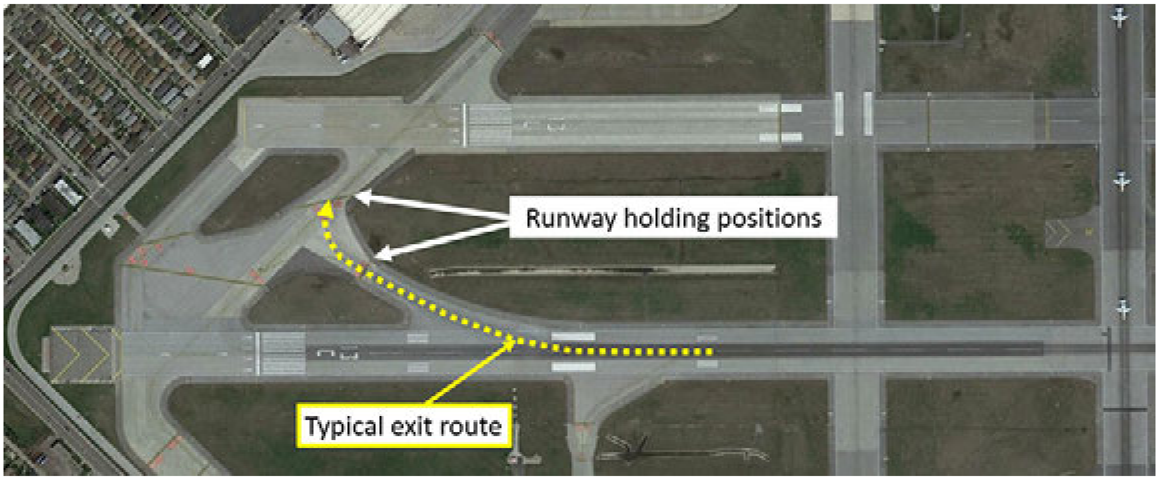


Figure 19. Phoenix Sky Harbor International Airport (KPHX), Arizona, U.S., provides an example of a closely spaced parallel runway configuration that has a rapid exit taxiway with a relatively straight section before the runway holding position. (Source: Google Earth, with TSB annotations)



Other than CYYZ, only 3 airports worldwide were identified as having a RET with a significant turn shortly before the runway holding position: Seoul Gimpo (Kimpo) Airport (RKSS), South Korea; Sapporo/New Chitose Airport (RJCC), Japan; and Chicago Midway International Airport (KMDW), Illinois, U.S. KMDW is the only one of the 3 that is located in North America, and this configuration exists at only 1 intersection (Figure 20).

Figure 20. Chicago Midway International Airport (KMDW), Illinois, U.S. has the only identified example, other than CYYZ, of a runway holding position located after a significant turn on a rapid exit taxiway in North America. (Source: Google Earth, with TSB annotations)



1.5.7 Other mitigation options

ICAO's *Manual on the Prevention of Runway Incursions* states:

> Once hot spots have been identified, suitable strategies should be implemented to remove the hazard and, when this is not immediately possible, to manage and mitigate the risk. These strategies may include:
>
> a) awareness campaigns;
>
> b) additional visual aids (signs, markings and lighting);
>
> c) use of alternative routings;
>
> d) construction of new taxiways; and
>
> e) the mitigation of blind spots in the aerodrome control tower.[48]

In accordance with this guidance, various organizations[49] carried out awareness campaigns in 2013 and 2017 regarding the risk of incursions between the parallel runways at CYYZ; however, the success of those campaigns could not be accurately measured. In addition to the awareness campaigns, the number of visual aids has continually been increased, as previously described. It was determined that the last strategy on the list—mitigating blind spots in the control tower—did not apply to these occurrences, and the remaining strategies—using alternative routings and building new taxiways—have not yet been implemented.

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48 International Civil Aviation Organization, Doc 9870 AN/463, *Manual on the Prevention of Runway Incursions*, First Edition (2007), Chapter 3, paragraph 3.4.3, p. 3-2.

49 These organizations included individual operators, pilot unions, airline associations, the TSB, and the GTAA.

1.5.7.1 Visual aid alternatives

Several options to improve visual aids have already been discussed and implemented. These include the improvements made in 2013 and the addition, in 2017, of mandatory signage on the Runway 06R/24L exits and of continuous runway side-stripe markings.

The LRST is considering 2 remaining options: installing inset flashing runway guard lights and adding runway status lights; however, at the time of publication of this report, there was no firm plan for implementation.

1.5.7.1.1 Inset flashing runway guard lights

Inset runway guard lights are often installed at runway holding positions where stop bars are not required under category II or III approach requirements. The lights are normally installed and spaced similar to stop bars; however, they use yellow or amber alternately flashing lights instead of solid red lights.

The 4th edition of TP 312 required that the intensity and beam spread of the inset runway guard lights be the same 200 cd, 20° main beam as the inset stop-bar lights. However, this changed significantly in the 5th edition, which now requires an intensity of 1000 cd and a beam spread of 48°.

The 4th edition of TP 312 also contained a standard that prohibits the collocation of inset runway guard lights and stop-bar lights[50]; however, this standard was removed in the 5th edition. The 5th edition does, however, prohibit the simultaneous operation of both lighting systems.[51]

1.5.7.1.2 Runway status lights

Runway status lights (RWSLs)[52] are a completely automated lighting system designed to enhance the pilot's awareness of when it is safe to enter, cross, or take off from a runway (Figure 21). The lighting system is currently operational in at least 17 airports in the U.S., 3 in Asia, and 1 in Europe.

The 5th edition of TP 312 describes RWSLs as follows:

> Note 1: Runway status light (RWSL) is an automated system that may be installed in conjunction with enhanced taxiway markings, stop bars or runway guard lights. It functions independently of any other visual system to

[50] Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 4th Edition (revised March 2005), section 5.3.20.4.

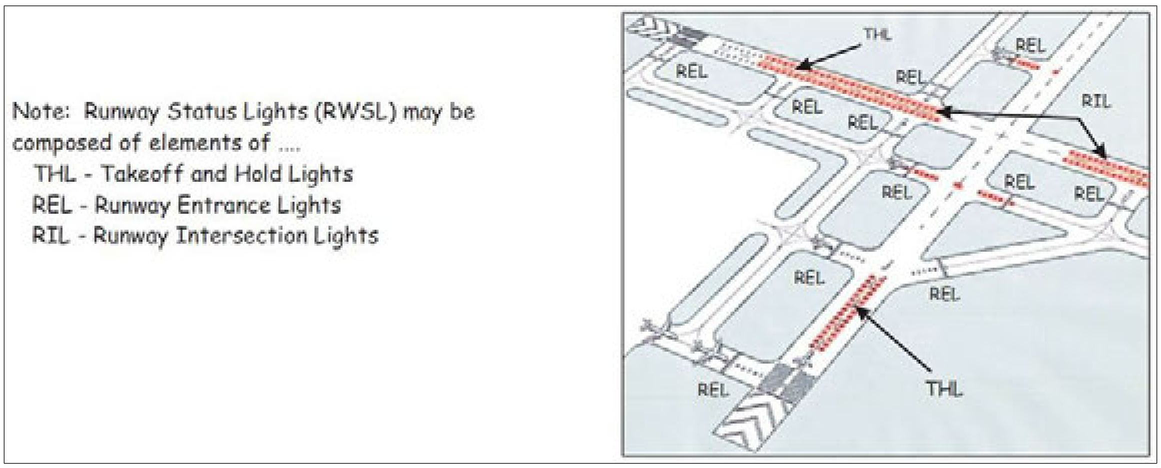
[51] Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 5th Edition (effective date 15 September 2015), section 5.3.26.16.

[52] "Runway status lights (RWSL) is [*sic*] a type of autonomous runway incursion warning system (ARIWS)." (Source: International Civil Aviation Organization, Annex 14 to the Convention on International Civil Aviation, Volume I – *Aerodrome Design and Operations*, Seventh Edition [July 2016], section 5.3.30, Introductory Note.)

provide direct warning to a pilot of an incursion danger on the runway ahead. The system comes in three basic forms: runway entrance lights (REL), take-off hold lights (THL) and runway intersection lights (RIL). Either system may be installed by itself, but it is preferred that the systems are installed so as to complement each other.

Note 2: The RWSL processor receives surveillance data of aircraft and vehicles on or near the aerodrome surface from the ground surface surveillance system to determine activation and deactivation of the REL, THL and RIL.[53]

Figure 21. Runway status lights (Source: Transport Canada, TP 312, Aerodrome Standards and Recommended Practices, 5th Edition [effective date 15 September 2015], inset of Figure 5-44)



Runway entrance lights (RELs) are a single row of red inset lights situated longitudinally between the hold line and the runway centreline, next to the taxiway centreline (Figure 22).

[53] Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 5th Edition (effective date 15 September 2015), section 5.3.18.

Figure 22. Example of lit runway entrance lights (Source: U.S. Federal Aviation Administration, "Runway Status Lights Photo Gallery," at https://www.faa.gov/air_traffic/technology/rwsl/gallery [last accessed 31 December 2018])

Take-off hold lights (THLs) have 2 rows of red inset lighting on the runway surface situated longitudinally on either side of the runway centreline for at least 450 m (1476 feet) near the beginning of the runway.

Runway intersection lights (RILs) have 2 rows of red inset lighting on the runway surface situated longitudinally on either side of the runway centreline for 900 m (2953 feet) preceding a runway intersection.

Each lighting system within the RWSL is completely automated, illuminating independently of ATC input, based on data inputs from the advanced surface movement guidance and control system (A-SMGCS).[54] The system provides direct warning to flight crews (or other ground vehicles) without the need for ATC communication.

RWSLs were designed to reduce the likelihood and severity of runway incursions in general. To address the specific type of incursion studied in this investigation, the system would function as follows: As a departing aircraft on Runway 24R or Runway 06L reaches a ground speed of 30 knots, or when an arriving aircraft on the same runway is within 1 nautical mile (nm) of landing, all of the RELs associated with that runway would illuminate between the hold lines and the runway centreline. The lights would signal to vehicles or taxiing aircraft to stop or to proceed no farther if previously cleared to enter the runway.

54 "A system providing routing, guidance and surveillance for the control of aircraft and vehicles in order to maintain the declared surface movement rate under all weather conditions within the aerodrome visibility operational level (AVOL) while maintaining the required level of safety." (Source: International Civil Aviation Organization, Doc 9830, *Advanced Surface Movement Guidance and Control Systems (A-SMGCS) Manual*, First Edition [2004], Glossary.)

If an aircraft or vehicle enters the area beyond the runway holding position, the THLs illuminate to signal to a departing aircraft that an incursion has taken place and that it needs to stop, or to abort the take-off roll if previously cleared to take off.

1.5.7.2 Perimeter taxiways

Another method to prevent or reduce runway incursions, recommended by ICAO, is to reduce runway crossing by constructing a perimeter taxiway:

> Many aerodromes have more than one runway, notably paired parallel runways (two runways on one side of the terminal), which creates a difficult problem in that either on arrival or departure an aircraft is required to cross a runway. Under such a configuration, the safety objective here is to avoid or at least keep to a minimum the number of runway crossings. This safety objective may be achieved by constructing a "perimeter taxiway". A perimeter taxiway is a taxi route that goes around the end of a runway, enabling arrival aircraft (when landings are on outer runway of a pair) to get to the terminal, or departure aircraft (when departures are on outer runway of a pair) to get to the runway, without either crossing a runway or conflicting with a departing or approaching aircraft.[55]

While a perimeter taxiway would reduce runway crossings, and thus runway incursions, installing such a feature may be difficult at runway complexes that are already operational, given local geographical restrictions.

1.5.7.3 Parallel taxiways

As mentioned, numerous airports around the world have constructed parallel taxiways between their closely spaced parallel runways, which prevents direct access from the RET to the adjacent runway, as described in EUROCONTROL's *European Action Plan for the Prevention of Runway Incursions*.[56] The parallel taxiway gives flight crews additional time and distance after exiting the landing runway to complete post-landing tasks and refocus their attention outside the aircraft.

In its best practices for the prevention of runway crossing incursions, EUROCONTROL has also stated the following:

> Aerodromes which have experienced serious runway incursion events have often chosen to modify the detail alignment of those taxiways which may be used as runway crossing entry points by introducing a significant change of direction shortly before a runway intersection occurs.[57]

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55 International Civil Aviation Organization, Annex 14 to the Convention on International Civil Aviation, Volume I – *Aerodrome Design and Operations*, Seventh Edition (July 2016), section 22.10.

56 European Organisation for the Safety of Air Navigation, *European Action Plan for the Prevention of Runway Incursions*, Version 3.0 (20 November 2017), p. 123.

57 SKYbrary, "Runway Crossing Incursions," at https://www.skybrary.aero/index.php/Runway_Crossing_Incursions#Prevention_-_Aerodrome_Design_and_Use (last accessed on 03 January 2019).

The turn from a parallel taxiway to the taxiway that intersects with and crosses the adjacent runway is commonly 90°, which is a lesser radius than that of turns normally seen on RETs and necessitates a reduction in taxi speed.

The distance travelled on the parallel taxiway also means that the runway crossing point is farther down the departure runway. Crossing the runway closer to its end can reduce the likelihood of collision with a departing aircraft, as the departing aircraft will likely be airborne or, if it is still on the ground when the incursion occurs, will have additional distance to abort the takeoff.

1.5.7.4 Effects on traffic capacity

In August 2014, the GTAA examined several operational or design alternatives intended to mitigate the type of runway incursion studied in this investigation and evaluated the impact of those alternatives on traffic capacity and/or delays of both arrivals and departures.

The options considered were[58]

- discontinuing the use of RETs D2 and D4 and using only RETs D and D6;
- discontinuing the use of RETs D2, D4, and D6 and using only RET D;
- discontinuing the use of RETs D1, D3, and D5 and using only RET D7;
- confirming that an aircraft that has landed on Runway 24L has stopped on the RET before clearing an aircraft for takeoff from Runway 24R;
- waiting until an aircraft that has landed on Runway 24L has crossed Runway 24R before clearing an aircraft for takeoff from Runway 24R;
- switching operations to have aircraft take off from the outer runway and land on the inner runway; and
- constructing a new taxiway connecting RET D4 to RET D6 and removing the RET D2 and D4 crossing points.

The scenarios involved in these options were simulated using the FAA's fast-time Airport and Airspace Simulation Model (SIMMOD).

The first 3 scenarios, involving discontinuing the use of various RETs, resulted in a 6–8% reduction in capacity in terms of aircraft movements per hour. This reduction was due mainly to longer runway occupancy times and to the single crossing location.

The options that required ensuring that the landing aircraft had either stopped on the RET or crossed the inner runway before clearing an aircraft for takeoff had the most significant impact on capacity, resulting in a reduction of approximately 19–24%. This reduction resulted from the need to increase spacing between arriving aircraft to facilitate departures between the arrivals, and to delay departures until landing aircraft had stopped.

58 Greater Toronto Airports Authority, Brief for Aviation Safety and Emergency Response Programs Branch, Aviation Services, "Capacity/Delay Evaluation of Operational and Design Alternatives for Mitigation of Runway 06L/24R Incursions" (18 August 2014), p. 2.

The option to switch departures to the outer runway resulted in a 9% reduction in capacity, which was a result of the required increase in spacing between arriving aircraft to allow departing aircraft to cross the arrival runway at the threshold. Additionally, this option raised concerns regarding the need for aircraft to routinely cross through the glide-path signal while other aircraft are on final approach.

The last option, involving the construction of a parallel taxiway, had the smallest impact on capacity (a 3% reduction). In the simulation, the parallel taxiway culminated in only one crossing point at the end of the runway, and this single crossing point was the source of the reduction in capacity.

1.6 Air traffic control

1.6.1 General

The NAV CANADA control tower at CYYZ is located approximately in the centre of the airfield, providing a view of the entire manoeuvring area. As the airfield in its entirety is large, certain portions of the manoeuvring area are relatively far from the tower. The distances between the RETs on the south complex and the tower range from 0.8 nm to 1.4 nm.

1.6.2 Departure and arrival runway usage

The airfield has 3 parallel runways in the east–west orientation and 2 in the north–south orientation. Because of the increased operational capacity when using 3 runways versus 2, the east–west operation is preferred during high-volume periods. Even during periods when traffic density requires only 2 runways, the east–west option is preferred because it still has a greater operational capacity than the north–south runways, lower approach minima (because of the prevailing winds), and shorter taxi routes. When only 2 runways are required in the east–west operation, the preferred option is normally to use runways 05/23 and 06L/24R.

At maximum capacity, with all 3 parallel runways in use (referred to as “triple runway operations”), the normal procedure on the south complex is to land aircraft on the outer runway (Runway 06R/24L) and depart from the inner runway (Runway 06L/24R). The alternate arrangement would require departing aircraft to cross both the arrival runway and the arrival runway’s glide-path signal while arriving aircraft are on short final for landing.

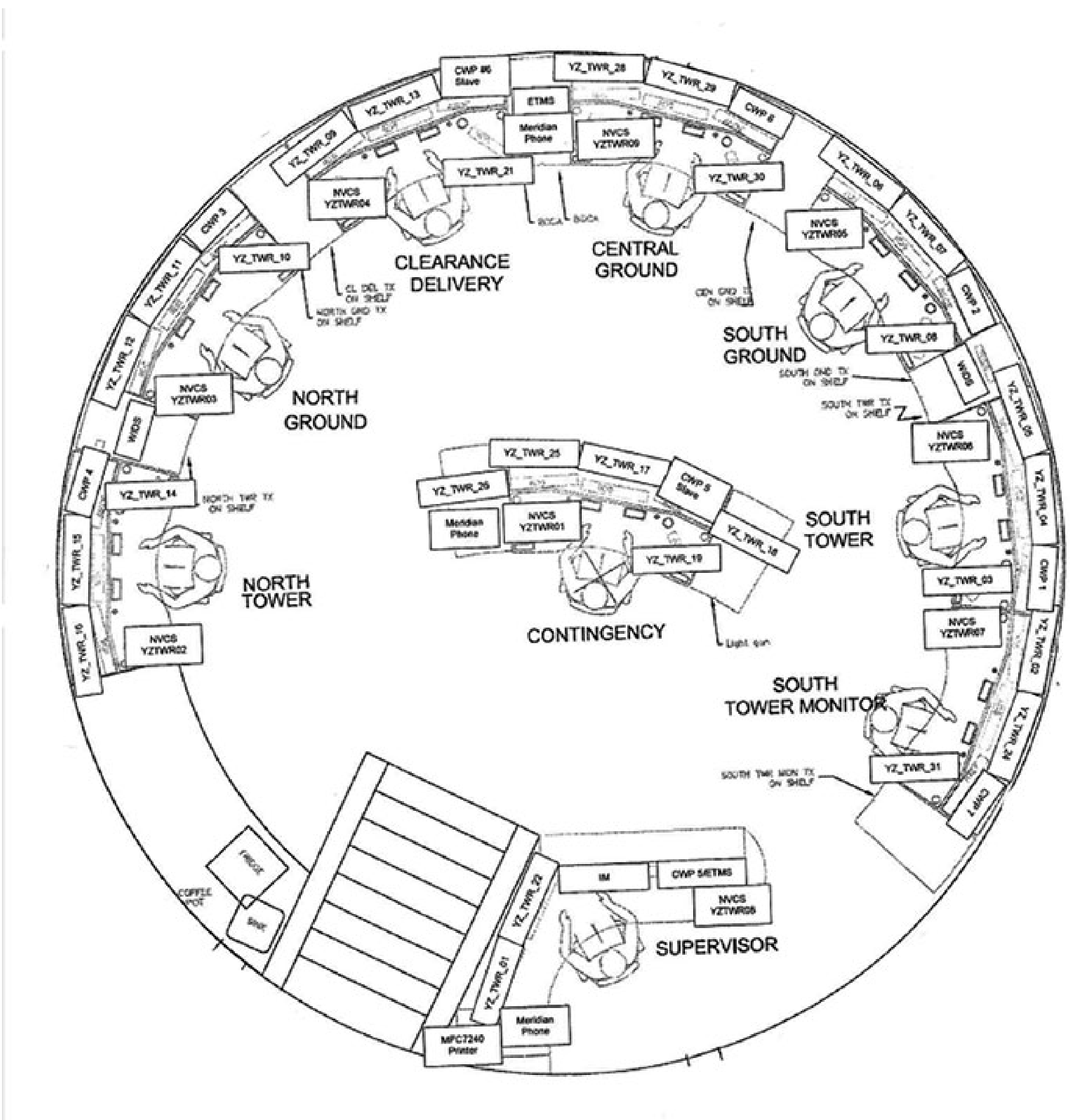
It was determined that the extra spacing required to operate this alternate method safely, as mentioned, would result in a 9% reduction in movements per hour compared to the current procedures.

1.6.3 Control positions

When operating at peak capacity, the workload and responsibilities in the control tower are distributed among several positions (Figure 23), including those of the

- north tower,
- south tower,
- south tower monitor,
- north ground,
- central ground,
- south ground,
- clearance delivery, and
- tower supervisor.

Figure 23. Control positions in the control tower at CYYZ (Source: NAV CANADA, Toronto Control Tower Unit Operations Manual [31 March 2016], C.1.4)



The south tower position is responsible for operations on the south complex parallel runways and for approaches and departures from those runways.

The positions can be combined during slower traffic periods; however, when the 2 runways on the south complex are in use simultaneously, the south tower and south tower monitor positions are always individually occupied.

1.6.3.1 South tower monitor

The south tower monitor controller works closely with the south tower controller and has several main priorities, including[59]

- to listen to and verify hold-short instructions issued by the tower controller;
- to listen to and verify hold-short readbacks from flight crews;
- to ensure that the stop bars are lit and to temporarily deactivate the stop bars once a crossing clearance has been issued;
- to watch aircraft approaching the hold-short position and monitor their speed in order to assess whether they are likely to stop; and
- to alert the tower controller immediately to any real or potential incursion.

The monitor controller operates as a second set of eyes for the south tower controller, and both closely monitor aircraft instructed to hold short of the inner runway. As part of this surveillance, these controllers monitor the speed at which an aircraft is travelling when approaching the runway holding position, which can be one of the earliest indications of a flight crew's intention to stop. When an aircraft is observed to be travelling too fast, the monitor controller will advise the tower controller, and a pre-emptive stop instruction will be issued. These early instructions likely often prevent an incursion.

There is no method of tracking the number of incursions prevented in this manner, but estimates were provided by various tower controllers, who described such events as occurring several times per week. Therefore, the effectiveness of the monitor controller may mask the true number of flight crews who miss the visual cues depicting runway holding positions and the incursions that would result without the controller's intervention.

1.6.4 Systems

Each control position in the tower is equipped with various tools or systems to monitor, control, and communicate with aircraft and ground vehicles, including but not limited to ground radar or surveillance systems, communication radios, and ground lighting control panels.

1.6.4.1 Advanced surface movement guidance and control system

The control tower at CYYZ is equipped with an A-SMGCS, or ground radar, which provides controllers with a real-time display of aircraft and vehicle traffic on the airport

59 NAV CANADA, *Toronto Control Tower Unit Operations Manual* (31 March 2016), C.10.1.

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.

1.6.4.1.1 Runway incursion monitoring and conflict alert system

The runway incursion monitoring and conflict alert system (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.[60]

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.[61]

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.

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.

RIMCAS can be susceptible to false alarms, which are generally due to erroneous target perception by the system. The frequency of such false alarms can vary, and their prevalence is not directly recorded. Information from controllers interviewed during this investigation suggested that the rate of their occurrence ranges from a few times per month to a few times per week.

1.6.4.1.2 Stop-bar overrun monitoring

Stop-bar overrun monitoring is an additional function of RIMCAS. When enabled, this function assesses aircraft and vehicle target positions and generates a stage 2 visual and aural alert to controllers when a target crosses an illuminated stop bar while entering a runway.[62] This alarm is reactive rather than predictive; it is triggered only once a stop bar has been crossed.

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

[61] Ibid., section 2, p. 3.

[62] Ibid., section 1.1, p. 1.

The alarm that sounds as part of the stage 2 alert following a stop-bar overrun is identical to the alarm generated by the runway incursion monitoring function.

In 2011, in an effort to reduce runway incursions, EUROCONTROL recommended that these alarms be made more distinguishable:

> When warning systems can be installed, such as within a surface movement guidance control system (A-SMGCS), provide aural (word) warnings not just sounds, when practicable.[63]

The ATC tower at Amsterdam Schiphol Airport (EHAM), Netherlands, operated by Luchtverkeersleiding Nederland, has already employed this type of verbal warning in its runway incursion alerting system.

1.6.4.1.3 Adjustable settings

The individual A-SMGCS display screens located at each controller position can be customized to reflect individual user preferences. The display settings include scale, orientation, and several options for selection of various alerts and alarms.

The system's runway incursion monitoring alerts can be adjusted so that they function only on runways that are specified as currently in use. This adjustment prevents false alarms by aircraft or vehicles operating on runways not being used for takeoff or landing.

The stop-bar overrun monitoring function can be disabled on individual displays to prevent false alarms and warnings from appearing on the displays of controllers who are monitoring areas that do not require stop-bar overrun protection.

Controllers can save their own default settings, which are then applied when controllers select their respective profiles upon taking control of a position. At the control tower at CYYZ, there was no requirement that stop-bar overrun alarms be set to ON in those defaults, and several controllers' profiles were found to have the default for those alarms set to OFF. As a result, during 6 of the 11 occurrences examined that took place between August 2015 and November 2017, the visual alert did not appear on the south tower controller's A-SMGCS display.

However, as long as at least 1 A-SMGCS display in the tower has the stop-bar overrun function set to ON, the alarm will be heard throughout the tower. During the investigation, it was determined that, in all 11 of the cases examined, at least 1 display had the stop-bar overrun function selected, and the alarm did sound in all cases. In 2 of those events, it was the controllers' 1st indication that an incursion had occurred.

When management of the CYYZ control tower became aware of the variability among individual user default settings, an operations directive was issued by memorandum in March 2017 requiring all default A-SMGCS display settings to include stop-bar overrun monitoring.

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[63] European Organisation for the Safety of Air Navigation, *European Action Plan for the Prevention of Runway Incursions*, Edition 2.0 (April 2011), Appendix K, p. K4.

1.6.4.2 Lighting control

Air traffic controllers control the airfield lighting using a control system touch-screen panel. Guidance and requirements for the use of the lights and for selection of lighting intensity levels are outlined in NAV CANADA's *Manual of Air Traffic Services* (MATS)[64] and supplemented by the *Toronto Control Tower Unit Operations Manual* and associated operations directives.

Stop-bar lights at specific exits can be turned on or off individually. They may be activated and deactivated manually or by using a delay setting that allows them to be temporarily extinguished following a runway crossing clearance and then automatically reactivated. The monitor controller is responsible for ensuring that the stop bars between the parallel runways are always on and that they are deactivated only when traffic is cleared across the inner runway.

The intensity level of the stop-bar lights is adjustable from levels 1 to 5, with level 5 being the brightest. The standard setting required by TP 312 during the day in good visibility conditions is level 3[65;] however, controllers at CYYZ normally select intensity 5. There is no formal guidance to set or check this intensity level, nor does the system automatically set the intensity to 5 by default.

The intensity of the airfield lighting is not recorded, so the intensity setting of the stop-bar lights during each of the incursions that were studied could not be determined. However, on one occasion when TSB investigators were on location at the south complex RETs, the stop-bar lights were not set to their maximum intensity.

1.6.5 Communication

Air traffic controllers at the CYYZ control tower follow the communication and phraseology guidelines set out in NAV CANADA's MATS.

When both south complex parallel runways are operationally active and both the south tower and south tower monitor controllers are in position, the controllers communicate using headsets and push-to-talk buttons connected to high-power transceivers and tuned to the south tower frequency. Transmissions are normally made by the south tower controller; the south tower monitor controller can also transmit on the frequency if necessary (e.g., in an emergency). However, anecdotally, that action has not proved necessary to date.

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64 The *Manual of Air Traffic Services* (MATS) is a collection of guidance provided by NAV CANADA to all air traffic services personnel. In 2016, the MATS replaced several different manuals, including the *Air Traffic Control Manual of Operations* (ATC MANOPS).

65 Transport Canada, TP 312, *Aerodrome Standards and Recommended Practices*, 5th Edition (effective date 15 September 2015), Table 8.4.1.9.

When an aircraft lands on Runway 24L or Runway 06R and is on the landing roll, the south tower controller issues an instruction to the flight crew to hold short of the applicable adjacent parallel runway (either 24R or 06L). ATC is required to obtain a readback of all runway hold instructions, and it is considered good practice for flight crews to provide a readback of such instructions.[66]

In all of the incursions examined in this investigation, ATC had issued a hold-short instruction, and the instruction had been accurately read back by the flight crews involved.

1.6.5.1 Safety-critical phraseology

In the event of a serious 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 takeoff, are not common and are considered only as a last resort. 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.[67]

In one of the cases examined in this investigation, the south tower controller observed an aircraft incurring on the inner runway at RET D4 and instructed a Boeing 787 to abort during its take-off roll on that runway. The abort instruction was issued using the standard phraseology "abort takeoff" specified in NAV CANADA's *Air Traffic Control Manual of Operations* (ATC MANOPS).[68,69]

The flight crew of the Boeing 787 did not recognize the instruction and continued the takeoff. In that crew's experience, an instruction from ATC to abort takeoff was always repeated and included the word "immediately."

Guidance in the ATC MANOPS at the time of the occurrence (and similarly in the MATS now) instructed controllers to cancel a previously issued take-off clearance if required. In addition to advising controllers to state the reason for the cancelled take-off clearance if

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[66] Transport Canada, TP 14371, *Transport Canada Aeronautical Information Manual* (TC AIM), RAC - Rules of the Air and Air Traffic Services (29 March 2018), section 4.2.5.

[67] NAV CANADA, *Manual of Air Traffic Services: Tower* (effective 31 August 2017), p. 96.

[68] This occurrence took place before the implementation of the MATS, when ATC MANOPS was the guidance document of authority. The abort-takeoff guidance remains the same in the MATS.

[69] NAV CANADA, *Air Traffic Control Manual of Operations* (ATC MANOPS), Part 3: Airport and VFR Control (effective 09 June 2015), section 337.1.

appropriate, ATC MANOPS specifies the phraseology to be used in these circumstances [emphasis in original]:

> **337.1**
>
> If circumstances require, cancel a previously issued take-off clearance and, when appropriate, inform the aircraft of the reason. […]
>
> ***337.1 Phraseology***
>
> *If a clearance to take off is cancelled:*
>
> *A. before the aircraft has started to roll—TAKE-OFF CLEARANCE CANCELLED;*
>
> *B. after the aircraft has started to roll—ABORT TAKEOFF.*[70]

The ATC MANOPS stated that the phrase "I say again" means "I repeat for clarity or emphasis"[71] and that "immediately" should be used only "when immediate action is required for safety reasons."[72] But the manual did not specifically recommend using this phraseology to emphasize an instruction to abort a takeoff. The whole of this guidance remains the same in MATS.

Similarly, ICAO's *Procedures for Air Navigation Services—Air Traffic Management* (PANS-ATM) indicates that the proper phraseology when cancelling a take-off clearance is [emphasis in original] "HOLD POSITION, CANCEL TAKE-OFF I SAY AGAIN CANCEL TAKE-OFF *(reasons)*."[73]

In situations in which the aircraft involved has already begun its take-off roll, the proper phraseology according to PANS-ATM is [emphasis in original] "STOP IMMEDIATELY [*(repeat aircraft call sign)* STOP IMMEDIATELY]."[74,75]

ICAO's *Manual on the Prevention of Runway Incursions*[76] recommends the same phraseology in these situations as that specified in PANS-ATM.

1.6.5.2 Other events involving missed critical air traffic control instructions

There have been other recent instances in Ontario of non-compliance with ATC instructions by flight crews who did not hear or recognize an instruction. Two TSB investigation reports[77] released in 2013 identified this deficiency.

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70 Ibid.

71 Ibid., Part 2: Communications, section 213.1.

72 Ibid., section 211.5.

73 International Civil Aviation Organization, Doc 4444, *Procedures for Air Navigation Services - Air Traffic Management* (PANS-ATM), Sixteenth Edition (10 November 2016), section 12.3.4.11.

74 Ibid.

75 According to PANS-ATM, "Words in square parentheses indicate optional additional words or information that may be necessary in specific instances." (Source: Ibid., section 12.2.9.)

76 International Civil Aviation Organization, Doc 9870 AN/463, *Manual on the Prevention of Runway Incursions*, First Edition (2007), Appendix A: Communications Best Practices, section 2.7.

77 TSB aviation investigation reports A13O0049 and A13O0045.

In the occurrence detailed in TSB Aviation Investigation Report A13O0049, the flight crew of a departing aircraft was instructed to abort their takeoff because 2 snow sweepers were working near the departure end of the runway. The instruction was issued using the phraseology specified in section 337.1 of the ATC MANOPS ("[aircraft call sign] abort takeoff.") The instruction was not repeated, the word "immediately" was not used, and the reason for the instruction to abort takeoff was not stated.

The flight crew, who were in a high-workload phase of flight, did not attend to the instruction until the incurring vehicles became visible. Nine seconds elapsed from transmission of the instruction to abort takeoff until the crew's initiation of a rejected takeoff. Among the findings as to the causes and contributing factors of the occurrence, the TSB investigation report included the following:

> The air traffic control instruction to abort take-off, which was simultaneous with other sensory input and was not sufficiently compelling to alter the crew's mental model of the situation or their expectation of an uneventful take-off, initially went unnoticed. As a result, the rejected take-off was not initiated until 9 seconds after the instruction.[78]

In the occurrence described in TSB Aviation Investigation Report A13O0045, an aircraft on a short final approach for Runway 24R at CYYZ was instructed twice to pull up and go around after an unattended maintenance vehicle rolled onto the threshold of the runway. Because of the prevailing visual conditions, the flight crew did not see the vehicle. The 2 instructions were ineffective because the 1st was masked by a simultaneous automated callout in the cockpit and the 2nd was truncated such that the full call sign was not transmitted. The TSB investigation report included the following finding as to causes and contributing factors:

> Although the crew heard a "go-around" transmission, without other supporting cues such as visually sighting an obstacle, the crew did not interpret the instruction to apply to them. Consequently, the communication was insufficient to challenge the flight crew's mental model of the situation, or their expectation of an uneventful landing.[79]

1.6.5.3 Automatic terminal information service

According to the *Transport Canada Aeronautical Information Manual* (TC AIM),

> ATIS is the continuous broadcasting of recorded information for arriving and departing aircraft on a discrete VHF/UHF [very high frequency / ultra high frequency] frequency. Its purpose is to improve controller […] effectiveness and to

[78] TSB Aviation Investigation Report A13O0049.

[79] TSB Aviation Investigation Report A13O0045.

> relieve frequency congestion by automating the repetitive transmission of essential but routine information.[80]

When both parallel runways on the south complex at CYYZ are in use, the ATIS message advises flight crews of the following:

- High-intensity runway operations[81] are in effect.
- Crews should minimize runway occupancy times and be alert to runway crossing clearances.
- Readback of all runway holding instructions is required.

The intent of the message is, in part, to alert crews to the risk of incursion on the inner runway.

In the occurrences studied in this investigation, most of the inbound flight crews involved received that message digitally, rather than over the radio, and many did not interpret it as an incursion warning. In some cases, crews who were interviewed following an incursion indicated that they had been concerned with exiting the landing runway in a timely manner, as advised by the ATIS message, and were attempting to ensure that they had adequately passed the exiting runway holding position.

1.6.5.4 Reporting and recording

All of the aircraft involved were equipped with flight data recorders (FDRs) and cockpit voice recorders (CVRs). However, FDR data was recovered in only 6 of the 11 events, and CVR data in only 3.

On the types of recorders involved in the incursions, CVR data is overwritten after every 2 hours that the unit remains powered, and FDR data after approximately every 25 hours.

The *Transportation Safety Board Regulations* require that the "owner, operator, pilot-in-command, any crew member of the aircraft and any person providing air traffic services that have direct knowledge of an occurrence must report"[82] the details of the event to the TSB "as soon as possible and by the quickest means available."[83]

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80 Transport Canada, TP 14371, *Transport Canada Aeronautical Information Manual* (TC AIM), RAC—Rules of the Air and Air Traffic Services (29 March 2018), section 1.3.

81 High-intensity runway operations are "operations, used at very busy airports, that consist of optimizing separation of aircraft in final approach in order to minimize runway occupancy time (ROT) for both arriving and departing aircraft and to increase runway capacity." (Source: Transport Canada, TP 14371, *Transport Canada Aeronautical Information Manual* [TC AIM], GEN – General [29 March 2018], section 5.1.)

82 Transportation Safety Board of Canada, SOR/2014-37, *Transportation Safety Board Regulations*, subsection 2(1).

83 Ibid., paragraph 2(3)(a).

For air traffic services personnel, NAV CANADA maintains an internal document entitled *Aviation Occurrence Reporting Procedures*. The purpose of this document is to provide a single source of information on the procedures for reporting aviation occurrences. It includes the following:

> Note: TSB is normally advised of all reportable occurrences via automated email once an AOR [aviation occurrence report] is filed. For accidents and high profile events the shift manager is required to call TSB via telephone.[84]

Several of the runway incursions examined in this investigation were not initially assessed by shift managers as high-profile and, consequently, a phone call to the TSB was not placed in those cases. Each of those delays in reporting resulted in a loss of critical data—often, most notably, data from the CVR recording.

1.7 Flight operations

1.7.1 Aircraft and operator type

The majority of the aircraft involved in the occurrences studied in this investigation (20 of 27, or 74%) were jets operated by U.S.-based regional carriers. The investigation sought to determine whether their predominance was reflective of a higher volume of traffic or whether U.S.-based regional jets were overrepresented.

In October 2017, with the assistance of the GTAA, the investigation examined ground surveillance data recorded during 81 172 arrivals on Runway 06R/24L from January 2015 to October 2017. The data were analyzed to determine the frequency of exit usage by each operator type and the common taxi speeds of aircraft types while approaching the hold line.

1.7.1.1 Frequency

The examination of the recorded data for the designated period specifically focused on usage of Runway 06R/24L and the associated RETs. It determined the following:

- Canadian and foreign medium- and wide-body aircraft in mainline operation accounted for 49 091 aircraft movements, or 60.4% of the total.
- Canadian regional carriers accounted for 24 950 aircraft movements, or 30.7% of the total.
- U.S.-based regional carriers accounted for 7131 aircraft movements, or 8.8% of the total.

U.S.-based regional carriers made up only 8.8% of the traffic; however, they accounted for 74% of the examined incursions.

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84 NAV CANADA, *Aviation Occurrence Reporting Procedures*, Version 5.0 (01 May 2016), Introduction, p. 4.

1.7.1.2 Taxiing speed

The average taxiing speed of each recorded aircraft movement in this subset of data was measured on the RET at a location between the 2 runway holding positions, and the following was determined:

- The median speed of all aircraft was 8 m per second (15.6 knots) (Table 5); however, the median speeds by aircraft type were as follows:
  - wide body (B777 or similar): 7 m per second (13.6 knots);
  - narrow body (B737 or similar): 8 m per second (15.6 knots); and
  - regional jet (CRJ or similar): 9 m per second (17.5 knots).
- There was no significant difference between the aircraft speeds of Canadian-based carriers and those of U.S.-based carriers, whether mainline or regional, while operating similar aircraft types.
- These speeds were compared with the recorded speeds in the data subset for the 11 aircraft in the most recent cases of incursion studied in this investigation.

Table 5. Taxiing speeds of aircraft involved in incursions on the runway compared with median speed by aircraft type

Date	Aircraft type	Average speed between runway holding positions (knots)	Speed versus median speed by aircraft type (knots)	Taxiing time between runway holding positions (seconds)
2015-08-02	CRJ-900	17.9	+0.4	13.5
2015-12-04	ERJ-145	15.0	–2.5	17.0
2016-05-09	CRJ-900	18.0	+0.5	7.5
2016-06-13	CRJ-900	14.5	–3.0	16.5
2016-08-16	CRJ-900	25.5	+8.0	11.0
2017-03-22	CRJ-700	21.0	+3.5	12.0
2017-04-22	ERJ-145	17.0	–0.5	16.0
2017-06-20	EMB-170	22.0	+4.5	16.0
2017-08-08	EMB-175	23.5	+6.0	11.0
2017-08-14	EMB-170	22.0	+4.5	6.2
2017-11-17	B767-300	14.0	+0.4	10.0

The median taxiing speed of the 10 regional jets that incurred on the runway was 18 knots, which was nearly identical to the median speed of that aircraft type within the larger sample size. Similarly, the speed of the B767-300 was consistent with the median speed of the larger aircraft types.

1.7.1.3 Crew experience and familiarity with CYYZ

Given that the majority of incursions involved U.S.-based regional carriers, flight crew experience and familiarity with CYYZ were considered possible factors. However, flight crews interviewed following the incursions since August 2015 that had involved U.S.-based regional carriers had a wide range of experience, both in total and on their respective aircraft types. Therefore, given the broadly varying range in their levels of experience, it was determined that flight crew experience was not a factor.

There was significant variability among flight crews with respect to their degree of familiarity with CYYZ. Many of the U.S. crews were familiar with CYYZ and had conducted flight operations into the airport numerous times. Others, however, were unfamiliar with CYYZ or at least with operations on the south parallel runway complex. In one case, one of the flight crew members had been completing an initial line-indoctrination flight at the time of the incursion. Nevertheless, even those U.S. crews who visited CYYZ the most frequently would likely have been much less familiar with the airport than would Canadian-based regional crews. It was therefore determined that familiarity with CYYZ was likely a factor in these incursions.

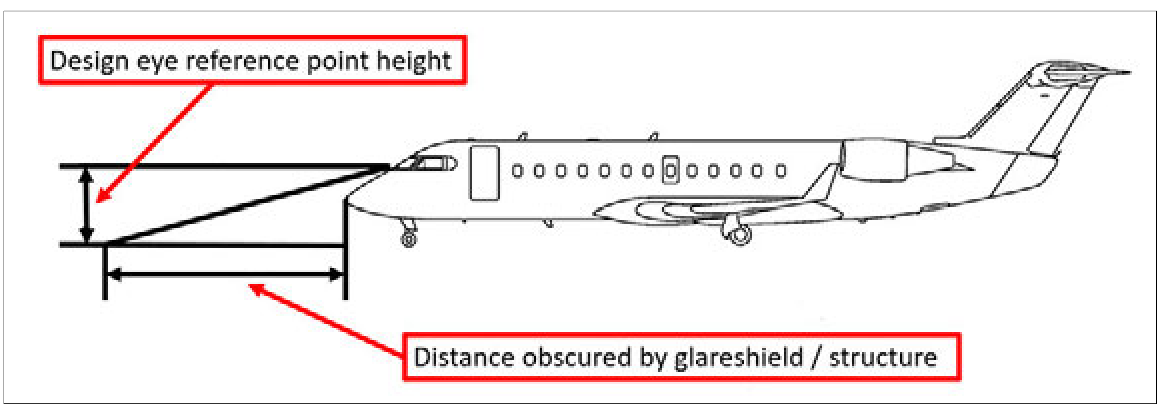
1.7.1.4 Field of vision

In a further effort to determine why smaller regional jets were involved in runway incursions more often than larger aircraft, the investigation examined the field of vision within the most common aircraft type (CRJ) and potential obstructions of that field.

In all aircraft, a portion of forward visibility is obscured by the glareshield or by the aircraft structure. The distance in front of the aircraft that is obscured varies among aircraft types and within types, depending on the aircraft's centre of gravity and its nose oleo extension.

Similarly, the height from which pilots view ground markings can affect the distance at which they are perceived. This height is referred to as the design eye reference point height (Figure 24), and it varies in the same way as the distance in front of the aircraft that is obscured by the glareshield or aircraft structure.

Figure 24. Design eye reference point height and obscured distance



The design eye reference point heights of the aircraft types that were involved in the incursions studied are listed in Table 6.

Table 6. Design eye reference point height and distance obscured of various aircraft types involved in the incursions examined

Aircraft type	Design eye reference point height*	Distance obscured
Bombardier CRJ series	2.9 m (9.5 feet)	7.2 m (23.8 feet)
Embraer ERJ 135/145	3.1 m (10.0 feet)	6.8 m (22.3 feet)
Embraer ERJ 170/175	3.9 m (12.9 feet)	11.7 m (38.4 feet)
Boeing 737 series	3.7 m (12.4 feet)	11.5 m (37.6 feet)
Boeing 767 series	5.5 m (18.2 feet)	12.1 m (39.8 feet)
Airbus 320 series	4.6 m (15.0 feet)	10.1 m (33.3 feet)

* These heights are approximate and may vary depending on the exact aircraft model and its centre of gravity and nose oleo extension.

1.7.2 Efforts to prevent incursions

Efforts to document best practices for preventing runway incursions have been made by both aircraft manufacturers[85] and regulators, including ICAO[86] and the FAA.[87]

A review of those documents indicated that many runway incursions attributed to pilot error result from a loss of crew situational awareness and highlighted the need for procedures and practices that reinforce the importance of treating taxiing as a phase of flight. Accordingly, the best practices call for standard operating procedures (SOPs) that encourage crews to devote as much attention to planning and conducting the taxiing phase as they do to other phases of flight. An FAA advisory circular on the topic stated:

> Increased traffic and expansion at many airports create complex runway and taxiway layouts. This additional complexity has made airport surface operations more difficult and the potential for runway incursions more hazardous than in the past. To increase safety and efficiency, it is necessary to lessen the exposure to hazards and risks by holding the flightcrew's workload to a minimum during taxi operations. This can be accomplished through SOPs that direct the attention of the flightcrew to essential tasks while the aircraft is in motion. The development and formalized training of safe operating procedures during taxi operations should be implemented by each operator.[88]

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85 Airbus Industrie, Flight Operations Briefing Notes: Runway and Surface Operations - Preventing Runway Incursions (May 2004).

86 International Civil Aviation Organization, Doc 9870 AN/463, *Manual on the Prevention of Runway Incursions*, First Edition (2007).

87 U.S. Federal Aviation Administration, Advisory Circular 120-74B: Parts 91, 121, 125, and 135: Flightcrew Procedures During Taxi Operations (30 July 2012).

88 Ibid., p. 2.

Among the flight crew techniques advocated to ensure situational awareness when taxiing are[89]

- conducting a thorough briefing of the anticipated taxiing route, including a review of any anticipated complex intersections and runway crossings;
- timing cockpit duties to avoid the period when approaching a runway; and
- performing the post-landing checklist only after the taxi clearance to the gate has been understood by both pilots or after reaching the holding position on the turn-off taxiway.

The recommendation to postpone post-landing checks is of even greater importance when the taxiing route involves crossing an active runway. The FAA circular states:

> After landing, nonessential communications and nonessential flightcrew actions should not be initiated until clear (on the inbound (terminal) side) of all runways in accordance with sterile cockpit procedures (e.g., changing radio frequencies and repositioning flaps, trim and speedbrakes).[90]

Airport geometry in general, and closely spaced parallel runways in particular, have been identified as factors that contribute to loss of situational awareness by flight crews involved in runway incursions. ICAO states:

> 2.6.1 Complex or inadequate aerodrome design significantly increases the probability of a runway incursion. The frequency of runway incursions has been shown in many studies to be related to the number of runway crossings and the characteristics of the aerodrome layout.
>
> 2.6.2 Common factors include: […] insufficient spacing between parallel runways […].[91]

The need for increased vigilance when taxiing between parallel runways is further reinforced in the FAA advisory circular calling for specific SOPs to prevent runway incursions. It includes the following note [emphasis in original]: "**CAUTION: Exercise increased awareness when taxiing in between active parallel runways.**"[92]

1.7.3 Best practices for effective briefings

Briefings are an essential tool for crews to maintain situational awareness. By providing an opportunity to assimilate operationally relevant information and anticipate its impact on the operation of the aircraft, briefings can be an effective threat-and-error countermeasure.

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89 Ibid.

90 Ibid., p. 8.

91 International Civil Aviation Organization, Doc 9870 AN/463, *Manual on the Prevention of Runway Incursions*, First Edition (2007), Chapter 2: Contributory Factors, section 2.6, p. 2-5.

92 Federal Aviation Administration, Advisory Circular 120-74B: Parts 91, 121, 125, and 135: Flightcrew Procedures During Taxi Operations (30 July 2012), p. 7.

A number of best practices have been identified to increase the effectiveness of crew briefings, both in general and with respect to preventing runway incursions in particular. An Airbus Industrie flight operations briefing note[93] provides generic guidance on conducting effective briefings. It highlights the fact that effective briefings are an important tool that supports SOPs in ensuring crews have common expectations of what is to take place and in assisting crews in anticipating unusual conditions or events. The briefing note provides best practices, including the following[94]:

- Briefings should be conducted during a period of low workload.
- Briefings should be interactive.
- Briefings should focus on what is different on the day.
- Briefings should always be conducted in depth, regardless of crew familiarity with a particular location or with each other.

With respect to the taxi route on arrival, the briefing note emphasizes that taxiing "should be considered as a critical phase of flight and be carefully briefed […] with special emphasis on the possible crossing of active runways […]."[95]

In its call for operators to develop specific SOPs to prevent runway incursions, the FAA advisory circular emphasizes that a briefing should include a review of the airport diagram, any hot spots, and their textual descriptions.[96] In addition, the circular calls for SOPs that require crews to describe how runway incursion threats will be mitigated:

> The flightcrew should brief the timing and execution of aircraft checklists and company communications at the appropriate times and locations so the pilot who is not taxiing the aircraft can be available to participate in verbal coordination with the pilot who is taxiing the aircraft.[97]

1.7.4 Threat-and-error management

The threat-and-error management model is a conceptual framework used to describe how flight crews manage situations that increase the risks associated with a given flight and to diagnose how situations developed following an occurrence. Included in the model are threats, errors, and undesired aircraft states. The model also outlines countermeasures that have been shown to be effective in managing these.[98]

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93 Airbus Industrie, Flight Operations Briefing Note: Standard Operating Procedures - Conducting Effective Briefings (June 2004).

94 Ibid.

95 Ibid., p. 11.

96 U.S. Federal Aviation Administration, Advisory Circular 120-74B: Parts 91, 121, 125, and 135: Flightcrew Procedures During Taxi Operations (30 July 2012), p. 4.

97 Ibid.

98 D. Maurino, "Threat and Error Management," presentation at the Canadian Aviation Safety Summit, Vancouver, BC, 18–20 April 2005.

1.7.4.1 Threats

Threats are conditions that are beyond the influence of the crew and serve to increase risk. They may include environmental conditions such as adverse weather, runway contamination, or challenging ATC clearances. If threats are identified and actively managed, they can be of little consequence. However, threats often lead to crew error and can result in undesired aircraft states.

1.7.4.2 Errors

Errors include actions or inactions by a flight crew that lead to deviations from organizational or crew expectations. These deviations may include

- aircraft handling errors, such as incorrect use of automation;
- procedural errors, such as completing checklists from memory or omitting briefings; or
- communication errors, such as missed callouts or incorrect ATC readbacks.

Errors may be the result of mismanaging a threat, or they may occur spontaneously. The key to error management is detection and action.

1.7.4.3 Undesired aircraft states

Undesired aircraft states are situations in which an aircraft is placed in a position of increased risk, most often due to mismanagement of a threat or error. Such states may include

- aircraft handling issues, such as altitude or speed deviations;
- ground navigation issues; or
- incorrect aircraft configuration, such as incorrect automation settings or late configuration for landing.

1.7.4.4 Threat-and-error countermeasures

A number of countermeasures have been recognized as effective in identifying and managing threats and errors in

- planning (standard briefings, stating plans, assignment of workload, and contingency management);
- execution (monitoring/cross-checking, workload management, and automation management); and
- monitoring or review (evaluation/modification of plans, inquiry, and assertiveness).

The skills necessary for the successful application of these countermeasures form the basis of the latest generation of crew resource management training.

1.7.5 Examined approach briefings

In the subset of the 11 most recent incursions, all of the flight crews had briefed the approach that they expected to conduct; however, due to the lack of CVR data in 8 of the 11 cases, the specific details of each briefing could not be determined with certainty in most cases.

Individual airline SOPs detail the mandatory items that flight crews must include in an approach briefing (Figure 25). A taxiing route briefing normally forms part of the approach briefing, which includes a review of aerodrome hot spots.

Figure 25. Typical approach briefing guidance within standard operating procedures

APPROACH BRIEFING

Paperwork

- ATIS information
- Notices to airmen (NOTAMs)
- Jeppesen chart notices

Approach chart

- Weather and wind
- Airspeed and/or altitude restrictions
- Designated approach and approach chart (chart number, date and notes)
- Runway info (touchdown zone elevation [TDZE], lighting, length)
- Navigation aids (NAVAIDs) (frequency and ident)
- Approach minima
- Minimum descent altitude (MDA) decision height (DH) settings
- Final approach fix / altitude
- Inbound course
- Initial approach altitude
- Missed approach plan

Terrain, taxi plan

- Terrain considerations
- Taxi route briefing (hot spots)

Special pages

- Jeppesen 10-7 pages
- Jeppesen 19-XX pages (if applicable)

The briefings that took place in the 11 incursions generally followed the SOPs. In some cases, however, the post-landing taxiing route briefing was not completed. In the cases in which it was completed, the portion of the briefing that detailed hot spots was limited to acknowledgement of the threat.

1.7.6 Depiction of hot spot locations on airport charts

All of the flight crews involved used approach charts developed by Jeppesen. The Jeppesen airport chart for CYYZ (Jeppesen CYYZ 10-9) shows the airport layout, including taxiways and hot spot locations (Appendix A). The locations of the hot spots are shown in magenta, overlaid on a black-and-white chart.

All of the RETs between the south parallel runways are depicted as hot spots on the Jeppesen chart, along with a description. The description of hot spot 1, for example, states, "Exiting [Runway] 24L on [Taxiway] D4 aircraft fail to hold short of and incur on [Runway] 06L/24R."[99]

The Jeppesen chart also includes, among several other notes, the following [emphasis in original]:

> CAUTION: Be alert to Runway 06L/24R crossing clearances. Be prepared to stop short of Runway 06L/24R. Readback of all runway holding instructions is required.[100]

Many of the flight crews involved in the 11 incursions studied stated that, although a thorough taxi briefing had not been completed, they had reviewed the individual hot spot depictions and were aware of the hazard.

1.7.7 Post-landing checklists

In all but one of the 11 incursions, at least 1 crew member was performing other flight-related duties, such as post-landing flows and/or checklists, while the aircraft was on the RET. In all of those cases, the captain was taxiing the aircraft and the first officer was performing these duties (Figure 26). In some cases, those tasks were ordered by the captain, and, in others, they were initiated by the first officer.

Figure 26. A typical post-landing checklist

POST-LANDING CHECK		
Auxiliary Power Unit..............	As Required	F/O [first officer]
Transponder/Radar	As Required/OFF	F/O
Flaps..	Up	F/O
Lights & Strobes.....................	As Required	F/O
Heated Probes	Off	F/O
Trims..	Zero & 7.0	F/O

Operator SOPs were examined following each incursion. In every case, the procedures required that the post-landing checklist be performed once the aircraft was clear of the active runway. Some SOPs required this task to be initiated by the captain's instruction, whereas others required only that the aircraft be clear of the active runway before the first officer executed the checklist. None of the SOPs examined required that the aircraft be stopped or that it first be clear of all active runways.

In contrast to the timing of this post-landing checklist, most of the operator SOPs included a note or guidance requiring that both flight crew members remain "head-up" (i.e., focus their attention outside the aircraft) when approaching hot spots or runway crossings. This guidance was commonly included in the normal taxi procedures or before-takeoff section and was intended to prevent runway incursions during taxiing for departure, while the first officer was "head-down" completing before-takeoff checklists.

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99 Jeppesen Airport Chart 10-9A – Toronto/Pearson Intl (06 October 2017).

100 Jeppesen Airport Chart 10-9 – Toronto/Pearson Intl (06 October 2017).

1.7.8 Effect of mental models on expectations and attention

Mental models are critical for effective performance in dynamic, time-critical environments, because they reduce the need for time-consuming evaluations of a given situation and enable quick actions. However, they can also lead to errors in how information is perceived.

In operational situations, people use their prior experience and knowledge to rapidly categorize the situation and select an appropriate course of action.[101] Therefore, in highly practised situations, attention and expectations are often driven by the person's existing mental model of the situation, with previous experience dictating what information is important and how the situation will unfold.

Human attention and the capacity to process information are, however, limited. While attention can be switched rapidly from one information source to another, humans can attend well to only one information source at a time. These limitations of attention require operators to adapt their focus according to the situation.

When pilots are attending to visual cues in an aircraft operating environment, this selective attention is heavily influenced by their mental model of the situation and by environmental expectations.[102] Simply stated, pilots are guided by their expectations of what information will be important and where visual cues are likely to be located in determining where to focus their attention.

1.7.9 Confirmation bias

When individuals have established a mental model of a situation, they tend to look for evidence that confirms or matches their current interpretation, and to disregard or downplay information that is inconsistent with that understanding. This tendency is called confirmation bias.

This bias can make it less likely that individuals reassess their initial interpretation and update it with new information. Likewise, it can lead them to hand-pick information that supports their current state of awareness, while dismissing information that is the opposite of what is expected.[103,104] In many circumstances, we hear what we expect to hear and see what we expect to see.

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

[102] C. D. Wickens and J. G. Hollands, *Engineering Psychology and Human Performance*, 3rd Edition (Prentice Hall, 2000), pp. 70–74.

[103] A. Tversky, and D. Kahneman, "Judgment under uncertainty: Heuristics and biases," 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).

[104] 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).

1.7.10 Electronic cockpit aids

There are a growing number of cockpit-based tools available that have been designed to aid situational awareness on the ground in airport environments. These tools are designed, in part, to help prevent runway incursions, as a significant portion of incursions result from degraded situational awareness.

Some of those systems are integrated with cockpit display and alerting systems, such as Thales' On-Board Airport Navigation System (OANS), or Honeywell's Runway Awareness and Advisory System (RAAS) and SmartRunway. Others are integrated into electronic-flight-bag (EFB) applications, such as Foreflight or Jeppesen Flightdeck Pro.

RAAS and SmartRunway are software additions to the enhanced ground proximity warning systems (EGPWSs) already installed on many aircraft. These additions use data stored in the EGPWS database and are coupled with the global positioning system (GPS) and other onboard aircraft systems to determine the aircraft's position on the surface. They have several advisories, including a visual and verbal alert when the aircraft is approaching a runway. They do not, however, detect conflicts or provide information about other aircraft.

OANS provides crews with increased situational awareness by providing a cockpit display that shows the aircraft's real-time position overlaid on an airport diagram. Similar to RAAS, OANS also advises flight crews when the aircraft is approaching a runway by displaying a pulsing message with the name of the runway. Both the OANS and RAAS/SmartRunway advisories are cued at predefined times and distances from the runway surface rather than at the actual runway holding positions.

Foreflight, Flightdeck Pro, and other EFB applications are similar to OANS in that they provide a visual depiction of an aircraft's current position at the airport; however, they do not provide explicit advisories or warnings regarding the aircraft's proximity to a runway.

None of the aircraft involved in the incursions included in this investigation were known to be equipped with RAAS, OANS, or EFB-based airport situational awareness aids.

1.7.11 Safety bulletins

As a result of the studies and investigations completed by NAV CANADA and the GTAA in 2012, a safety campaign was held to raise awareness and to reduce recurrence. The U.S. Regional Airline Association distributed an advisory to its members, and most member airlines—including, in particular, those that had already been involved in incursions at CYYZ—distributed safety bulletins to their flight crew members. Most of those bulletins were distributed in 2013.

Between 2013 and 2017, and during the course of this investigation, most operators of aircraft that had been involved in incursions reacted to the incidents in part by reminding their flight crews of the risk through memoranda, bulletins, or other interim measures.

In August 2017, following the 12th consecutive runway incursion by U.S. regional carriers, the TSB published a safety advisory[105] to renew awareness of this recurring issue and to prompt similar carriers to take action. The safety advisory was distributed widely, but was targeted directly to U.S. regional carriers who operated flights into CYYZ.

[105] TSB Safety Advisory A17O0038-D1-A1.

2.0 ANALYSIS

All of the incursions studied in this investigation occurred after the flight crews involved had landed on Runway 06R/24L, had been instructed by air traffic control (ATC) to hold short of Runway 06L/24R, and, despite intending to stop, had missed the visual cues identifying the respective locations of the runway holding positions. To pass the Runway 06L/24R holding positions, the flight crews had missed the Runway 06L/24R elevated signage, elevated stop bars, runway guard lights, painted mandatory hold signage, enhanced taxiway centreline lighting, enhanced holding position markings, and illuminated stop bars.

The analysis will discuss the causes and contributing factors that led to the flight crews not detecting the runway holding positions, the effectiveness of the risk defences currently in place on the south complex of Toronto/Lester B. Pearson International Airport (CYYZ), and potential strategies for mitigating the ongoing risk by reducing either the probability of incursions or the severity of their consequences.

The factors are categorized into 3 types: those related to the aerodrome, those involving ATC, and those that concern flight operations.

2.1 Aerodrome

2.1.1 Rapid exit taxiways

During high-volume traffic periods at CYYZ, the use of triple runway operations allows for maximum operational capacity in terms of aircraft movements per hour. To help achieve that capacity, all of the runways are equipped with rapid exit taxiways (RETs), which allow aircraft to exit the landing runways at higher speeds, reducing runway occupancy times.

In their current configuration, the 2 closely spaced parallel runways on the south complex are directly connected by the RETs that exit the outer runway. Given that the parallel runways are spaced 305 m (1000 feet) apart, the RETs are relatively short.

On most of the commonly used RETs, the distance between the runway holding positions is approximately 130 m (427 feet); that distance is reduced to 70 m (230 feet) on RET D6. This portion of each RET includes a section intended to make it possible for aircraft to reduce speed following exit from the runway, yet the large radius of the RET curves enables relatively fast speeds. Therefore, although aircraft are decreasing speed when transiting this area, their taxiing speeds are normally higher than taxiing speeds of aircraft approaching runway holding positions at other locations at CYYZ.

At the recorded median taxiing speed of all aircraft types on the RETs, an aircraft would normally travel the distance between the runway holding positions in 16 seconds, or 9 seconds in the case of RET D6. Aircraft taxiing faster than the median speed would cover this distance in even less time, as was the case in many of the incursions studied in this investigation, and among regional jets in general.

If taxiways are not designed to limit the speed at which aircraft approach a runway holding position, there is a risk that aircraft will approach too quickly, reducing the time available for crews to identify important visual cues and for ATC to intervene before an aircraft incurs on the runway surface.

In addition, the short distance between the hold lines and the common practice of sequencing post-landing checklists after exiting a runway means that flight crews are often occupied with other tasks while taxiing between the lines. Although this period may normally be sufficient for crews to identify visual cues, it can be insufficient if portions of that time are occupied with other tasks.

In the examined occurrences, the short distance between the runway holding positions on the RETs connecting the parallel runways, together with aircraft taxiing speeds that are faster than typical, limited the time available for flight crews to identify the visual cues designating the respective holding positions while completing post-landing tasks.

2.1.2 Stop-bar lighting

One of the most salient visual cues available to flight crews approaching the runway holding position is the stop-bar lighting. This lighting includes a string of red lights inset into the pavement and 2 pairs of elevated stop-bar lights at either end of the line.

Both sets of lights were directionally oriented in accordance with the guidance provided in the 4th edition of Transport Canada's *Aerodrome Standards and Recommended Practices* (TP 312), which was in effect when the runway was certified. The guidance required that the inset lights be aimed parallel to the taxiway centreline and also permitted the elevated lights to be aimed toward a location where aircraft would likely stop.

As a result of this setup, neither the inset nor elevated stop-bar lights at each runway holding position were oriented toward aircraft approaching from the taxiway curve. Consequently, the majority of the lighting was not visible until aircraft were nearly at the stop line, which limited the time available for taxiing flight crews to recognize the visual cue.

The 5th edition of TP 312 provides more specific guidance with regard to the directional orientation of both sets of lights. If the changes contained in the updated guidance were implemented at the south complex of CYYZ, the stop-bar lighting would be more visible to approaching aircraft.

In addition to the directional orientation of the lights, the investigation noted that the intensity of the stop-bar lights was occasionally inconsistent. The inconsistency was caused by the use of differing light fixtures that originated from different manufacturers and had different specifications. In a few cases, the lights were obscured or non-functional. It could not be determined whether this deficiency had a direct result on any particular occurrence, although if inset stop-bar lights have differing brightness and beam spread or are obscured or non-functional, there is a risk that they will be ineffective in alerting flight crews to stop.

None of the flight crews involved in the incursions studied in this investigation recalled seeing the inset stop-bar lights or recognizing the location of the runway holding position. The intensity of the inset stop-bar lighting was insufficient to attract the crews' attention as they approached the runway holding positions, which contributed to the crews' not recognizing the position.

2.1.3 Marking and signage

During the course of this investigation, in consultation with the local runway safety team (LRST), the Greater Toronto Airports Authority (GTAA) made 2 relevant changes to the paint markings at CYYZ in a continuing effort to address the incursion issue.

Several flight crews reported during interviews that they had difficulty distinguishing the transition from the taxiway to the runway and reported seeing only 1 of the 2 sets of runway holding position markings (hold lines) when taxiing on the RET.

Mandatory instruction sign markings were added to the runway holding positions on exits from Runway 06R/24L, and unbroken runway side-stripe markings were added to Runway 06L/24R.

The added mandatory instruction sign markings will likely increase the conspicuity of the holding positions and thereby better draw flight crews' attention to the 1st line encountered during the transition from landing to holding short. If flight crews can better identify both runway holding positions, there may be a reduced incidence of their crossing the 2nd line while believing it to be the 1st.

The runway side-stripe marking adds a visual cue to the transition from the taxiways to the runway. It may help prevent flight crews that have already crossed the runway holding position from entering the runway surface.

Although these changes were incorporated on RET D6 by October 2017, another 2 incursions[106] have occurred at this location since that time. As with the incursions following the conspicuity improvements made in 2013, the incursions following these 2017 improvements suggest that these types of enhancements alone are likely insufficient to significantly reduce the risk of runway incursions.

2.1.4 Runway holding position following a curve

The configuration of the south complex was compared with that of other high-volume airports around the world that incorporate closely spaced parallel runways with RETs between them.

The other locations that did not have an intermediate parallel taxiway generally followed 1 of 2 patterns. At airports where the distance between the parallel runways was greater than 305 m (1000 feet), and where the taxiway included a curve, the turn was normally followed by a straight section before the hold line. At airports where the spacing between parallel runways was 305 m (1000 feet) or less, the RET did not normally include a significant curve before the runway holding position. The configuration at CYYZ is

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[106] These were the November 2017 incursion previously mentioned, and an incursion in June 2018, which was outside the period covered in this investigation.

uncommon in that the runway holding positions on the RETs are situated immediately following a 65° curve.

The only high-volume airports that were identified as having similar configurations were Seoul Gimpo (Kimpo) Airport (RKSS) in South Korea, which has significantly lower operational volume than CYYZ, and Sapporo/New Chitose Airport (RJCC) in Japan, which is equipped with runway status lights (RWSLs). One exit at Chicago Midway International Airport (KMDW), Illinois, U.S., is also similarly configured.

2.1.5 Runway holding position distance

At airports throughout Canada and the U.S., and internationally, the runway holding positions are normally established at the minimum distance from the runway centreline prescribed in the applicable manual. The minimum in Canada and internationally is 90 m (295 feet). In the U.S., depending on the aircraft types using the runway, the minimum is either 85 m (280 feet), or, for narrow-body or smaller aircraft, 76 m (250 feet).

At CYYZ, the commonly used RETs (D1, D2, D3, D4, and D5) have runway holding positions protecting Runway 06L/24R at a distance of 115 m (377 feet), and for RET D6 the distance is farther, at 140 m (459 feet). These placements were designed following a recommendation in the 4th edition of TP 312, which called for a distance of 115 m (377 feet) at locations where there are frequent runway crossings.

On the RETs, the runway holding positions are situated immediately following a 65° curve, and the distance of each runway holding position from the runway it protects exceeds that required by current guidance or commonly seen at other high-volume airports. Flight crews of arriving aircraft may be unfamiliar with the taxiway configuration and the distance to the runway holding position, and the respective crews of the aircraft involved in the incursions expected to see the runway holding position at a different location.

This uncommon placement can affect flight crews' recognition of the associated visual cues. When crews are attending to visual cues in the runway environment, selective attention is influenced by the crews' mental model of the situation and by what they expect to see in the environment.[107] Guided by their expectations of what information will be important and where visual cues are likely to be located when determining where to focus their attention, crews will look for a hold line in the approximate location where they expect to see one.

If runway holding positions are not established at distances that are consistent with those at other airports, there is an increased risk that flight crews will not recognize the visual cues designating those positions because of an expectation that the positions will be in the locations that they are accustomed to.

[107] C. D. Wickens and J. G. Hollands, *Engineering Psychology and Human Performance*, 3rd Edition (Prentice Hall, 2000), pp. 70–74.

The holding positions on the D6 RET are the farthest from the runways that they protect, and the distance between its exiting and entering holding positions is the shortest, contributing to the higher rate of incursion at this intersection.

2.1.6 Common crossing locations

The U.S. Federal Aviation Administration (FAA) has stated that a very high percentage of the most serious runway incursions occur within the first two thirds of the runway length. The likely reason for this is that departing aircraft are usually still on the ground or have just become airborne, whereas landing aircraft are still in the high-speed portion of the landing roll.

On the south complex at CYYZ, RETs D1, D2, and D3 intersect the runway in the first two thirds of its length. These 3 exits account for approximately 42% of the crossing traffic. RET D4, which alone accounts for 46% of crossings, is just beyond the two-thirds point.

If commonly used runway crossings are situated where aircraft departing from the runway are normally still on the ground or airborne at a low altitude, and an aircraft incurs on the departure runway, there is a significantly increased risk of collision.

2.1.7 Direct access

Of the 130 high-volume airports examined, CYYZ was the only airport identified in Canada or the U.S. where the RETs allow direct access to an adjacent runway and where the runways are spaced 305 m (1000 feet) or more apart. Although some of the identified airports in the U.S. do incorporate RETs with direct access to an adjacent runway, all of the parallel runways at those airports are spaced less than 305 m (1000 feet) apart. This close spacing makes it more difficult to incorporate an intermediate parallel taxiway.

There are no restrictions in TP 312 or the International Civil Aviation Organization's (ICAO's) Annex 14 precluding the direct-access layout of the south complex. However, the FAA's advisory circular on airport design[108] and the European Organisation for the Safety of Air Navigation's (EUROCONTROL's) November 2017 version of the *European Action Plan for the Prevention of Runway Incursions*[109] recommend against this type of configuration.

The RETs provide direct access to the adjacent runways rather than to another transitional surface. Flight crews of arriving aircraft missed the visual cues depicting the runway holding position while conducting post-landing tasks and, as a result, incurred on the inner runway, posing a serious risk of collision with departing aircraft.

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[108] U.S. Federal Aviation Administration, Advisory Circular 150/5300-13A: Airport Design (26 February 2014).

[109] European Organisation for the Safety of Air Navigation, *European Action Plan for the Prevention of Runway Incursions*, Version 3.0 (20 November 2017), p. 123.

2.1.8 Mitigation options

Efforts to document best practices for preventing runway incursions have been made by both aircraft manufacturers[110] and regulators, including ICAO[111] and the FAA.[112] A review of those documents highlighted the importance of adopting a systemic approach to reducing incursions that aims to eliminate hazards, where practicable, and mitigate those that cannot be eliminated.

The ICAO *Manual on the Prevention of Runway Incursions* recommends that, once hazardous areas are identified, strategies to manage or mitigate the risk should be implemented, including awareness campaigns, additional visual aids, alternate routings, or, ultimately, the construction of new taxiways.

2.1.8.1 Awareness campaigns

Over the period covered by this investigation, individual operators, pilot unions, airline associations, the TSB, and the GTAA have distributed several bulletins, or safety advisories, to raise awareness of the incursion risk on the south complex at CYYZ.

The bulletins focused mainly on identifying the threat and suggested that individuals address the threat through increased vigilance. These types of awareness campaigns can be effective in the short term, and, in this case, the periodic reduction in incursions following the release of those messages suggests that they were somewhat effective.

The primary disadvantage of such campaigns is that their effectiveness diminishes over time. If the periodic reduction in incursions following previous campaigns was due in part to their effectiveness, then the subsequent increases or return to previous rates could likely be explained similarly—that is, the effect of the bulletins wore off.

There are other limitations to the effectiveness of such bulletins. They may not reach a large number of individual operators or provide timely reminders. They also do not generally recommend any particular strategy to address the threat other than to be careful.

2.1.8.2 Increased conspicuity

Although the stop-bar lights were illuminated at the time of each incursion, the flight crews of approaching aircraft did not notice them. Issues in directional orientation, inconsistent lighting intensity, and obstructions were identified, but these issues on their own were likely not significant enough to account for how frequently flight crews missed seeing the lights entirely.

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110 Airbus Industrie, Flight Operations Briefing Notes: Runway and Surface Operations – Preventing Runway Incursions (May 2004).

111 International Civil Aviation Organization, Doc 9870 AN/463, *Manual on the Prevention of Runway Incursions*, First Edition (2007).

112 U.S. Federal Aviation Administration, Advisory Circular 120-74B: Parts 91, 121, 125, and 135: Flightcrew Procedures During Taxi Operations (30 July 2012).

Visual cues placed in locations that are not consistent with expectations need to be significantly more salient to attract a flight crew's attention and divert it from their current area of focus. As shown in these occurrences, if visual cues intended to alert flight crews to holding positions in uncommon locations are not sufficiently compelling to alter a flight crew's mental model of the situation, there is a continued risk that those cues will go unnoticed by crews.

Organizations outside Canada have different requirements for the intensity and beam spread of stop-bar lighting. The FAA calls for lights that have a much larger spread, of 48° (versus 20° specified by Transport Canada), and a slightly brighter intensity, of 300 candelas (cd) (versus 200 cd). ICAO's standards are similar to those of Transport Canada; however, ICAO recommends increasing the intensity of these lights to 1800 cd if they are used as part of an advanced surface movement guidance and control system (A-SMGCS) or in bright sunlight in areas identified as posing a high risk.

To enhance the conspicuity of the stop bars, ICAO recommends significantly increasing the intensity of the stop-bar lights in bright daytime conditions. Additionally, it is now possible to reduce the lateral spacing between lights to less than the original 3 m (10 feet). In a trial of a stop bar with spacing reduced to 1.5 m (5 feet) in conjunction with the use of light-emitting diode (LED) filaments, this option was "shown to greatly increase the visibility of the stop bars in all light conditions."[113]

Another alternative discussed during LRST meetings was to augment the conspicuity of the runway holding position by installing collocated inset runway guard lights. These lights would be installed at the same location as the stop-bar lights, but would alternately flash yellow rather than red only.

Generally, the advantage of a red, rather than yellow, light is that red is known to mean "stop." In the incursions examined in this investigation, it was not a question of the flight crews being unaware that they needed to stop; rather, they simply missed seeing the lights entirely. In such cases, a flashing set of lights, especially with an intensity of 1000 cd and a beam spread of 48°, would therefore likely provide an advantage over the steadily illuminated red lights at 200 cd and 20°.

Some concerns remain to be addressed regarding switching from stop bars to inset runway guard lights, such as their compatibility with current ATC stop-bar overrun alarms and their usage during category II/III weather conditions.

2.1.8.3 Runway status lights

Runway status lights (RWSLs) directly fulfill a mitigation strategy previously set out in the TSB Watchlist: the installation of new technological defences that reduce the incidence of

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[113] European Organisation for the Safety of Air Navigation, "Request for support message: runway incursion prevention aerodrome stop bar operating policy," in *Hindsight 19* (summer 2014), p. 18.

serious runway incursions by providing automated direct-to-pilot warnings. RWSLs are now in use at numerous airports in the U.S. and at some airports internationally.

The main advantages of RWSLs are that they operate automatically and provide warnings directly to flight crews, without the need for intervention by controllers. Moreover, the warnings can be conveyed without radio communication, which could be a critical benefit if the latter is restricted owing to frequency congestion.

RWSLs generally have 3 components: runway entrance lights (RELs), runway intersection lights (RILs), and take-off hold lights (THLs). The operational characteristics of these components were examined to determine whether they could have been effective mitigations in the cases studied in this investigation, had RWSLs already been installed.

It was determined that RILs would not have been an effective defence, because none of the examined incursions took place at a runway-to-runway intersection.

Depending on their exact configuration, THLs likely would have illuminated in 5 of the 11 cases to alert the departing flight crews to the presence of an incurring aircraft. Of those 5 cases, there were only 2 in which ATC had considered an aborted or cancelled take-off clearance necessary. Given that the 3 aircraft in the remaining cases departed safely without the warning, it could not be determined whether aborting the takeoffs would have been a safer course of action.

The examination of RELs showed that they would have illuminated in 9 of the 11 cases. The inset RELs on the taxiway centreline would have displayed red as the taxiing aircraft approached the stop bar. Because the red lights are situated along the centreline of the taxiway and extend from a point just before the runway holding position to the runway surface, they are visible for an extended period. Although it is possible that the flight crews would have seen these lights, this could not be determined with certainty, given that the other visual cues were missed.

In other types of scenarios, the automatic operation of the RELs is a critical function. The RELs illuminate without controller input, for example in cases when a controller has forgotten an aircraft or issued an inappropriate clearance. They also illuminate if a flight crew is momentarily lost or is unaware of their aircraft's proximity to an active runway with current traffic.

Unlike increased conspicuity, the automatic function of the RELs would not necessarily have been an effective mitigation in any of the occurrences. In each case, the flight crews were aware of the other runway and knew that they had to stop. The controllers were aware of the aircraft's movements as well and had lit the stop bars, issued hold-short instructions, received correct readbacks, and were monitoring for compliance.

2.1.8.4 Relocation of holding position

Given that the uncommon placement of the runway holding positions can adversely affect a flight crew's recognition of its associated visual cues, relocating the positions to their common locations may appear to solve this deficiency.

Relocating the runway holding positions closer to the runway centreline—to a position more consistent with that at other airports—would likely reduce the frequency of incursions because the hold lines would then be situated where flight crews expect to see them. However, this reduction in frequency may not result in an overall reduction in risk.

Moving each hold line closer to the runway it protects would displace it from its current location immediately following the 65° curve, and situate it at a point that follows the short, straight section of taxiway. This repositioning would reduce the unique proximity of the hold line to the curve, making its location more consistent with that at other airports. Further, it would create additional taxiing distance, extending the time for flight crews to notice the visual cues designating the runway holding position.

If the runway holding positions were repositioned at a point that follows the short, straight section of taxiway, the lights installed at each position, including the inset and elevated stop bars and elevated guard lights, could be realigned to orient them straight down the taxiway, rather than having them angled toward the inside of the corner. Again, this alignment would provide consistency with that seen at most other airports.

The sole disadvantage of relocating the runway holding positions closer to the runway surface is that, when an aircraft does advance over the hold line, the shorter distance to the runway will reduce the time available for ATC to react and instruct the flight crew to stop before the aircraft breaches the runway surface. This closer proximity to the runway and, therefore, to the departing aircraft, may increase the severity of such incursions.

Of the 11 most recent incursions examined in this investigation, only 3 involved aircraft that continued to the point of breaching the runway surface. Given no change in other variables, and assuming that crews do not see the hold lines, if the hold lines had been relocated and the incurring aircraft had travelled the same distance past the hold lines that they did in the cases examined, 6 aircraft would have breached the runway edge.

If the RETs continue to provide direct access to adjacent runways and runway holding positions are moved closer to their respective departure runways, there may be a reduction in the frequency of incursions; however, there could be an increase in severity if an aircraft does incur on the runway surface while an aircraft is departing.

2.1.8.5 Parallel taxiway

As shown in these occurrences, if flight crews of aircraft that exit the landing runway on a RET are not provided with sufficient taxiway distance to accomplish post-landing tasks before reaching the runway holding position, and if their speed is not reduced by taxiway design characteristics when approaching these positions, there is a continuing risk that flight crews who perform these tasks and do not reduce their speed will incur on the inner runway.

While individual changes can be recommended to operators, and pilots' awareness of standard operating procedures (SOPs) and of the need for vigilance can be increased through training and bulletins, these measures may not reach all of the operators and pilots who currently fly into CYYZ or who may do so in the future. Although such changes could improve briefings, alter routines, and raise awareness, they are unlikely to universally and permanently change the expectations that flight crews have for consistency among airport designs.

Directionally re-orienting the stop-bar lights, ensuring that they are all functioning uniformly, reducing the spacing between them, switching them to flashing inset runway guard lights, and possibly incorporating RELs should increase overall conspicuity. Nevertheless, the recurrence of incursions following improvements made in 2013 and 2017 to the conspicuity of visual cues to runway holding position locations suggests that, if the runway holding positions remain in the same locations and flight crews are not primed to focus their attention outside the aircraft immediately upon exiting a landing runway, there is a continued risk that crews will miss the visual cues, regardless of further conspicuity improvements.

This investigation has identified several causal, contributing, and risk factors that are directly related to airport geometry: the short distance between runway holding positions on the RETs, the direct access of the RETs to the adjacent runways, the speed at which aircraft approach the hold line, the displaced distance of the runway holding positions, and the locations of common runway crossing points (Figure 27). With the possible exception of taxiing speeds, these factors cannot be addressed by increasing conspicuity or amending operators' SOPs.

As previously discussed, examination of the 130 busiest airports by passenger volume identified CYYZ as the sole airport in North America that has parallel runways spaced 305 m (1000 feet) or more apart but lacks an intermediate parallel taxiway. While adding a parallel taxiway may not be the only solution to the incursion risk, it would likely address most of the causal, contributing, and risk factors identified in this investigation.

If there were a parallel taxiway, aircraft that exit onto an RET would taxi onto a transitional surface that parallels the landing runway and travel on that surface before making a 90° turn to hold short of the departure runway. As a result, the distance between the exiting and hold-short runway holding positions would be lengthened significantly, allowing the flight crew more time to complete post-landing tasks, if they continue to be done at that time.

The additional taxiing surface would also mean that aircraft would no longer be going directly from the RET to the adjacent runway, which would allow flight crews more time to reduce the speed at which they approach the runway holding position. The shorter-radius 90° turn would also necessitate a reduction in speed. In addition, the runway holding positions would be returned to their typical 90 m distance, and the crossing points could be placed closer to the end of the runway (Figure 28).

Figure 27. Current configuration of the south complex at CYYZ (Source: Google Earth, with TSB annotations)

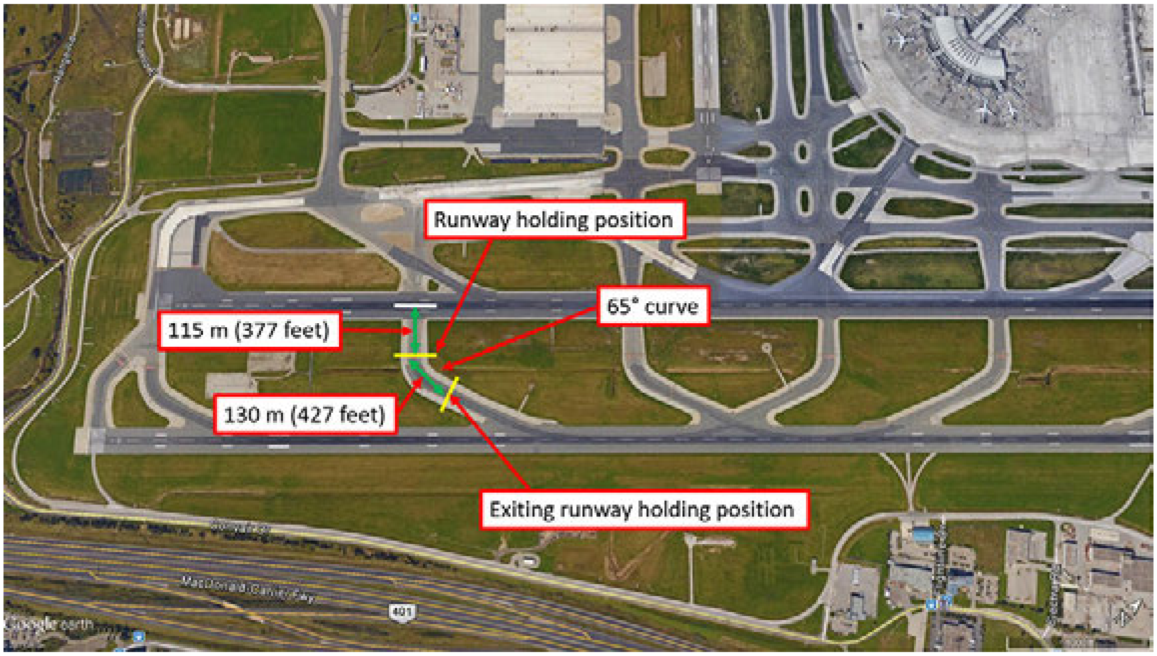
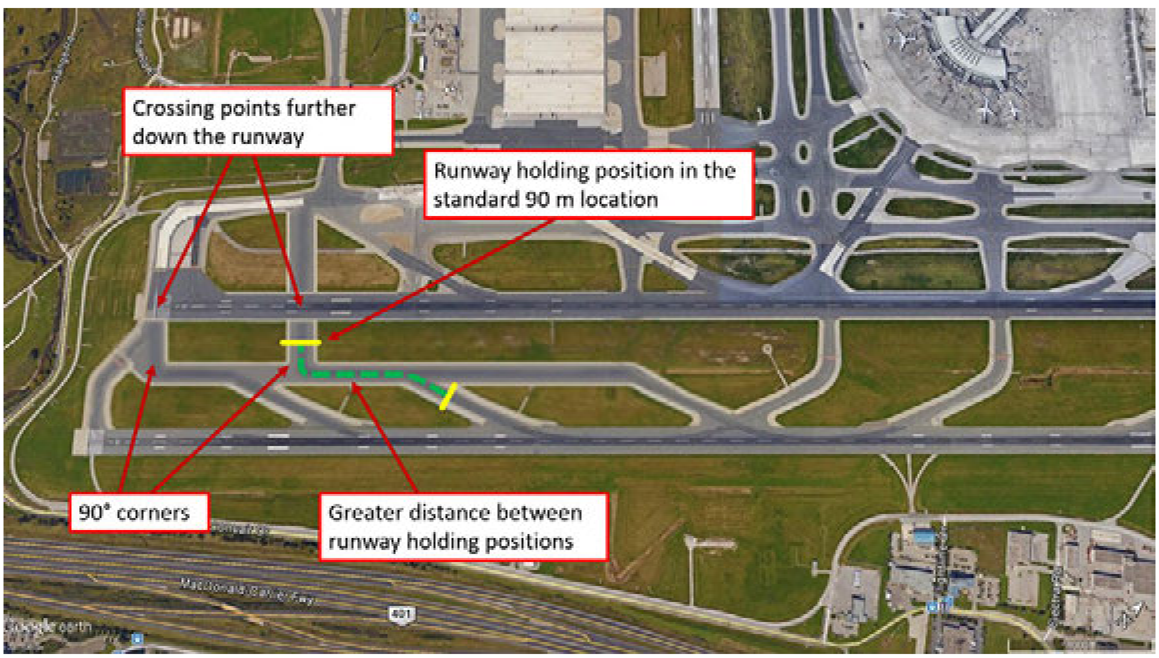


Figure 28. Hypothetical configuration of the south complex at CYYZ (Source: Google Earth, with TSB annotations)



2.2 Air traffic control

2.2.1 General

All of the incursions examined in this investigation were a result of flight crew inaction and the underlying causal and contributing factors that led to that inaction, rather than actions or inactions by air traffic controllers.

In these occurrences, ATC was the last line of defence to reduce the severity of the runway incursions and was generally effective in doing so. Each of the developing incursions was detected by the controllers through visual monitoring and alarms from the runway incursion monitoring and conflict alert system (RIMCAS). When necessary, the incurring aircraft were quickly instructed to stop, and these rapid instructions prevented most of the aircraft from reaching the runway surface.

Although ATC was not directly linked to the cause of these incursions, several risks were identified during the investigation that could contribute to incursions in the future or reduce the effectiveness of the defences in place to mitigate the likelihood of a resulting collision.

2.2.2 Automatic terminal information service

Automatic terminal information service (ATIS) messages are intended to automate the repetitive transmission of essential but routine information to improve controller effectiveness and relieve radio frequency congestion. Along with other information, ATIS messages include details about identified hazards that flight crews should be aware of. The standard ATIS message used during triple runway operations advises flight crews that high-intensity runway operations are in effect and that crews should therefore minimize runway occupancy times and pay attention to runway crossing instructions.

The portion of that message that is intended to raise awareness of the known incursion hazard between the parallel runways states, “Be alert to runway crossing instructions” and “Readback of all hold-short instructions is required.” This wording suggests that insufficient attention to crossing instructions by flight crews is the hazard. In fact, the hazard is that crews are not identifying the runway holding position and are incurring on the inner runway. Most of the flight crews who were interviewed following an incursion did not recall the ATIS message; those who recalled it stated that they had neither recognized it as a warning nor adjusted their plans.

If the portion of the ATIS message that is intended to alert flight crews to the risk of runway incursions on the inner runway does not clearly identify the hazard, there is a risk that the use of this defence will not be effective, because crews will remain unaware of the hazard.

2.2.3 Runway incursion monitoring and conflict alert system

Each controller position in the tower is equipped with an A-SMGCS screen, which displays ground-based traffic and alerts from the RIMCAS.

2.2.3.1 False alarms

Incorrect target perceptions by the RIMCAS can cause the system’s incursion-monitoring function to produce false alarms. These perceptual errors can arise for a variety of reasons, including radar signal reflection off ground features or precipitation and errors from multipath propagation of the signals. When such errors lead to excessive false alarms, controllers periodically disable the RIMCAS.

NAV CANADA has made numerous attempts over many years to reduce the frequency of false alarms by improving the ground surveillance system, most recently with the addition of multilateration and new system software; however, the false alarms remain. The prevalence of false alarms is not accurately known, as the alarms are not specifically tracked.

Given that RIMCAS false alarms are somewhat common, controllers may question the validity of the alarms until the source can be confirmed either visually or on the display. If RIMCAS false alarms occur with routine frequency, there is a risk that RIMCAS alarms will be disregarded or that remedial actions will not be executed in a timely fashion.

2.2.3.2 Default settings

Each individual controller can customize the default settings that determine which RIMCAS alerts are active, depending on which position they are occupying. The runway incursion–monitoring function is specific to the runway surface being used and monitored, and needs to be modified depending on the type of operation at the time. This function can be, and occasionally is, disabled entirely if false alarms become distracting.

At the time of these occurrences, there was no guidance that instructed controllers to set defaults for any of the runway incursion monitoring alerts. Given the various possibilities for active runway configurations, a standard default would not likely be effective at ensuring the safest setting was selected.

The stop-bar overrun alerting function can be selected separately from the runway incursion monitoring function. This feature is not tied to any specific runway and, when selected to ON, monitors all of the stop bars on the airfield. The stop-bar overrun alert sounds only if an aircraft crosses a lit stop bar; therefore, it is unlikely that a stop-bar overrun alert would be false, and there would therefore be little reason to disable the alert. A crossed stop bar is always a serious situation.

The stop-bar overrun alert was the controller's first indication of the incursion in 2 of the examined 11 cases. In all other cases, the alert sounded either at the same time as the controller saw the incursion happening or shortly thereafter.

In 6 of the 11 examined cases, the stop-bar overrun alert feature had been disabled at the south tower position at the time of the incursion because of the default setting saved on the individual controller's profile. However, in all 11 examined cases, the alert sounded as designed in each case because it was selected to ON at other positions in the tower.

Nevertheless, if user-selectable settings for stop-bar overrun alerting systems are not defaulted to ON, there is a risk that the alerts will be disabled at the time of an incursion and will not alert the controllers to the critical situation.

When management of the control tower at CYYZ became aware that the default setting was OFF, they published an operations directive in March 2017 requiring that all controllers set the stop-bar overrun alert function to ON by default in their saved profiles.

2.2.4 Audible alerting

The audible alarm that sounds as a result of a stage 2 runway incursion monitoring alert is identical to the audible alarm for a stop-bar overrun alert. Each alert has an associated visual depiction on the A-SMGCS display, which is the only way for a controller to distinguish with certainty what triggered the alarm.

The need to distinguish between these alarms has previously been identified, and at least 1 airport in Europe already uses verbal systems to differentiate the source of the alarm.

Because false runway incursion monitoring alerts are somewhat common, controllers may delay their response to these indistinguishable audible alerts, pending verification. The stop-bar overrun feature, however, is not known to produce false alerts. Therefore, if the audible component of overrun alerts were significantly different from that for potentially false incursion alerts, controllers might be able to more easily identify the source of the conflict and, as a result, issue more timely mitigation instructions.

If audible alarms that are intended to alert controllers to various differing critical situations sound identical, there is a risk that those alarms will not draw the attention of controllers to the specific threats that they indicate.

2.2.5 Lighting control

TSB investigators noted that, on one occasion, the stop-bar lights had not been set to their maximum intensity. Given that the intensity of the lights is not recorded, the level to which they had been set at the time of each incursion could not be determined.

In accordance with the *Manual of Air Traffic Services* (MATS), controllers generally vary the strength of airfield lighting, depending on the degree of daylight and on weather conditions, and the stop-bar lights may have been adjusted to the same level as those other lights. There is currently no guidance or procedure requiring the stop-bar lights to be set to maximum intensity.

If procedures do not require user-selectable settings for stop-bar light illumination to be selected to full intensity by default, there is a risk that the lights will be set to an intensity that is insufficient to draw the attention of flight crews.

2.2.6 Urgent safety-critical transmission phraseology

Air traffic controllers do not regularly issue urgent safety-critical instructions. Such instructions include, but are not limited to, instructions to abort takeoff, cancel a take-off clearance, pull up and go around, or stop (when the aircraft is on the ground).

In one of the occurrences examined in this investigation, ATC instructed a departing aircraft to abort its takeoff because of an incursion. The instruction stated only the aircraft's call sign followed by "abort takeoff" and was issued in the same tone that the controller used for all transmissions. That phraseology was not consistent with the flight crew's previous experiences, and they did not recognize that the transmission was directed at them or note its content. As a result, they continued the takeoff.

The TSB has previously investigated occurrences in which instructions to abort takeoff or initiate a go-around were not acted upon by the flight crews involved. In those occurrences, the phraseology used was not sufficiently compelling to capture the attention of the crews and ensure that they recognized the significance of the instruction during a high-workload phase of flight.

The phraseology used by the controller in the abort instruction mentioned above, and in the previous cases investigated by the TSB, followed the guidance provided by NAV CANADA in both the current MATS and the previous *Air Traffic Control Manual of Operations* (ATC MANOPS).

The international guidance for issuing these instructions differs from that of NAV CANADA. The phraseology for cancelling a take-off clearance in ICAO's *Procedures for Air Navigation Services—Air Traffic Management* (PANS-ATM) requires controllers to repeat the instruction, normally prefaced by the phrase "I say again," and to repeat the words "stop immediately!" if the aircraft has already begun its take-off roll.

ATC procedures in Canada do not specifically require the use of these techniques when cancelling a take-off clearance. Although the ATC MANOPS generally specifies that repeating an instruction may be used for emphasis and provides for the term "immediately" to be used when required for safety reasons, these techniques are not specifically required when cancelling a take-off clearance, aborting a takeoff, or instructing an aircraft to go around.

The take-off and landing phases of a flight are periods of high workload for the flight crew. During periods of high workload, individuals focus most of their attention on the most critical tasks and, as a result, filter or ignore sensory input that they deem less relevant or important. If ATC transmissions that require immediate action by a flight crew are not sufficiently compelling to attract the crew's attention during periods of high workload, there is risk that those transmissions will not be recognized or acted on.

2.2.7 Occurrence reporting

Of the 11 most recent events examined in this investigation, the TSB was able to acquire data from the flight data recorder for only 6 events and from the cockpit voice recorder for only 3. The remaining data were lost because the TSB was not notified of the event until after the recordings had been overwritten.

NAV CANADA's procedural document for occurrence reporting states that the shift manager must contact the TSB immediately following an accident or a high-profile event; however, there is no guidance as to what constitutes a high-profile event. As a result of that limited guidance, the respective shift managers in the cases involving loss of data had assessed those events as not sufficiently high-profile to warrant an immediate notification.

If inter-organizational procedures are not clear and specific with regard to immediate notification in the event of a serious incident, there is a continuing risk that the TSB will not be advised of the incident in sufficient time to secure on-board recordings, resulting in loss of information that may have been valuable to the assessment of safety deficiencies.

2.3 Flight operations

All of the incursions examined involved flight crews who had been instructed to hold short, had accurately read back the instruction, had understood that they needed to stop, and had understood that they were approaching an active runway. However, despite those factors, they did not recognize the visual cues that identified the runway holding position, and the aircraft incurred on the runway.

This section will describe the underlying factors that led to the crews' lack of recognition of those visual cues, including their limited familiarity with and anticipation of the uncommon taxiway layouts, the degree of adequacy of approach briefings, the timing of post-landing checks, the aircraft's taxiing speed while approaching the hold line, and other available defences.

2.3.1 Expectation of common taxiway characteristics

As described in section 1.5, the runway holding positions on each RET between the parallel runways are situated immediately following a curve and at a distance of either 115 m or 140 m from the centreline of the runway it protects. When compared with layouts in other high-volume airports in North America, the curves are very rare and the distances are entirely unique. This uniqueness creates a situation in which the holding positions are not located where crews are expecting them to be.

Attention is a limited resource, and expectation plays a critical role when crews are determining where to focus. In terms of situational awareness, the flight crews' expectation that the stopping position would be located farther along their path meant that their attentional resources were not effectively directed outside the aircraft at the appropriate time to allow them to perceive the hold-line markings and other visual cues in sufficient time to stop.

In other words, the uncommon location of the runway holding positions, after the curve in their respective taxiways and farther back from the runway than normal, created a situation in which flight crews did not anticipate the need to stop in that particular location. As a result, the attention of the crews was not focused outside the aircraft at the appropriate time to identify the holding position. This situation often resulted in the crews not recalling seeing the visual cues at all.

A flight crew's mental model of their operating environment influences the ways in which they interpret and explain the information they perceive. Greater value tends to be placed on information that is consistent with a person's mental model (a tendency known as confirmation bias), while inconsistent information tends to be discounted. In the events examined, the crews who recalled noticing the visual cues of the runway holding position disregarded them, believing that those cues were depicting the exiting position, not the runway holding position.

Because of that confirmation bias, those flight crew members whose attention was centred outside the aircraft while approaching the runway holding position were likely focused on a position farther down the taxiway, where the runway holding position is typically located. Therefore, they likely disregarded the nearby visual cues, which did not conform to their mental model.

Over time, as flight crews become more familiar with the RETs at CYYZ, their expectation of the placement of the runway holding positions changes. Although the events examined were not limited to flight crews who were unfamiliar with the airport, flight crews based in the U.S. were overrepresented in the number of incursions versus their Canadian counterparts, likely because they are generally less familiar with the uncommon location of runway holding positions in RETs of the south complex at CYYZ.

2.3.2 Approach briefings

All of the flight crews involved in the occurrences examined and completed approach briefings, per their respective company's SOPs. These briefings generally covered only those items specifically laid out in the SOPs. The presence of hot spots on the taxi route was noted by some crews, but not all.

2.3.2.1 Airport charts

As part of their approach briefings, flight crews consult the CYYZ airport chart. The chart provides details about the airport and taxiway layout and associated information, such as warnings and runway incursion hot spots.

When specifying each of the runway incursion hot spots, the chart informs flight crews that, in the past, aircraft have not held short as required at these locations and have incurred on Runway 06L/24R. This information is true and may result in an increased level of awareness, but it provides no guidance to assist crews in addressing the threat, such as detailing the uncommon location of the runway holding position after a curve, or its uncommon distance from the runway. It is likely that the hazards of those factors were not completely understood when the hot spot descriptions were written.

The airport chart also includes a cautionary note advising flight crews to be alert to runway crossing clearances and to be prepared to hold short of Runway 06L/24R. This advice seems to be intended to help crews avoid incursions, but it is not focused on the most relevant issue. Runway incursions at CYYZ—both recently and further in the past—have not been caused by crews missing crossing clearances or being unaware that they needed to hold short.

To effectively identify the actions necessary to avoid a runway incursion, flight crews require more information than the fact that there have been previous runway incursions at a particular location. If they do not understand the reasons why previous incursions have taken place, it will be difficult for them to anticipate the specific actions necessary to prevent a recurrence.

The airport charts, supplied to assist flight crews in planning their arrivals to CYYZ, identified the presence of runway incursion hot spots and contained general warnings about this type of incursion. However, the charts lacked sufficient information to impart a clear understanding of the risk or lead the crews to take effective mitigating measures.

2.3.2.2 Standard operating procedures for taxi briefings

Briefings are an essential tool for helping crews to maintain situational awareness. By providing an opportunity to assimilate operationally relevant information and anticipate its impact on the operation of the aircraft, briefings can be an effective threat-and-error management tool.

Best practices for preventing runway incursions have focused on identifying methods to increase the likelihood that both flight crew members will anticipate hazardous locations during the taxiing phase. Specifically, it has been recommended that a thorough interactive crew briefing that focuses on what is different on that day be completed. The briefing should address the taxiing phase in detail, including required runway crossings and hot spots, and discuss the timing of checklists and other non-essential cockpit tasks.

If taxi briefings are not thorough, there is a risk that flight crews will be unaware of known or predictable hazards likely to be encountered during the taxiing phase, and this lack of awareness, and associated lack of planned mitigation, may result in a runway incursion or collision.

In the incursions examined, the approach briefings completed by the flight crews generally followed the guidance laid out in each company's SOPs, which frequently included a prompt for crews to brief the taxiing route, including the applicable hot spots. However, in some cases, crews did not brief the expected taxiing route. In the cases in which a taxi briefing was completed, the portion of the briefing that mentioned hot spots was simply a recognition of the threat and did not include a plan or discussion of any mitigation strategy.

Guidance from the FAA in 2012 called for operators to develop specific SOPs to prevent runway incursions. The FAA advisory circular emphasized that a thorough taxi briefing should include a review of the airport diagram, including hot spots and their textual descriptions. In addition, the circular called for SOPs that would require crews to describe how runway incursion threats would be mitigated: by briefing the timing and execution of checklists and communications, so that neither crew member was preoccupied or head-down when approaching an active runway.

In the cases examined in this investigation, although the operators' SOPs included approach-briefing guidance encouraging flight crews to identify various hazardous situations, the SOPs did not require crews to discuss how those situations would be addressed. As a result, although some of the crews were aware of hazard hot spots at CYYZ and conducted briefings on them, the crews made no adjustment to their normal routines.

If approach briefings that draw attention to previously identified hazards do not also provide options to mitigate them, there is a continuing risk that flight crews will be unprepared to mitigate those hazards when they arise.

2.3.3 Post-landing tasks

Given that the approach briefings that were conducted did not describe an adjustment to the normal routine following landing, the flight crews in most cases maintained their standard practice of initiating the post-landing flows and checklists after exiting the landing runway. Those actions diverted the attention of one, and occasionally both, of the crew members from the more critical task of locating the runway holding position.

The airlines involved all had similar procedures in place that called for these post-landing checklists to be completed once the aircraft was clear of the landing runway. There was some variation as to whether these checklists could be initiated by the first officer or needed to be ordered by the captain; however, both variations resulted in the checklists being executed immediately after exiting the runway.

When post-landing checklists are being completed, the field of vision of the individual completing them is drawn toward the centre pedestal, instrument panel, and overhead panel (i.e., inside the cockpit). Having 1 crew member distracted from the task of taxiing the aircraft while approaching an active runway reduces the likelihood that visual cues depicting the runway holding position will be noticed, and increases the risk of a runway incursion.

Guidance published by the FAA in 2012 recommended that thorough taxi briefings be completed to prevent incursions and that, in an effort to maintain situational awareness, post-landing tasks should be initiated only when the aircraft is clear of all runways and on the terminal side of the runway complex. At the time of publication of this investigation, none of the operators involved in the occurrences examined had incorporated either of these recommendations in their SOPs.

If SOPs prompt flight crews to conduct post-landing tasks before coming to a stop, or before they are clear of all runways, there is a risk that those tasks will distract crews from more safety-critical responsibilities.

Although the SOPs may have prompted this distraction, the procedures also often included a requirement for both crew members to be head-up when approaching hot spots or runway crossings. In some cases, there was a requirement for the captain to ensure that the first officer was head-up at these times but there was also a requirement for the captain to order the first officer to initiate the post-landing checks, which requires the first officer to be head-down.

SOPs that called for post-landing checks to be conducted after exiting the landing runway and those that required both flight crew members to be head-up when approaching runway hot spots did not take into account that the taxiways exiting the runway had direct access to the adjacent runway. As a result, it was left to the flight crews' discretion whether to follow one SOP or the other, and those whose aircraft incurred had chosen to complete the post-landing checks.

2.3.4 Aircraft taxi speed and field of vision

The speed at which aircraft taxi when approaching the runway holding positions can significantly affect the amount of time available to crews in which to identify the visual cues indicating the position.

An examination of routine aircraft taxiing speeds on the RETs approaching the runway holding positions showed that speed was generally inversely proportional to the size of the aircraft—the larger the aircraft, the slower it approached. The exact reason for this difference was not determined. However, it is likely that flight crews of larger aircraft recognize that they need a greater distance to stop, due to momentum; as a result, they reduce their speed while taxiing.

This investigation found that smaller regional jets accounted for approximately 39.5% of the traffic landing on Runway 06R/24L and holding short of Runway 06L/24R, yet they accounted for 77.8% of the incursions studied.

Regional jets were overrepresented in the number of incursions, likely due to the higher speed at which these aircraft types approached the runway holding position, both during the incursions and when compared with larger aircraft in general. This higher speed reduced the time available to identify the necessary visual cues.

The CRJ and ERJ 135/145 series aircraft have design eye reference point heights that are lower than those of other common aircraft, such as the Boeing 737; however, the field of vision obscured by the glareshield or aircraft structure on these smaller aircraft types is also less. The larger regional jets (ERJ 170s) have an eye height and obscured distance similar to those of the Boeing 737.

Although the height at which ground markings are viewed can affect the distance at which the markings are first perceived, it could not be determined whether this characteristic played a role in the incursions.

2.3.5 Other available defences

2.3.5.1 Electronic cockpit aids

Many runway incursions are caused by a flight crew being unaware of their proximity to the runway or that the runway they are crossing is active.

Electronic cockpit aids that help increase situational awareness—such as Thales' On-Board Airport Navigation System (OANS), Honeywell's Runway Awareness and Advisory System, or other electronic-flight-bag (EFB) applications—would likely help mitigate this common root cause of typical incursions by ensuring that crews are aware of their exact position and their proximity to the runway surface.

When considered as direct mitigations for the types of incursions examined in this investigation, the cockpit aids that provide advisories may have contributed to reducing the severity of the incursions by alerting crews that they were approaching a runway.

These systems display or sound an alert as the aircraft is approaching a runway at a position predetermined by design and dependent on speed. Although such advisories would not necessarily have been triggered at or before the runway holding positions, the flight crews involved may have stopped their aircraft before or without ATC intervention, had these warnings been available to them.

By contrast, the heightened situational awareness of the aircraft's position on the taxiway that would be provided to flight crews by the visual depiction of the aircraft on the airport diagram, seen in both OANS and the EFB applications, would likely have been of limited benefit in these incursions.

The flight crews in each of the examined incursions were already fully aware of which taxiway they were on and that they were approaching an active runway. An additional aid to remind them of this information, especially one that would require at least momentary visual attention inside the cockpit at a time when full attention is required outside, would probably not have increased the likelihood of identifying the visual cues designating the runway holding position.

3.0 FINDINGS

3.1 Findings as to causes and contributing factors

3.1.1 Aerodrome

1. The short distance between the runway holding positions on the rapid exit taxiways (RETS) connecting the parallel runways, together with aircraft taxiing speeds that are faster than typical, limited the time available for flight crews to identify the visual cues designating the respective holding positions while completing post-landing tasks.

2. Neither the inset nor elevated stop-bar lights at each runway holding position were oriented toward aircraft approaching from the taxiway curve. As a result, the majority of the lighting was not visible until aircraft were nearly at the stop line, which limited the time available for taxiing flight crews to recognize the visual cue.

3. The intensity of the inset stop-bar lighting was insufficient to attract the crews' attention as they approached the runway holding positions, which contributed to the crews' not recognizing the positions.

4. On the RETs, the runway holding positions are situated immediately following a 65° curve, and the distance of each runway holding position from the runway it protects exceeds that required by current guidance or commonly seen at other high-volume airports. Flight crews of arriving aircraft may be unfamiliar with the taxiway configuration and the distance to the runway holding position, and the respective crews of the aircraft involved in the incursions expected to see the runway holding position at a different location.

5. The RETs provide direct access to the adjacent runways rather than to another transitional surface. Flight crews of arriving aircraft missed the visual cues depicting the runway holding position while conducting post-landing tasks, and, as a result, incurred on the inner runway, posing a serious risk of collision with departing aircraft.

6. The holding positions on the D6 RET are the farthest from the runways that they protect, and the distance between its exiting and entering holding positions is the shortest, contributing to the higher rate of incursion at this intersection.

3.1.2 Flight operations

1. All of the incursions examined involved flight crews who had been instructed to hold short, had accurately read back the instruction, had understood that they needed to stop, and had understood that they were approaching an active runway. However, despite those factors, they did not recognize the visual cues that identified the runway holding position, and the aircraft incurred on the runway.

2. The airport charts, supplied to assist flight crews in planning their arrivals to CYYZ, identified the presence of runway incursion hot spots and contained general warnings about this type of incursion. However, the charts lacked sufficient information to impart a clear understanding of the risk or lead the crews to take effective mitigating measures.

3. Although the operators' standard operating procedures (SOPs) included approach-briefing guidance encouraging flight crews to identify various hazardous situations, the SOPs did not require crews to discuss how those situations would be addressed. As a result, although some of the crews were aware of hazard hot spots at CYYZ and conducted briefings on them, the crews made no adjustment to their normal routines.

4. Given that the approach briefings that were conducted did not describe an adjustment to the normal routine following landing, the flight crews in most cases maintained their standard practice of initiating the post-landing flows and checklists after exiting the landing runway. Those actions diverted the attention of one, and occasionally both, of the crew members from the more critical task of locating the runway holding position.

5. SOPs that called for post-landing checks to be conducted after exiting the landing runway and those that required both flight crew members to be head-up when approaching runway hot spots did not take into account that the taxiways exiting the runway had direct access to the adjacent runway. As a result, it was left to the flight crews' discretion whether to follow one SOP or the other, and those whose aircraft incurred had chosen to complete the post-landing checks.

6. The uncommon location of the runway holding positions, after the curve in their respective taxiways and farther back from the runway than normal, created a situation in which flight crews did not anticipate the need to stop in that particular location. As a result, the attention of the crews was not focused outside the aircraft at the appropriate time to identify the holding position.

7. Those flight crew members whose attention was centred outside the aircraft while approaching the runway holding position were likely focused on a position farther down the taxiway, where the runway holding position is typically located. As a result, they likely disregarded the nearby visual cues, which did not conform to their mental model.

8. Flight crews based in the United States were overrepresented in the number of incursions versus their Canadian counterparts, likely due to the fact that they are generally less familiar with the uncommon location of runway holding positions in RETs of the south complex at CYYZ.

9. Regional jets were overrepresented in the number of incursions, likely due to the higher speed at which these aircraft types approached the runway holding position, both

during the incursions and when compared with larger aircraft in general. This higher speed reduced the time available to identify the necessary visual cues.

3.2 Findings as to risk

3.2.1 Aerodrome

1. If runway holding positions are not established at distances that are consistent with those at other airports, there is an increased risk that flight crews will not recognize the visual cues designating those positions because of an expectation that the positions will be in the locations that they are accustomed to.

2. If visual cues intended to alert flight crews to holding positions in uncommon locations are not sufficiently compelling to alter a flight crew's mental model of the situation, there is a continued risk that those cues will go unnoticed by crews.

3. If inset stop-bar lights that are installed to draw attention to the runway holding position have differing brightness and beam spread or are obscured or non-functional, there is a risk that they will be ineffective in alerting flight crews to stop.

4. If taxiways are not designed to limit the speed at which aircraft approach a runway holding position, there is a risk that aircraft will approach too quickly, reducing the time available for crews to identify important visual cues and for air traffic control to intervene before an aircraft incurs on the runway surface.

5. If commonly used runway crossings are situated where aircraft departing from the runway are normally still on the ground or airborne at a low altitude, and an aircraft incurs on the departure runway, there is a significantly increased risk of collision.

6. The recurrence of incursions following improvements made in 2013 and 2017 to the conspicuity of visual cues to runway holding position locations suggests that, if the runway holding positions remain in the same locations and flight crews are not primed to focus their attention outside the aircraft immediately upon exiting a landing runway, there is a continued risk that crews will miss the visual cues, regardless of further conspicuity improvements.

7. If the RETs continue to provide direct access to adjacent runways and runway holding positions are moved closer to their respective departure runways, there may be a reduction in the frequency of incursions; however, there could be an increase in severity if an aircraft does incur on the runway surface while an aircraft is departing.

8. If flight crews of aircraft that exit the landing runway on a RET are not provided with sufficient taxiway distance to accomplish post-landing tasks before reaching the runway holding position, and if their speed is not reduced by taxiway design characteristics

when approaching these positions, there is a continuing risk that flight crews who perform these tasks and do not reduce their speed will incur on the inner runway.

3.2.2 Air traffic control

1. If air traffic control transmissions that require immediate action by a flight crew are not sufficiently compelling to attract the crew's attention during periods of high workload, there is a risk that those instructions will not be recognized or acted on.

2. If runway incursion monitoring and conflict alert system (RIMCAS) false alarms occur with routine frequency, there is a risk that RIMCAS alarms will be disregarded or that remedial actions will not be executed in a timely fashion.

3. If audible alarms that are intended to alert controllers to various differing critical situations sound identical, there is a risk that those alarms will not draw the attention of controllers to the specific threats that they indicate.

4. If user-selectable settings for stop-bar overrun alerting systems are not defaulted to ON, there is a risk that the alerts will be disabled at the time of an incursion and will not alert the controllers to the critical situation.

5. If procedures do not require user-selectable settings for stop-bar light illumination to be selected to full intensity by default, there is a risk that the lights will be set to an intensity that is insufficient to draw the attention of flight crews.

6. If inter-organizational procedures are not clear and specific with regard to immediate notification in the event of a serious incident, there is a continuing risk that the TSB will not be advised of the incident in sufficient time to secure on-board recordings, resulting in loss of information that may have been valuable to the assessment of safety deficiencies.

7. If the portion of the automatic terminal information service (ATIS) message that is intended to alert flight crews to the risk of runway incursions on the inner runway does not clearly identify the hazard, there is a risk that crews will remain unaware of the hazard and that the use of this defence will not be effective.

3.2.3 Flight operations

1. If approach briefings that draw attention to previously identified hazards do not also provide options to mitigate them, there is a continuing risk that flight crews will be unprepared to mitigate those hazards when they arise.

2. If taxi briefings are not thorough, there is a risk that flight crews will be unaware of known or predictable hazards likely to be encountered during the taxiing phase, and

this lack of awareness, and associated lack of planned mitigation, may result in a runway incursion or collision.

3. If SOPs prompt flight crews to conduct post-landing tasks before coming to a stop, or before they are clear of all runways, there is a risk that those tasks will distract crews from more safety-critical responsibilities.

4.0 SAFETY ACTION

4.1 Safety action taken

Since the 1st incursion covered in this investigation, all parties involved have been taking safety action. This safety action is described throughout the report.

4.2 Safety action required

4.2.1 Phraseology for use in safety-critical scenarios

Over the past 5 years, the TSB has investigated 3 events in Ontario[114]—including one of the incursions detailed in this report—in which air traffic control (ATC) instructions issued to flight crews to address a conflict were not recognized or acted on.

When air traffic controllers recognize a conflict between aircraft or vehicles—such as when an aircraft is on the take-off roll and another aircraft incurs on the runway—they must issue prompt instructions to resolve the conflict. These instructions need to be recognized and understood by the intended recipients so that the safest course of action can be taken. If these instructions are not actioned, there is a risk that the conflict may result in a collision.

The current guidance provided to air traffic controllers in Canada with respect to the phraseology to be used in these safety-critical situations is different from international guidance. It does not prescribe any attention-getting enhancements, such as using the word "immediately" or repeating the instruction. Without these enhancements, the instruction may not be compelling enough to attract the intended recipient's attention, and, as the phraseology may be different from what flight crews are expecting, there is a risk that the instruction will not be immediately understood, particularly during periods of high workload. These 2 factors may result in the instruction not being actioned and an increased risk of collision.

Therefore, the Board recommends that

> NAV CANADA amend its phraseology guidance so that safety-critical transmissions issued to address recognized conflicts, such as those instructing aircraft to abort takeoff or pull up and go around, are sufficiently compelling to attract the flight crew's attention, particularly during periods of high workload.
>
> **TSB Recommendation A18-04**

4.2.2 Timing of post-landing procedures

Once an aircraft has landed on a runway and the landing roll is complete, the flight crew must perform a series of post-landing tasks. As detailed in this investigation, during normal operations, most flight crews begin these tasks when the aircraft is clear of the landing runway, in accordance with their operator's standard operating procedures (SOPs). These

[114] TSB aviation investigation reports A13O0049 and A13O0045, and the 02 August 2015 incursion examined in this report.

tasks, or checklists, are usually brief and occupy only a small amount of one or both of the flight crew members' attention.

At airports that have closely spaced parallel runways, aircraft that have landed on the outer runway normally exit the runway via a rapid exit taxiway, which sometimes terminates directly on the inner runway. In most cases, ATC will instruct flight crews to hold short of this runway because the runway is in use by other departing or arriving traffic. In these cases, it is essential that, immediately after exiting the landing runway, flight crews focus their attention on acquiring the visual cues necessary to identify the runway holding position in order to prevent the aircraft from incurring on the other active runway.

Most operators' SOPs require that the post-landing checks be conducted once the aircraft is clear of the landing runway. However, as shown in this investigation, if these SOPs are followed when flight crews are operating on closely spaced parallel runways, they may focus their attention inside the cockpit at a time when their full attention and visual focus are required outside. As a result of this distraction, flight crews may miss the visual cues and incur on the active runway, which presents a significant risk of collision.

In 2012, the U.S. Federal Aviation Administration (FAA) published guidance for operators to help them develop and implement SOPs to prevent runway incursions. Although this guidance advises flight crews to initiate non-essential post-landing actions—such as raising flaps or adjusting trim—after the aircraft is clear of all active runways, it does not propose any specific amendments to post-landing SOPs that reflect this advice. None of the operators involved in the occurrences studied had incorporated any changes to their post-landing SOPs to address this concern.

Therefore, the Board recommends that

> the Department of Transport work with operators to amend standard operating procedures so that post-landing checks are sequenced only after landing aircraft are clear of both active runways when closely spaced parallel runway operations are in effect, rather than the current common practice of sequencing the checks once landing aircraft are clear of the landing surface.
>
> **TSB Recommendation A18-05**

The Board also recommends that

> the United States Federal Aviation Administration work with operators to amend standard operating procedures so that post-landing checks are sequenced only after landing aircraft are clear of both active runways when closely spaced parallel runway operations are in effect, rather than the current common practice of sequencing the checks once landing aircraft are clear of the landing surface.
>
> **TSB Recommendation A18-06**

4.2.3 Taxiway design and conspicuity

The taxiway layout between the closely spaced parallel runways at Toronto/Lester B. Pearson International Airport (CYYZ) has several characteristics that are uncommon when compared with those at other airports, both within North America and globally. The runways are spaced a relatively short distance apart, and the rapid exit taxiways provide direct access to the adjacent runway without first progressing to another transitional surface. The runway holding positions are located immediately following a 65° curve and are situated at greater distances from the protected inner runway than is seen elsewhere.

These uncommon characteristics, and the short distance between the runways, present significant challenges for flight crews. When exiting the landing runway, crews are normally occupied with other tasks and, because they are using a rapid exit taxiway, the aircraft is usually travelling at taxi speeds that are faster than typical. A flight crew's unfamiliarity with these uncommon characteristics, the short amount of time and distance available, and distraction due to other tasks reduces their ability to identify the runway holding positions. As demonstrated by the occurrences covered in this investigation, if these positions are not identified, aircraft can incur on the other active runway and potentially collide with another aircraft.

International guidance recommends many strategies to address runway incursions. All but one of these have been implemented on the south complex at CYYZ; the remaining strategy is to make physical changes to the taxiway layout.

A change of this scale may be required to increase the distance and taxiing time between runway holding positions, to reduce the taxiing speeds of aircraft approaching the hold-short line, to prevent direct access to adjacent runways from rapid exit taxiways, and to re-situate visual cues in common locations. Among the possible reconfigurations that may address these factors is the inclusion of an intermediate parallel taxiway between the runways, as found at numerous other airports with parallel runways.

It is recognized, however, that a change this significant cannot be made overnight, and simpler incursion mitigation strategies may need to be implemented, or current strategies improved, in the meantime. Although much has been done over the past few years to improve the conspicuity of the runway holding positions, options still remain, such as altering the type, amount, or intensity of the runway holding position lighting, which may further improve the likelihood that flight crews identify the cues and stop before incurring on the runway.

Therefore, the Board recommends that

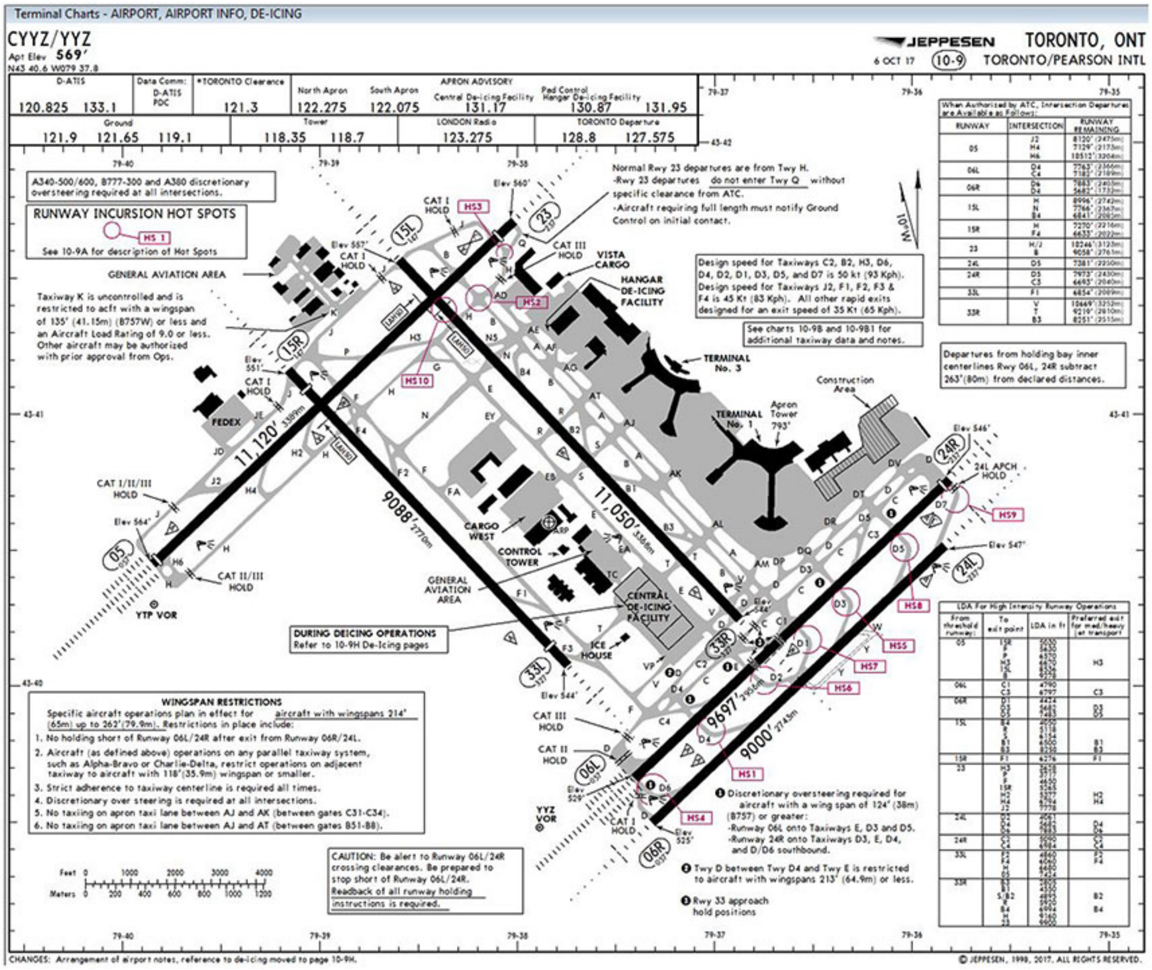
> the Greater Toronto Airports Authority make physical changes to the taxiway layout to address the risk of incursions between the parallel runways and, until these changes can be made, make further improvements to increase the conspicuity of the runway holding positions.
>
> **TSB Recommendation A18-07**

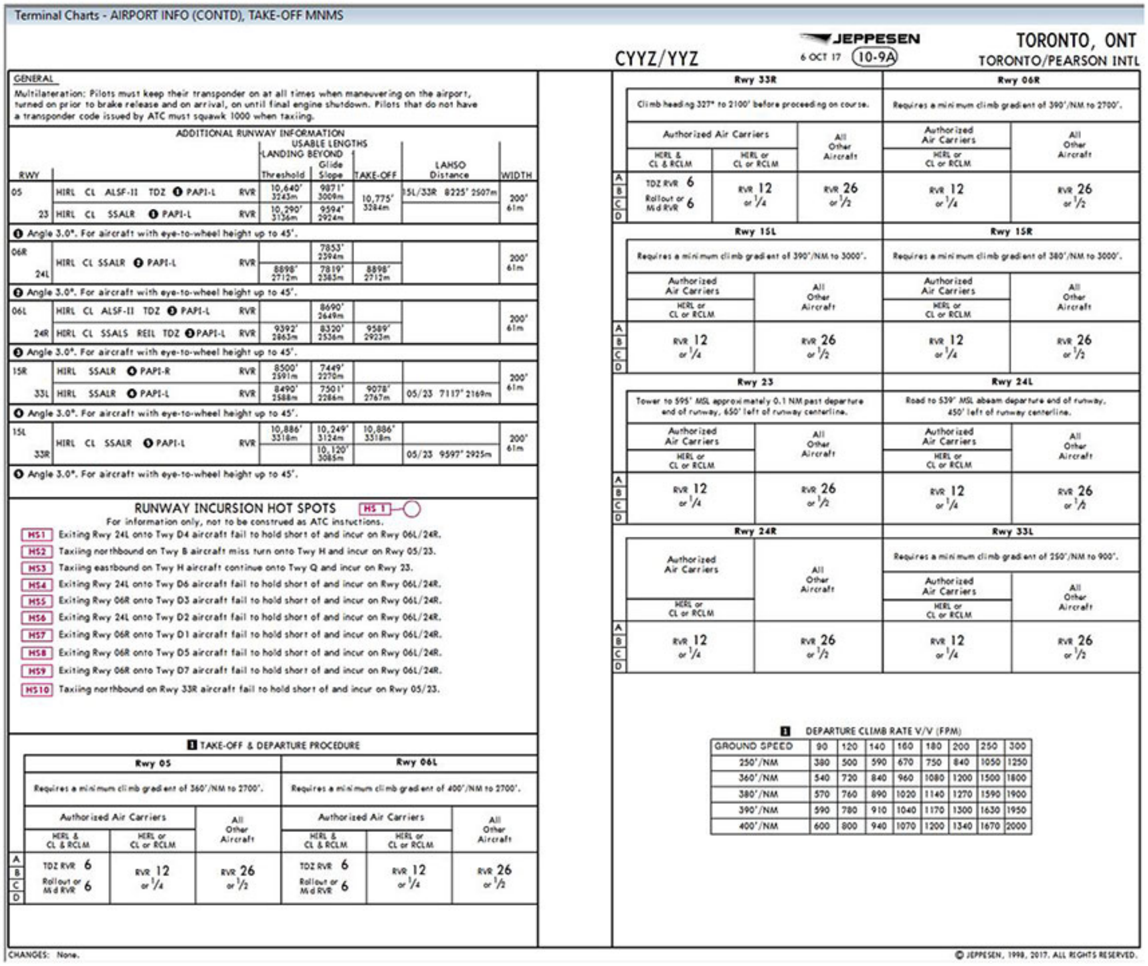
This report concludes the Transportation Safety Board of Canada's investigation into this safety issue. The Board authorized the release of this report on 28 November 2018. It was officially released on 31 January 2019.

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

APPENDICES

Appendix A – Jeppesen Airport Charts for CYYZ





Terminal Charts - AIRPORT INFO (CONTD), TAKE-OFF MNMS

CYYZ/YYZ — JEPPESEN — 6 OCT 17 — 10-9A — TORONTO, ONT — TORONTO/PEARSON INTL

GENERAL

Multilateration: Pilots must keep their transponder on at all times when maneuvering on the airport, turned on prior to brake release and on arrival, on until final engine shutdown. Pilots that do not have a transponder code issued by ATC must squawk 1000 when taxiing.

ADDITIONAL RUNWAY INFORMATION

RWY			Usable lengths: Landing beyond Threshold	Landing beyond Glide Slope	TAKE-OFF	LAHSO Distance	WIDTH
05	HIRL CL ALSF-II TDZ (1) PAPI-L	RVR	10,640' 3243m	9871' 3009m	10,775' 3284m	15L/33R 8225' 2507m	200' 61m
23	HIRL CL SSALR (1) PAPI-L	RVR	10,290' 3136m	9594' 2924m			
(1) Angle 3.0°. For aircraft with eye-to-wheel height up to 45'.							
06R	HIRL CL SSALR (2) PAPI-L	RVR		7853' 2394m			200' 61m
24L			8898' 2712m	7819' 2383m	8898' 2712m		
(2) Angle 3.0°. For aircraft with eye-to-wheel height up to 45'.							
06L	HIRL CL ALSF-II TDZ (3) PAPI-L	RVR		8690' 2649m			200' 61m
24R	HIRL CL SSALS REIL TDZ (3) PAPI-L	RVR	9392' 2863m	8320' 2536m	9589' 2923m		
(3) Angle 3.0°. For aircraft with eye-to-wheel height up to 45'.							
15R	HIRL SSALR (4) PAPI-R	RVR	8500' 2591m	7449' 2270m			200' 61m
33L	HIRL SSALR (4) PAPI-L	RVR	8490' 2588m	7501' 2286m	9078' 2767m	05/23 7117' 2169m	
(4) Angle 3.0°. For aircraft with eye-to-wheel height up to 45'.							
15L	HIRL CL SSALR (5) PAPI-L	RVR	10,886' 3318m	10,249' 3124m	10,886' 3318m		200' 61m
33R				10,120' 3085m		05/23 9597' 2925m	
(5) 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 instuctions.

- HS1 Exiting Rwy 24L onto Twy D4 aircraft fail to hold short of and incur on Rwy 06L/24R.
- HS2 Taxiing northbound on Twy B aircraft miss turn onto Twy H and incur on Rwy 05/23.
- HS3 Taxiing eastbound on Twy H aircraft continue onto Twy Q and incur on Rwy 23.
- HS4 Exiting Rwy 24L onto Twy D6 aircraft fail to hold short of and incur on Rwy 06L/24R.
- HS5 Exiting Rwy 06R onto Twy D3 aircraft fail to hold short of and incur on Rwy 06L/24R.
- HS6 Exiting Rwy 24L onto Twy D2 aircraft fail to hold short of and incur on Rwy 06L/24R.
- HS7 Exiting Rwy 06R onto Twy D1 aircraft fail to hold short of and incur on Rwy 06L/24R.
- HS8 Exiting Rwy 06R onto Twy D5 aircraft fail to hold short of and incur on Rwy 06L/24R.
- HS9 Exiting Rwy 06R onto Twy D7 aircraft fail to hold short of and incur on Rwy 06L/24R.
- HS10 Taxiing northbound on Rwy 33R aircraft fail to hold short of and incur on Rwy 05/23.

TAKE-OFF & DEPARTURE PROCEDURE

Rwy 05 — Requires a minimum climb gradient of 360'/NM to 2700'.

Rwy 06L — Requires a minimum climb gradient of 400'/NM to 2700'.

Rwy	Authorized Air Carriers: HIRL & CL & RCLM	Authorized Air Carriers: HIRL or CL or RCLM	All Other Aircraft
05 (A/B/C/D)	TDZ RVR 6 / Rollout or Mid RVR 6	RVR 12 or 1/4	RVR 26 or 1/2
06L (A/B/C/D)	TDZ RVR 6 / Rollout or Mid RVR 6	RVR 12 or 1/4	RVR 26 or 1/2
33R (A/B/C/D)	TDZ RVR 6 / Rollout or Mid RVR 6	RVR 12 or 1/4	RVR 26 or 1/2

Rwy 33R — Climb heading 327° to 2100' before proceeding on course.

Rwy 06R — Requires a minimum climb gradient of 390'/NM to 2700'.

Rwy 15L — Requires a minimum climb gradient of 390'/NM to 3000'.

Rwy 15R — Requires a minimum climb gradient of 380'/NM to 3000'.

Rwy 23 — Tower to 595' MSL approximately 0.1 NM past departure end of runway, 650' left of runway centerline.

Rwy 24L — Road to 539' MSL abeam departure end of runway, 450' left of runway centerline.

Rwy 24R

Rwy 33L — Requires a minimum climb gradient of 250'/NM to 900'.

Rwy	Authorized Air Carriers: HIRL or CL or RCLM	All Other Aircraft
06R (A/B/C/D)	RVR 12 or 1/4	RVR 26 or 1/2
15L (A/B/C/D)	RVR 12 or 1/4	RVR 26 or 1/2
15R (A/B/C/D)	RVR 12 or 1/4	RVR 26 or 1/2
23 (A/B/C/D)	RVR 12 or 1/4	RVR 26 or 1/2
24L (A/B/C/D)	RVR 12 or 1/4	RVR 26 or 1/2
24R (A/B/C/D)	RVR 12 or 1/4	RVR 26 or 1/2
33L (A/B/C/D)	RVR 12 or 1/4	RVR 26 or 1/2

DEPARTURE CLIMB RATE V/V (FPM)

GROUND SPEED	90	120	140	160	180	200	250	300
250'/NM	380	500	590	670	750	840	1050	1250
360'/NM	540	720	840	960	1080	1200	1500	1800
380'/NM	570	760	890	1020	1140	1270	1590	1900
390'/NM	590	780	910	1040	1170	1300	1630	1950
400'/NM	600	800	940	1070	1200	1340	1670	2000

CHANGES: None.

Appendix B – Glossary

AOR	aviation occurrence report
ARIWS	autonomous runway incursion warning system
ASIS	Aviation Safety Information System
A-SMGCS	advanced surface movement guidance and control system
ATC	air traffic control
ATC MANOPS	Air Traffic Control Manual of Operations
ATIS	automatic terminal information service
AVOL	aerodrome visibility operation level
CADORS	Civil Aviation Daily Occurrence Reporting System
cd	candela
CVR	cockpit voice recorder
CYYZ	Toronto/Lester B. Pearson International Airport
DH	decision height
EFB	electronic flight bag
EGPWS	enhanced ground proximity warning system
EHAM	Amsterdam Schiphol Airport
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration
FDR	flight data recorder
F/O	first officer
GPS	global positioning system
GTAA	Greater Toronto Airports Authority
ICAO	International Civil Aviation Organization
KIAH	George Bush Intercontinental/Houston Airport
KMDW	Chicago Midway International Airport
KPHX	Phoenix Sky Harbor International Airport
LED	light-emitting diode
LRST	local runway safety team
MATS	Manual of Air Traffic Services
MDA	minimum descent altitude
NAVAID	navigation aid
nm	nautical mile

NOTAM	notice to airmen
OANS	On-Board Navigation System
PANS-ATM	Procedures for Air Navigation Services–Air Traffic Management
RAAS	Runway Awareness and Advisory System
REL	runway entrance light
RET	rapid exit taxiway
RIL	runway intersection light
RIMCAS	runway incursion monitoring and conflict alert system
RJCC	Sapporo/New Chitose Airport
RKSS	Seoul Gimpo (Kimpo) Airport
ROT	runway occupancy time
RWSL	runway status light
SII	safety issue investigation
SIMMOD	Airport and Airspace Simulation Model
SMS	safety management system
SOP	standard operating procedure
TC	Transport Canada
TC AIM	Transport Canada Aeronautical Information Manual
TDZE	touchdown zone elevation
THL	take-off hold light
TP 312	Aerodrome Standards and Recommended Practices
UHF	ultra high frequency
VHF	very high frequency