Runway Safety

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Information provided through analysis of runway incursions is useful in many ways. Analysis of the errors made by pilots, controllers, and vehicle drivers is the first step toward developing error mitigation strategies. Furthermore, successful design of future systems requires knowledge of characteristics of the incursions experienced today as well as the successes and limitations of previously implemented strategies This paper explores what is known about the human errors and other factors that have been identified as contributing to runway incursions, and offers some error mitigation strategies. The data presented will be useful in helping to design the most effective tools for safety, increasing capacity, and for estimating the safety benefits of proposed system enhancements.

Introduction

Analyses of runway incursions provide critical measures of aviation safety. These events are analyzed not only to assess the incidence and severity of reportable adverse events, but also to glean information necessary for the development of error mitigation strategies and automated decision aids for pilots and controllers. Traditionally, runway incursions are classified by attribution to pilot deviations, controller errors, or vehicle/pedestrian deviations (see Table 1)—and by the severity of their outcome (see Table 2).

Incident Type	Definition
Pilot Deviation (PD)	**A pilot deviation (PD) is an action of a pilot that violates any Federal Aviation Regulation. For example, a pilot fails to obey air traffic control instructions to not cross an active runway when following the authorized route to an airport gate**
Operational Error (OE)	**An operational error (OE) is an action of an air traffic controller that results in: Less than the required minimum separation between two or more aircraft, or between an aircraft and obstacles (e.g., vehicles, equipment, personnel on runways). An aircraft landing or departing on a runway closed to aircraft.**

Vehicle/Pedestrian Deviation (VPD)	**A vehicle or pedestrian deviation (V/PD) includes pedestrians, vehicles, or other objects interfering with aircraft operations by entering or moving on the movement area without authorization from air traffic control. NOTE: This runway incursion type includes aircraft being towed and mechanics taxiing aircraft for maintenance or gate re-positioning.**

Table 1: Definition of Runway Incursion Types. (Federal Aviation Administration, Annual Runway Safety Report 2008, p. 16)

Beginning in Fiscal Year (FY) 2008, the Federal Aviation Administration (FAA) adopted the International Civil Aviation Organization (ICAO) definition of a runway incursion: *Any 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.* The severity scheme defines runway incursions that involve a conflict between two aircraft or an aircraft and a vehicle or pedestrian with a classification as an A-, B-, or C- category event. A D-category event would only be used in the case of a single aircraft/vehicle or person entering a runway safety area without authorization.

Category	Definition of Severity Category
A	Separation decreases and participants take extreme action to narrowly avoid a collision, or the event results in a collision
B	Separation decreases and there is a significant potential for collision
C	Separation decreases but there is ample time and distance to avoid a potential collision
D	Little or no chance of collision but meets the definition of a runway incursion

Table 2: Definitions of Runway Incursion Severity Categories (Federal Aviation Administration, Annual Runway Safety Report 2008, p. 12)

This paper presents the results of analyses of recent runway incursions in the United States and uses these data to describe:

- Common types of runway incursions involving a conflict between two aircraft or between an aircraft and a vehicle.
- Common types of errors by controllers, pilots, and vehicle drivers that result in runway incursions.
- Risk factors for runway incursions and risk mitigation strategies to prevent both the errors that result in runway incursions and to prevent collisions resulting from incursions.

Common Types of Runway Incursions

Runway incursions can be described in several ways. The FAA routinely describes incursions in terms of attribution (to OEs, PDs, and VPDs) and the severity of the outcome. Other ways to describe incursions, proposed in this paper, include examining the situations that resulted in the incursions. The first major demarcation in the type of situation that resulted in the incursion is whether the event involved a single aircraft, vehicle or pedestrian (entering a runway safety area without authorization), or a conflict between an aircraft that is taking off or landing and another aircraft, vehicle or pedestrian. These situations, or scenarios, that result in runway incursions can be described in terms of what the aircraft was doing at the time (e.g., taxiing, taking off or landing). It is the situations of runway incursions that involve a conflict with an aircraft landing or taking off that will be described here.

Conflict with a landing aircraft

In FY2008, as in previous years, the most common type of conflict was a taxiing aircraft or vehicle conflicting with a landing aircraft. This includes taxiing aircraft or vehicles crossing the runway or otherwise violating the runway (i.e., crossing the hold short line, crossing the runway edge, or entering the runway) in front of a landing aircraft. (It does not include conflicts with a landing aircraft and another aircraft taking off or landing on an intersecting runway as these events are categorized separately.) Similar to past years, for FY2008, this scenario accounted for 44% of the total number of runway incursions involving a conflict[2]. In the same year, this scenario accounted for 18% of all of the runway incursions[3]. Only 4% of these were the most serious (A- and B-category) in terms of outcome, due, in part, to the fact that the majority (59%) of these events resulted in a go-around. Incidents that result in the landing aircraft going around present much less risk of collision that those that involve the aircraft completing the landing. It is also the case that 48% of these events the encroaching aircraft crossed the hold short line, but did not cross the runway edge.

As previously discussed, runway incursions are attributed to controller error (termed "operational errors" or OEs), pilot deviations (PDs) or vehicle/pedestrian deviations (VPDs). In FY 2008, the majority (63%) of the incursions involving taxiing in front of a landing aircrafts were attributed to PDs, 18% were attributed to OEs, and 19% to VPDs.   In fact, crossings and potential crossings in front a landing were involved in 52% of the runway incursions (involving a conflict) attributed to pilot error. In comparison, crossings and potential crossing in front of a landing aircraft accounted for 23% of the OEs that involved a conflict.

The large difference in attribution of these events between pilots and controllers is likely due to the details behind the definition of a runway incursion used in the U.S.   That is, any incidence of a pilot entering a runway without authorization with an aircraft on approach would be counted as a runway incursion. However, if a controller cleared an aircraft to enter a runway in front of a landing aircraft, the event would not meet the definition of a runway incursion as long as the aircraft on the ground was clear of the runway while the landing aircraft was at least not yet over the threshold or the landing aircraft was instructed to go around before reaching the threshold. Different Air Traffic Service Providers use different criteria in this regard (all are consistent with the ICAO definition of an incursion). It is important to know the definitions used when interpreting such statistics.

Conflict with an aircraft taking off

The second most common type of incursion with a conflict in 2008 was a taxiing aircraft or vehicle conflicting with a takeoff. This includes crossing the runway or otherwise violating the runway (i.e., crossing the hold short line, crossing the runway edge, or entering the runway) in front of an aircraft taking off. (This does not include conflicts between an aircraft taking off and another aircraft taking off or landing on an intersecting runway as these events are categorized separately.) This scenario accounted for 37% of the total number of runway incursions involving a conflict. Only 40% of these events were attributed to controller error with 49% attributed to pilot error 11% to vehicle or pedestrian deviations. However, crossings and potential crossings in front of a takeoff was the most common scenario in controller errors involving a conflict, accounting for 43% of the OEs (but only 34% of PDs). While only six of these conflicts with a crossing aircraft resulted in an A- or B- severity outcome, the aircraft continued the takeoff (as opposed to aborting) in almost half (47%) of these instances, creating a potentially serious situation.

Other scenarios

When combined, taxiing aircraft and vehicles crossing (or potentially crossing) in front of landings and takeoffs accounted for the vast majority (80%) of the incursions involving a conflict with another aircraft (and 33% of all of the runway incursions in FY2008). The remainder involved different configurations, such as operations on intersecting runways operations on intersecting runways (9%), and two operations on the same runway in the same (8%) or opposite (1%) direction. An additional 1% involved a conflict with a stationary aircraft or vehicle on the runway.

An Example of an Effective Targeted Mitigation Strategy

The following is an example of how analyses such as those presented above can be a critical component in the identification of a risk mitigation strategy. It also exemplifies the limitations of substituting the opinion of subject matter experts for data in estimating specific risks in the system. Specifically, it demonstrates the difference between risk as perceived by the users in the system and the actual risk, supported by data.

Identified Risk

In working group discussions of risk in surface operations, pilot and controller subject matter experts identified “landovers” (that is, an aircraft landing over the aircraft holding on the runway) as a serious safety threat to air carrier operations. Landovers can occur as the result of: a pilot landing on the wrong runway, while an aircraft is holding on the runway for takeoff, or a controller mistakenly clearing an aircraft to land on a runway on which an aircraft is holding for takeoff. In the collection of industry best practices with respect to runway safety, some pilots on the Runway Safety Joint Safety Implementation Team (JSIT) recommended that all aircraft lights be illuminated whenever an aircraft is on a runway, in order to help mitigate this risk[4]. Other pilots on the team recommended that the landing light be reserved as a signal that the aircraft is rolling for takeoff. It was noted that there was no consistent practice among air carrier pilots concerning the use of the landing light(s) while lined up on the runway waiting for takeoff, or when cleared for takeoff. That is, some pilots would illuminate all of the lights (including the landing light) as they lined up on the runway with the expectation that this made the aircraft more visible to aircraft on approach and it would help prevent an aircraft on approach from landing on the same runway (i.e., landing over them). Other pilots would not illuminate the landing light until the takeoff clearance had been received. Thus, they used the landing light as a signal that the aircraft was on takeoff roll.

The Analysis

In support of the JSIT working group formed to examine this issue, a human factors analysis of runway incursions from FY2000 – FY2002 was conducted. The purpose of this analysis was to help determine which of these two aircraft lighting strategies would reduce more risk. To this end, incursions involving an air carrier aircraft were examined to determine the relative risk of landovers (and potential landovers) as compared with crossings (and potential crossings) in front of a takeoff. While landovers were found to be rare, crossings in front of a takeoff were not. In FY2000 - FY2002, almost half (47%) of the most severe (A- and B-category) runway incursions attributed to pilot or controller error were due to crossings and potential crossings in front of an aircraft taking off. Only 15% percent of these A- and B-category events involved a landover or potential landover.

Crossing in front of a takeoff was also found to be a common scenario among serious incursions involving large aircraft. While crossings and potential crossings in front of an aircraft taking off constituted 47% of all A- and B- level incursions, these incidents constituted 66% of the total A- and B-level incursions that involved air carriers (i.e., non-GA) aircraft. Landovers and potential landovers constituted only nine percent of serious (A and B) incursions that involved larger aircraft.

When an aircraft is on final approach, pilots cannot reasonably be expected to "see" an aircraft holding in position, especially at night. Whether the landing lights are on or off would be expected to have little, if any, effect on the pilot's ability to "see" the holding aircraft - even at night - for two reasons. First, the landing light is not very conspicuous from the viewpoint of an aircraft on approach. In fact, a demonstration conducted by the FAA showed that pilots in a landing aircraft could see the strobe of an aircraft on the ground long before they could identify whether or not the landing light was on. Second, when landing, the pilot's attention is not focused on the threshold of the runway. Pilots are trained to look at the far end of the runway and the horizon when landing, so that they do not "spot" the runway and land short. While pilots should be accustomed to scanning the runway before landing, a stationary object (as it would be seen during the day) or set of lights (as it would be seen at night, or in haze) would have a tendency to blend into the background; it would not attract attention like a moving object would – especially in the periphery of the visual field.

On the other hand, if the use of the landing light was reserved to indicate that the aircraft had received a takeoff clearance, the landing light could be a very useful cue to an aircraft on an intersecting taxiway expecting to cross the runway. Since it can be very difficult to discern movement of an oncoming aircraft, reserving the use of the landing light when initiating takeoff roll would provide other pilots with an indication of the intent of the aircraft in position, that is, whether it is holding in position or taking off.

This analysis also revealed that the strategic use of the landing light would be a much more effective mitigation strategy for preventing an aircraft or other vehicle crossing the runway in front of a takeoff than turning the light on while taking the runway would be for preventing a landover. First, an aircraft crossing in front of another aircraft on takeoff roll is a much more likely event than a landover. Second, the strategic use of the landing light has the potential for being much more effective for signaling pilots and vehicle drivers downfield that the aircraft is rolling than it does for increasing the conspicuity of the aircraft to pilots on approach.

The potential for use of the landing light as a signal that the aircraft is taking off is powerfully endorsed by Captain Robert Bragg, who was the Pan Am first officer in the 1977 crash of two B-747s on the runway in Tenerife. In this accident, a KLM flight taking off in heavy fog, crashed into the top of a Pan Am aircraft that was taxiing down the runway in the opposite direction. In Captain Bragg's words, "we saw the KLM airplane; it didn't surprise us too much, because we were aware that he was down there. And the first thing that got my attention was that his landing lights were on." (tenerifecrash.com). He later stated that they couldn't tell that the aircraft was moving toward them until it came closer and they saw the landing lights jiggle (Bragg, 2009).

No cost Risk Mitigation Strategy – Lights on for Takeoff

For the reasons discussed above, the consensus of the user group convened by the Office of Runway Safety was that when holding in position (lined up) for takeoff, the landing lights should be off until take-off clearance is received. Based on this recommendation, the Office of Flight Standards added the following recommendation to the air carrier Standard Operating Procedures (FAA Advisory Circular 120-74A):

> *When holding in position for takeoff, the landing lights should be off until take-off clearance is received; in this way, it provides an indication to ATC and other aircraft that the aircraft is rolling.*

As is stated in the AC, "The SOP of turning on landing lights when take-off clearance is received is a signal to other pilots, ATC, and ground personnel that the aircraft is moving down the runway for takeoff." All exterior lights, including the landing lights are also to be turned on when crossing a runway.

Since the implementation of this procedure, the incidence of serious ("A" and "B") runway incursions resulting from crossing in front of a takeoff has decreased over 20%. For FY2000 – 2002, the percentage of "A" and "B" level incursions involving crossings and potential crossings in front of a takeoff was 47%. This decreased to 26% in 2004 and has remained at that level or lower through FY2008. In addition to instances in which pilots who had been cleared to cross the runway stopped upon seeing the onset of the landing light of an aircraft at the end of the runway, there have been instances in which the landing light onset served as a cue to the controller that the pilot was taking off on, or crossing, the runway**.** While the FAA has disseminated this information to pilots, the effectiveness of this mitigation strategy lies in each pilot adhering to the procedure. It is only through 100% compliance that the "lights on" signal can maintain its integrity. Worldwide harmonization of this no-cost procedure could provide global benefit to the aviation community.

Controller Error

Several studies have sought to identify types of controller errors that result in runway incursions (Bales, Gilligan and King, 1989; Steinbacher, 1991; Cardosi and Yost, 2001). Each of these studies has identified a memory lapse that is, temporarily forgetting about an aircraft, vehicle, or a runway closure.

Forgetting

Memory lapse is consistently the most common single identifiable factor in controller errors resulting in a runway incursion. Temporarily forgetting about an aircraft, vehicle, or a runway closure was associated with 22% of the OEs that resulted in runway incursions in FY2008.

Forgetting about an aircraft. Several serious runway incursions have been reported as due to controllers either issuing a landing clearance after forgetting about an aircraft holding in position waiting for takeoff clearance on the same runway, or forgetting about the aircraft cleared to land and instructing an aircraft to line up on the same runway. From FY2004-2007 there were nine incursions that involved a controller forgetting about an aircraft holding on the runway, five of these were classified as an A- level severity event, and two were classified as “B”s. There were no such events in FY2008.

From FY2005 – FY2008 there was an average of nine incidents per year in which a controller forgot about a landing aircraft (or issued a clearance consistent with forgetting about a landing aircraft). Rarely do reports explicitly refer to the controller forgetting about the arrival, for example:

> *A Hawker H25B was cleared to land on Runway 17L. A Cessna C172 reported ready for takeoff on Runway 17L at Taxiway A-1 (approach end). Local Control (LC) issued takeoff clearance forgetting about the arrival. The H25B was in the flair as the C172 taxied passed the hold short line. LC recognized the conflict and instructed the C172 to make a 180*.

In the vast majority of the reports, the errors are consistent with the controller forgetting about an aircraft, but are not stated as such, for example:

> *Local Control (LC) cleared a Cessna C172 to land on a 3 mile final for Runway 27L. A Piper PA34 called ready for departure and was cleared for take-off on Runway 27L full length. The C172 was on short final when the PA34 crossed the hold line and was told by LC to stop. The PA34 stopped slightly over the hold short lines.*

Unfortunately, an analysis to identify causal or coincident factors could not be supported by the available data. Most reports of such incidents do not state when the landing clearance was issued, or give details as to what else was going on at the time. Because of this, there was insufficient information to shed light on causal or coincident factors for this type of error.

Forgetting about a closed runway. In FY 2008, 5% of the controller errors that resulted in a runway incursion involved controllers clearing an aircraft to takeoff or land on closed runways. There were four cases of an aircraft being cleared to takeoff on a closed runway and five cases of an aircraft being cleared to land on a closed runway. One of these landing aircraft, however, was an emergency landing. The controller informed the pilot that the runway was closed and scanned the runway to ensure it was clear, but failed to use the proper phraseology of “landing at your own risk.”

Mitigation Strategies for Forgetting Errors.

Contrary to some popular advertisements, there is no magic bullet for improving the capacity of human memory in healthy adults. There are, however behavioral strategies that can be used to protect against errors due to temporarily forgetting about an aircraft, runway closure, etc. Highly regimented procedures (such as position relief briefings) benefit from checklists. In the tower, however, the information that is usually forgotten is something of a temporary nature. Memory aids (such as for runway closure and temporary designation to another controller) continue to be studied and refined. Human factors training for controllers could help educate them on the behaviors and conditions that help memory (such as writing something down or repeating it) and impair memory (such as environmental distractions and temporary or abnormal situations). This type of training course is also designed to strengthen what is perhaps the most effective safety net in tower operations – controller teamwork. Effective teamwork can help to detect and correct errors before they result in incursions. In fact, the number of errors that are caught and corrected by the supervisor or a controller on another position before they result in a reportable event is unknown. Another initiative to look at the “saves” on a developing incident is the Air Traffic Safety Action Program (ATSAP). This program is a voluntary reporting program that seeks to improve the information available on the “saves” on which mitigation strategies can be developed.

Controller Coordination Errors

Another common type of controller error, identified in 15% of the OEs in FY2008, is inadequate (i.e., erroneous or lack of) coordination among controllers. This inadequate coordination usually involved a runway crossing. At some airports (or in some configurations), the local controller is responsible for all runway crossings. In other cases, the ground controller handles the runway crossings. Coordination issues arise when a controller neglects to get the appropriate approval for a crossing, or when there is a miscommunication about the coordination, or when the controller forgets about a coordination that he/she approved.

Readback/Hearback Errors.

Verbal communications is a vital safety net in the aviation system. In response to a transmission from a controller, a pilot will often (but not always) repeat the instruction back to the controller (hence the term *readback*)[5]. A pilot's readback of a controller's instruction is an important safety net for catching communication errors. In general, readback errors are relatively rare, occurring in response to less than one percent of controller transmissions (e.g., see Cardosi, 1994). However, "hearback errors" or the controller's failure to correct the readback error is a perennial factor in operational errors, both on the surface and in the air. In FY2008, readback/hearback errors were associated with 20% of the runway incursions attributed to OEs. Thirty-four percent these errors were not readback/hearback errors *per se*, as they did not involve a failure to correct a pilot's incorrect readback; rather, they involved a failure on the controller's part to obtain a readback of a "hold short" instruction.

Detection and Correction of Controller Error.

In addition to identifying what goes wrong in the system, it is equally important to identify what goes right. Unfortunately, information on how errors are caught before they result in incursions is not yet available. However, an examination of how errors that result in incursions are caught and corrected is helpful in identifying needed refinements of today's mitigation strategies.

At equipped airports, errors that results in a runway incursion may or may not be detected by automated systems such as Airport Movement Area Safety System (AMASS) or Aircraft Surface Detection Equipment Model X (ASDE-X). More often, these errors are detected by the controller that issued the clearance, another controller, a pilot, or vehicle driver. Alternatively, it is possible that no one caught the error in time to change the outcome.

In FY2008, 27% of the conflicts (between two aircraft or between an aircraft and vehicle) attributed to controller error, were not detected in time for pilots to take action. Two examples follow:

> *Airport vehicle requested clearance on Runway 9 for light maintenance. This was approved and Local Control (LC) activated the Red Runway Occupied Light. Approximately 29 minutes later, LC issued takeoff clearance Runway 9 full length to a Cessna C750 forgetting about the vehicle. Runway 9 was not visible to the tower due to fog. Pilot of C750 reported passing a vehicle on the runway*.

> *When issuing the new runway instructions, the ground controller meant to say hold short of Runway 8L but instead said 4L. Aircraft 1 crossed the hold line at Golf with Aircraft 2 on short final Runway 8L and ultimately Aircraft 1 crossed runway 8L when Aircraft 2 was on landing roll.*

One-third (35%) of these events were detected and corrected (or attempted to be corrected) by the controller that issued the clearance that resulted in the conflict. Another 8% were detected by another controller (6% by a controller on another position and 2% by an acting supervisor). Only 2% of the conflicts were detected by vehicle drivers involved. Nineteen percent of the conflicts resulting from controller error were detected by the pilot. In these cases the pilot took corrective action and/or informed the controller of a potential conflict. For example:

> *Ground Control (GC) instructed an Airbus A319 to turn left on Bravo cross Runway 13 join C (new taxiway). The A319 pilot read back cross Runway 9L and GC confirmed. As the A319 approached Runway 9L at Delta, pilot again asked if he was cleared to cross 9L and GC said affirmative. Local Control (LC) had cleared a Beech BE40 for take off on Runway 9L full length. The BE40 pilot noticed the Airbus on the runway and aborted after rolling less than 100 feet*.

An additional 8% of the conflicts occurred as a result of a controller error were detected by automation (AMASS, ASDE-X, Runway Status Lights). In most cases, these involved an AMASS alert. (Detection of runway conflicts by AMASS will be discussed in more detail in a later section). In one case, the newly implemented Runway Status Lights alerted the pilot to the conflict:

> *Local Control West 1 (LW1) cleared a SAAB SF34 for take off on Runway 36R from intersection Bravo. LW1 thought the SF34 had been cleared into position and hold. LW1 then cleared a McDonnell-Douglas MD80 to cross Runway 36R at Yankee.*

The SF34 pilot then reported they had been cleared for takeoff but they "saw the red lights" (of the Runway Status Light System). The SF34 was held in position and once the MD80 cleared the runway, takeoff clearance was given. Closest horizontal proximity reported was 9,275 feet.

Pilot Errors

Several studies have identified a "loss of situational awareness" as the most common pilot error that result in runway incursions (Kelly and Steinbacher, 1993; Adam and Kelly, 1996; Joint Safety Analysis Team, 2000). This categorization is quite broad and can rightly include all but communication errors[6]. Even the more specific term, "loss of spatial awareness" can be too comprehensive to be useful. This typically refers to the pilot thinking they are at one location when they are actually at another. However, this error category can encompass everything from misjudging the proximity to the runway (and mistakenly crossing the hold short lines) to landing on the wrong runway. For that reason, errors that might be described as "loss of situational awareness" will be categorized into more specific errors here.

Correct Readback Followed by Unauthorized Maneuver.

The most common type of pilot error that resulted in a runway incursion involving a conflict with an aircraft or vehicle was a correct readback of a controller instruction followed by an unauthorized maneuver. This type of pilot error was involved in 54% of all PDs resulting in runway incursions involving a conflict in FY2008. Most (83%) of these errors involved the pilot correctly reading back a "hold short" instruction. The result of approximately half (47%) of these errors in which the pilot correctly readback the hold short instruction, was that the pilot stopped before reaching the runway edge.

The reports of pilot deviations that result in runway incursions rarely include information as to why these errors occurred. In order to gain insight into the situations that result in the most common type of pilot error, that is, reading back an instruction correctly, but then initiating another action, an analysis of reports submitted to the Aviation Safety Reporting System (ASRS) was conducted (DiFiore and Cardosi, 2006). This study examined 300 ASRS reports of airport surface movement events (i.e., runway incursions and surface incidents) at the 34 busiest towered airports submitted between May 2001 and August 2002. Most (78%) of the reports were filed by a captain or first officer who was operating the aircraft under FAA Parts 121or 135 and was directly involved in the incident.

Thirty-five percent of the ASRS reports involved incidents in which pilots crossed the hold short lines without authorization. This 35% mirrors the 38% frequency of pilots crossing the hold short without authorization in the runway incursion data. Among the ASRS reports where a pilot crossed the hold short lines without authorization, more than 40% of the pilots reported a loss of "position awareness"; that is, they intended to hold short, and crossed the hold short lines without realizing it. In such cases, crossing the hold short lines without authorization was most often related to the pilot performing heads-down tasks. In fact, in 26% of these ASRS incidents, the pilot reported being heads down in the cockpit performing either checklists or programming flight deck systems as they crossed the hold short lines.

In one-third of the ASRS reports involving a pilot erroneously crossing the hold short lines, either expectations or force of habit was mentioned as a contributing factor. Pilots frequently mentioned that either the hold lines were not where they expected them to be or that they were accustomed to taking a certain route to the assigned runway (and thus holding at a different location than instructed). In these cases, when the instructions were different from what was expected, pilots unintentionally reverted to what they had done in the past. In addition, some pilots reported simply following the aircraft in front of them across the hold lines, even though they intended to hold short.

This analysis of ASRS reports showed that loss of position awareness is also the number one factor involved in pilots *entering* and *crossing* a runway without authorization. Again, the analysis of ASRS reports revealed that the most common contributing factor to these types of errors was the pilot being heads down. One-third of the pilots who reported crossing or entering the runway without authorization reported that one of the pilots was head-down at the time of the incident, most often conducting a checklist.

Another coincident factor to crossing the runway without authorization was the use of “taxi to” instructions. Pilots did not report any confusion regarding the intent of the “taxi to” instruction, but an error in position awareness, combined with the implicit clearance to cross intervening runways, resulted in the pilot crossing a runway without a clearance. For example, in some cases pilots took a wrong turn and ended up crossing a runway that they wouldn’t have crossed if they had taken the correct route. In other cases, the aircraft was not where the controller thought that the aircraft was. The instruction to “taxi to” implied a clearance to cross a runway that the controller did not intend the aircraft to cross. Changes to this procedure, such as requiring that clearances to cross all active runways be explicitly stated, are currently being considered within the Safety Management System process.

ASRS reports reveal a very different type of pilot error in the cases in which an aircraft enters the runway without clearance and holds in position awaiting authorization for takeoff. This type of error was almost always attributed to communication errors. Ninety-four percent of these reports cited communication issues as directly contributing to the incident. The most commonly cited communication factors were readback/hearback errors, accepting another aircraft's clearance, frequency congestion, and blocked communications.

Positional Errors.

In FY2008, 14% of all incursions attributed to pilot deviations were due to pilots missing a turn, taking a wrong turn, misidentifying their position on the airport surface to the controller, or making other errors involving spatial position on the ground. This does not include taking off from, or landing on, the wrong runway.

A pilot is much more likely to land on a wrong runway than to takeoff on a wrong runway, In FY2008, there were 12 instances of the pilot taking off from the wrong runway (11 of them were General Aviation pilots). There were 29 instances in which the pilot landed on the wrong runway. (In one additional incursion, it was clear that the pilot would have landed on the wrong runway if the controller had not noticed that the pilot was lined up for the wrong parallel and sent the aircraft around.) There are clear patterns to this type of error. While the majority (70%) involved general aviation pilots, air carrier pilot are also vulnerable. In two cases (one GA, one air carrier), the pilot landed on the same runway (pavement), wrong direction. By far, the more common error, involved in 83% of all instances of pilots landing on the wrong runway, involves landing on a runway that was parallel to the runway referenced in the clearance.

A similar error pattern is evident in incidents involving pilots landing on taxiways. While these events do not meet the definition of runway incursion, they can involve a risk of collision. In FY2008, there were 18 instances of pilots landing on taxiways. All but one of these instances involved GA pilots. One of these reports did not specify the taxiway on which the landing occurred. In the vast majority of the remainder (76%), the pilot landed on a taxiway parallel to the assigned runway. In all but one case, the assigned runway was a parallel with a “Left”or “Right” designator. These errors fell into two patterns. One common error is that pilots landed on the taxiway to the “left” or “right” of the assigned runway with the “left” or “right” designation, respectively (e.g., landed on taxiway P which is to the left of the assigned runway 27L). The most common error pattern occurred at airports with one runway significantly longer than the other. In these cases, pilots were cleared to land on the shorter parallel and landed on the taxiway parallel to the longer runway. That is, they mistakenly view the longer runway and its taxiway as the L/R pair of runways. An example is a pilot cleared to land on the shorter parallel, 9L and landing on taxiway Papa, which is to the left of the longer runway 9R. Landing on taxiways is often a localized problem. Of these events in FY2008, five occurred at a single airport.

Error Detection

In FY2008, only 14% of the conflicts occurred as a result of pilot error (PDs) went undetected until after the event was over. Most (75%) were detected by the controller who had issued the clearance that was deviated. Five percent of these events were detected by the pilots who made the errors and an additional 5% were detected by other pilots. Two percent were detected by automation (e.g., AMASS). In the remainder of the events (2%), there was insufficient information in the report to determine who detected the conflict.

Error Mitigation Strategies

Coincident with this study was the implementation of enhanced surface markings. This included making the hold short lines more distinct (by painting a black background behind the yellow lines) and highlighting the centerline leading up to the hold short lines to provide an additional cue to pilots that they are approaching an entrance to a runway. This should help pilots avoid the error of crossing the hold short lines when they intend to hold short (although it is too early to look for a correlation in the data).

Other planned mitigation strategies include cockpit surface moving maps and continued educational and awareness campaigns. Given the distinct difference in the pattern of errors found involving GA and non-GA (Part 121, Part 135, and military) pilots, an opportunity to reduce the number of incursions with reinforcement of basic communication skills within the GA community is warranted. In addition, during flight training, the term “ground school” typically refers to the initial instruction that takes place in a classroom, rather than in the aircraft. The number of runway incursions attributed to GA pilots demonstrates a need for better education in surface operations in both initial training "ground school" and in the annual "check-ride". Finally, all pilots should continue to be encouraged to minimize heads-down time while taxiing, particularly when approaching a runway.

Vehicle Driver Errors

In FY2008, there were 52 reports of runway incursions that involved a conflict with an aircraft that were caused by vehicles or pedestrians. While a small percentage of these are due to unauthorized pedestrians on the airport surface, the majority (79%) involve vehicles. In half of these incursions involving a conflict with an aircraft (and 51% of all incursions caused by vehicle drivers), the driver never contacted air traffic control. The vast majority of vehicles involved in conflicts are not rogue vehicles, but rather, are authorized to operate on the airport surface. While there are occasional reports of privately owned vehicles (as well as bicycles and golf carts) causing these incursions, most involve airport vehicles, maintenance taxis, construction and emergency response vehicles.

Error Detection

In FY 2008, there were 206 runway incursions caused by vehicles or pedestrians. Fifty-two of these incursions involved a conflict with an aircraft. Approximately half (48%) of these conflicts were first detected by an air traffic controller. One-quarter (25%) were detected by the pilot involved. Four percent were detected by a vehicle driver and 12% went undetected until the event was over.

Error Mitigation Strategies

One of the error mitigation strategies that the Office of Runway Safety has initiated is to improve training provided to airport vehicle drivers. As part of this effort, a series of studies on the use of simulators to train airport vehicle drivers has been conducted. The first study demonstrated clear benefits for such training, using a high-fidelity simulator (Chase and Hannon, 2006). The second study sought to determine whether the same benefits could be attained with a lower-cost simulator (Chase, 2006). Recent efforts detailed the hardware, software, and resources required for an airport to build their own customized low-cost simulator (Chase and Donohoe, 2007).

Runway Incursions: Risk Factors and Mitigation Strategies

A multitude of factors can contribute to, or detract from, the risk of a runway incursion. These include:

- Airport layout – the geometry and use of the runways and taxiways.
- Equipment – all displays and automated decision aids and alerting systems for pilots and controllers as will as that used for communication, navigation, surveillance.
- Procedures – this includes those required by the Federal Aviation Regulations (FARs) as well as Standard Operating Procedures (SOPs) and best practices.

While a complete list of factors is beyond the scope of this paper, this last section will provide an example of each of those identified above.

Airport Layout

The number and layout of the runways and taxiways can have a profound effect on the inherent risk in surface operations. For example, use of end-around taxiways minimizes the probability of serious runway incursions by minimizing runway crossings at the high-energy portion of the runway. Crossings mid-field can create serious conflicts due to pilot, controller, or vehicle driver error. While use of end-around taxiways would not be expected to prevent these errors, the effects of the errors would be mitigated and less likely to result in a collision than if the same error occurred mid-field.

Just as the risk of crossing a runway varies with the portion of the runway that is crossed, so does the risk of holding on the runway awaiting take-off clearance. There are important differences in the severity of the outcome of runway incursions involving aircraft holding for a full-length departure versus those involving aircraft holding on the runway at an intersection. Situations in which the controller forgets about an aircraft holding on the runway are always serious, however, if the aircraft is holding on the high energy portion of the runway, it is vulnerable not only to another aircraft landing over it, but also landing and rolling into it, and taking off into it. From 1991 – 2001 there were four collisions involving aircraft holding on the runway – all of them involved aircraft holding for intersection departures. Three of them were attributed to controller error (Los Angeles, 1991; Van Nuys, 2001; and Sarasota, 2000). Another (St. Louis, 1994) was caused when a pilot taxied onto the wrong runway after being cleared to hold on another runway for an intersection departure. The runway that the pilot erroneously entered had a departing MD-82 on takeoff roll.

Proximity of Parallel Runways. The number of incursions on parallel runways is related to the spacing between the parallels. Even though the number of closely-spaced (1000' or less centerline to centerline) parallel runways far outnumbers those spaced greater than 1,000' apart, the closely-spaced parallels are involved in more incursions. Data from FY2002 - 2007 show that there were 1.6 times more runway incursions on closely-spaced parallels than those spaced more than 1000' apart. As can be seen in Figure 1; however, the outcomes of the incursions are comparable between the two groups. Figure 2 shows that the type of pilot errors (e.g., unauthorized takeoffs or landings) are also similarly distributed between the two groups of runway spacing. Unfortunately, the total number of operations on these runways during that time period is not available.

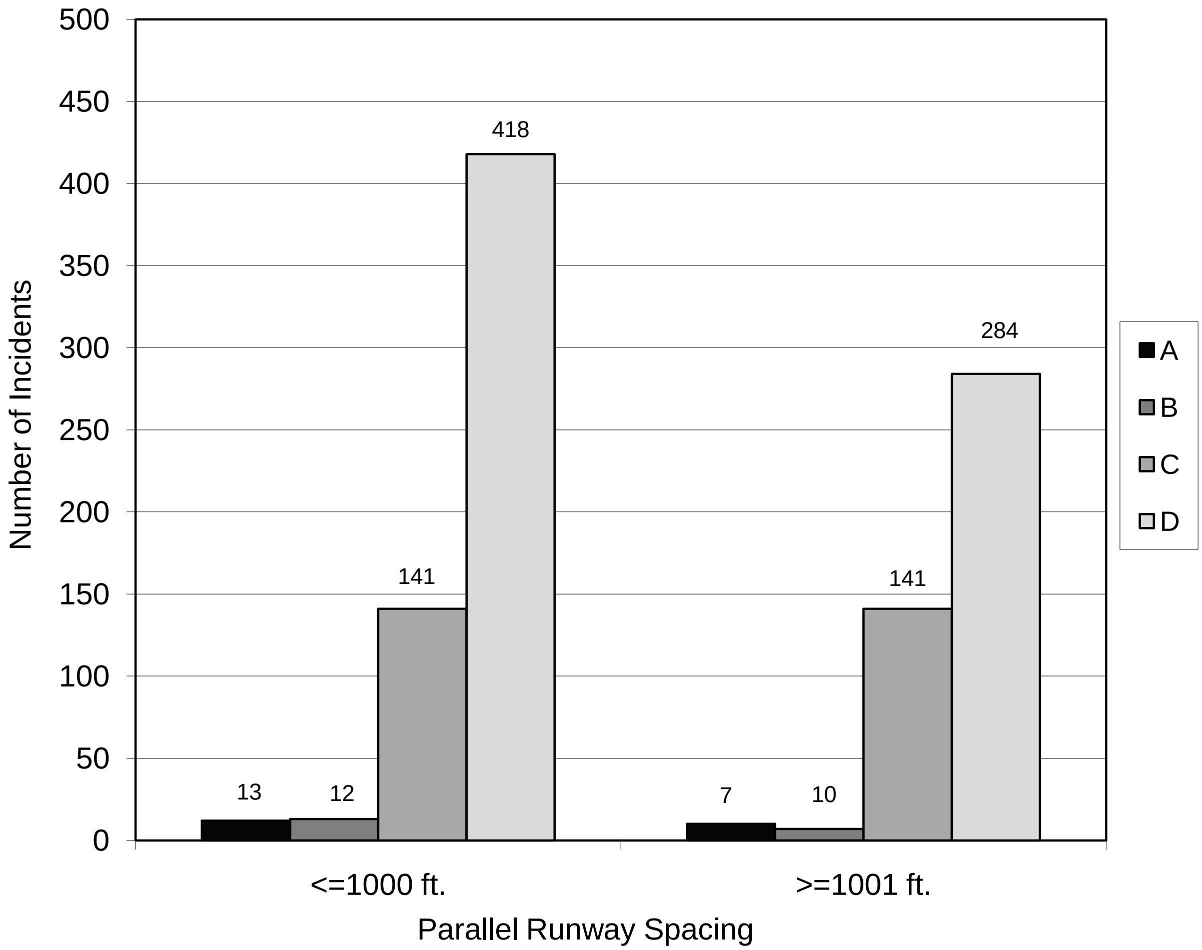

Figure 1. FY04-08: Pilot Deviations by Parallel Runway Spacing

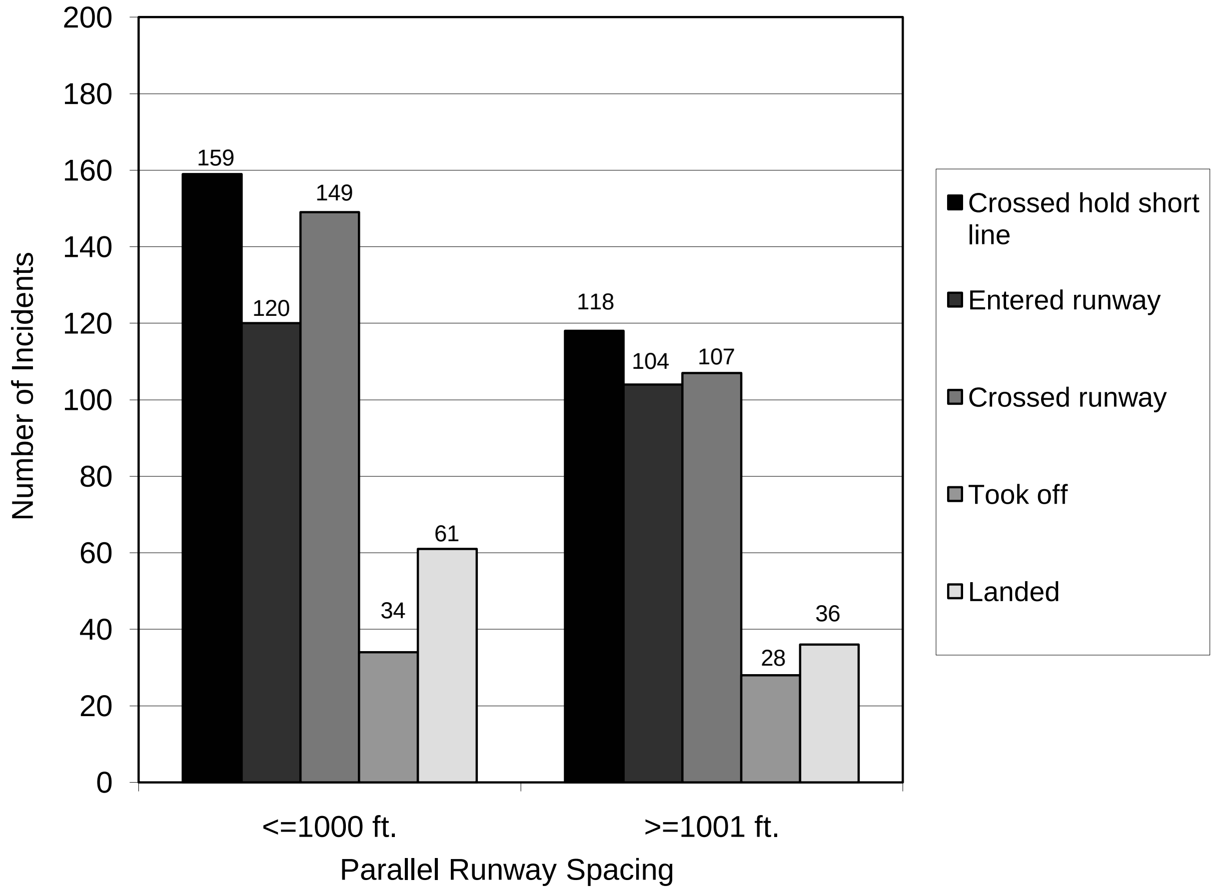

Figure 2. Unauthorized Pilot Action by Parallel Runway Spacing

Equipment

AMASS. The reports of runway incursions rarely cite the influence or effectiveness of mitigation strategies. The exception to this involves the AMASS system. First billed erroneously as a "runway incursion prevention" device, it was later, and more correctly, described as a device to help prevent collisions arising from runway incursions. AMASS gives the air traffic controller an alert in many, but not all, conditions that result from incursions involving a single runway that could result in a collision. (AMASS logic is in the process of being revised in order to recognize conflicts between aircraft operating on intersecting runways).

All alerting systems must find the ideal operational balance between legitimate alerts and false alarms. In order to be able to alert in all situations that could result in collisions, the false alarm rate would be so high that controllers would end up ignoring or "tuning out" legitimate alerts. To avoid this "crying wolf" syndrome from occurring, parameters are set so that the system alerts to most, but not all, situations that could result in a collision.

From FY2002 – 2008, there were 165 reports of runway incursions that mentioned an AMASS alarm. (An alarm was assumed to have occurred if the narrative stated that "the event met the parameters in AMASS to trigger an alarm".) These reports were examined to glean information regarding the interaction between the timing of the AMASS alerts and pilot and controller actions. In 30 events, it is clear that the controller took corrective action, but the information on the AMASS alert is unclear (i.e., "This event met the parameters configured within AMASS to trigger an alarm.")

The remainder of the reports fell into several categories. The event was classified as an "AMASS save" if the narrative stated that AMASS alarmed and an instruction was given, unless the circumstances were such that the pilot could not comply with the instruction or the instruction had been issued before the AMASS alert activated. There were 40 such events in the database. An example follows:

> *Pick-up truck entered the Runway 32L/27L intersection without authorization. AMASS alarmed for B747, over approach lights for Runway 32L, and was instructed to go-around. Closest horizontal and vertical separation was 3,000 and 100 feet respectively*.

There were 10 events in which the controller action preceded the AMASS alert and 5 additional cases in which the alert was coincident with controller action. In 17 cases, AMASS alerted just after, or coincident with, the pilot taking corrective action. In one case the alert was coincident with the corrective action of a vehicle driver.

In 50 events, AMASS alerted but no action was taken. Examples of these events follow:

Example 1:

> *A Cessna C525 was taxied to Runway 19R for departure. The C525 crossed the hold line at Taxiway F without clearance and approached the west edge of Runway 19R and conflicted with a DASSAULT FA10 landing Runway 19R. AMASS alerted.*

The FA10 flew past the C525, altitude unknown, and touched down just north of Taxiway M. Distance from M to 19R threshold is approximately 1,875 feet. The FA10 pilot stated they past the C525's position before the Cessna entered the runway and did not over fly it.

Example 2:

Aircraft 1, A320, landed Runway 22L and was issued taxi instructions via Taxiway J to cross Runway 22R. Aircraft 2, Beech BE99 (Canadian registered) was issued taxi instructions to Runway 22R. Due to subsequent coordination with departure and Port Authority, Local Control (LC) forgot about Aircraft 1 and issued take-off clearance to Aircraft 2 via Taxiway C (approximately 6,000 feet from Taxiway J). AMASS alerted as Aircraft 1 was approaching Runway 22R on Taxiway J just as Aircraft 2 became airborne. Aircraft 2 rotated 3,500 feet from J and over flew Aircraft 1 by approximately 300 feet. Pilot of Aircraft 2 did comment about the aircraft crossing the runway. LC asked Aircraft 2 if they were OK, in which the pilot responded "we're fine, we had plenty of room".

An example of a case (in FY2004) in which AMASS alarmed too late to prevent a collision:

Ground Control (GC) approved a tug towing a MD-80 to cross Runway 35 via Taxiway D-4 to Taxiway E-4 without coordinating with Local Control (LC). LC cleared Aircraft 1 for take-off via Taxiway K, intersection departure, Runway 35.

Aircraft 1 observed the tug pull onto Runway 35 while on his departure roll. Aircraft 1 veered left, aborting his take-off, to avoid hitting the tug but clipped his right wing tip on the tug and ended up off the runway. Aircraft 1 advised tower they impacted the tug. This collision resulted in damage but no injuries. Taxiway K is 1,950 feet from Taxiway E-4. AMASS alarmed when N941MA was 100 feet from Taxiway E-4.

Voice Communication. Systems such as AMASS, ASDE-X, and Runway Status Lights are the most highly visible ATC safety alerting systems in the runway environment. On the flight deck, surface moving maps hold great promise for mitigating the number and severity of runway incursions. An often overlooked aspect of equipment involved in surface operations is the radio which is the most widely-used safety link between controllers and pilots.

While voice communications are usually high quality and surprisingly accurate, the volume and complexity of the traffic at busy airports makes voice communications a tenuous safety link. Kelly and Steinbacher (1993) were the first to identify frequency congestion as a contributing factor to runway incursions. This finding was echoed by controllers and pilots in extensive surveys of tower controllers (Kelly and Jacobs, 1998) and airline pilots (Adam, Kelly, and Steinbacher, 1994; Adam and Kelly, 1996).

Perhaps because of the frequency congestion, 27% the local controllers' transmissions and 33% of the ground controllers' transmissions are responded to by pilots with only an acknowledgement (e.g., “roger”); an additional 7% of the local control transmissions are responded to with only a mike click (Cardosi, 1994). Twenty-eight percent of the controller messages on the local control frequencies (Cardosi, 1994) and 32 % on ground control (Burki-Cohen, 1995) are responded to with a full readback. This is dramatically lower than the 71% of the controllers’ transmissions en route and 60% of the TRACON controllers’ transmissions that are fully read back (Cardosi, Brett, and Han, 1997). This same series of studies also revealed that the factor most consistent with controller-pilot miscommunications (as defined as readback errors and pilot requests for repeats) is similar call signs on the same frequency. This was a coincident factor in 12% of the miscommunications on the local frequencies.

Blocked and partially-blocked (also known as "stepped-on") communications first emerged as a well-known threat to aviation safety in 1977 with the collision on the runway at Tenerife. As the amount of air traffic and radio frequency congestion increases, blocked and partially-blocked transmission present an increasing risk to aviation safety. When a pilot or controller is not able to access a frequency due to a "stuck mike," the most fundamental safety net - that provided by voice communications between pilots and controllers - is gone. Partially-blocked transmissions (“step-ons") are far more common than microphones stuck in the transmit position. While these events are typically less dramatic than that of a stuck mike, they too, and have the potential for disaster.

Wider use of Controller-Pilot Data Link Communications (CPDLC) has been proposed to significantly reduce both frequency congestion and the number of communication errors. CPDLC has allowed for some routine transmissions in an extremely limited implementation. While CPDLC will provide a sorely needed alternative to voice communication between pilots and controllers, it is not appropriate for time-critical communications. Nor is it is expected to reduce the rate of communications errors. Any alternative to voice communication is likely to change the types of errors observed, but is not likely to reduce the error rate. With CPDLC, for example, it would still be possible to send the wrong message to an aircraft or for the pilot to misread the instruction. There are also legitimate concerns about the effect of the lack of “party-line” information (that is, the ability of pilots to hear the clearances issued to other aircraft) and about the increased “heads-down” time needed to read the clearances.

Procedures

An example of a flight deck SOP (i.e., landing lights on for runway operations) has already been discussed. This section presents an example of using incident data to assess the contribution of a given type of operation to overall risk in surface operations.

Between FY 2002-2008 there were 35 incursions (18 OEs and 17 PDs) involving simultaneous takeoffs on intersecting runways. Ten of these 35 involved two aircraft holding for takeoff on intersecting runways at the same time, leading to both aircraft acting on the takeoff clearance.

Below is an example of a FY2008 event:

> *A Boeing B737-300 was issued taxi into position and hold Runway 12R full length. The B733 pilot was issued traffic landing on the crossing runway, Runway 4, but not that traffic would be holding on Runway 4. A second Boeing B733 was issued taxi into position and hold Runway 4 and advised of landing traffic but not that traffic would be holding Runway 12R. Local Control (LC) issued takeoff clearance to the Runway 4 B733. The readback was partially blocked and then ended with the Runway 4 B733 stating "cleared for takeoff". LC then transmitted "other aircraft calling say-again" LC noticed both B733 aircraft beginning take off roll and told the B733 on 12R to stop. The 12R B733 aborted, prior to ATCT instructions, approaching Foxtrot and exited the runway at Hotel. The Runway 4 B733 continued departure. Horizontal distance from Foxtrot to Runway 4 intersection is approximately 2,000 feet. Distance from Hotel to intersection of Runway 4 is approximately 1,150 feet.*

While most (7 of 10) incursions were classified as OEs, the situation is a set up for pilot error. In four of the ten cases, the narrative stated that the holding aircraft was advised of the departing traffic on the intersecting runway. This means that issuing such advisories is *not* an effective risk mitigation strategy. While ten events in six years is a very low level of incidence compared with the number of operations, it also implies that we can continue to expect one to two events of this nature in the future per year, unless the procedure is changed. Whether this is an operationally acceptable risk depends on the benefits to capacity of using the procedure.

CONCLUSIONS

Analysis of runway incursions has pointed to specific errors made by pilots, controllers, and airport vehicle drivers that can be mitigated through education, changes in behaviors, and advances in technology (such as the implementation of surface moving maps). However, there is significant room for improvement in the information that is collected and reported. The more detailed the causal factor information in future reports, the more useful this analysis will be. In general, better baseline measures are also needed. Specifically, if the numbers of operations per runway were readily available, the level of risk associated with closely spaced parallel runways could be assessed. Continuous analysis of the runway safety data, combined with improvement of the information collected, and increased availability of baseline performance measures is, and will continue to be, the foundation for improving runway safety.

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[2] The average for FY2004 to FY2007 was 41% with a range of 38% to 45%.

[3] Comparable information from previous years is not available, since runway incursions not involving a conflict were not analyzed in this way prior to FY2008.

[4] See Federal Aviation Administration, 2002 for a complete list of JSIT activities and planned safety enhancements.

[5] The only instruction in which a readback is required is one to “hold short” of a runway. If a controller does not receive a readback in response to this instruction, he/she is required to obtain one.

[6] Surprisingly, in 11% of the FY2008 pilot errors resulting in runway incursions with a conflict (39% of all pilot deviations resulting in a runway incursion), the pilot did not contact ATC for a clearance (to taxi, takeoff, or land). Only 2% of these events involved a non-functioning or non-existent radio. Not surprisingly, the vast majority (77%) of these errors were incurred by General Aviation (GA) pilots.

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List of Acronyms

Acronym	Description
AC	Advisory Circular
AMASS	Airport Movement Area Safety System
ASDE-X	Aircraft Surface Detection Equipment Model X
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATSAP	Air Traffic Safety Action Program
CPDLC	Controller-Pilot Data Link Communications
FAA	Federal Aviation Administration
FARs	Federal Aviation Regulations
FY	Fiscal Year
GA	General Aviation
GC	Ground Control
ICAO	International Civil Aviation Organization
JSIT	Joint Safety Implementation Team
LC	Local Control
OE	Operational Error
PD	Pilot Deviation
SOP	Standard Operating Procedures
TRACON	Terminal Radar Approach Control
VPD	Vehicle/Pedestrian Deviation

Data Tables for Graphs

Table for Figure 1: FY04-08: Pilot Deviations by Parallel Runway Spacing

	Parallel Runway Spacing	
Severity	**<=1000 feet**	**>=1001 feet**
A	13	7
B	12	10
C	141	141
D	418	284

Table for Figure 2: Unauthorized Pilot Action by Parallel Runway Spacing

	Parallel Runway Spacing	
Unauthorized Pilot Action	**<=1000 feet**	**>=1001 feet**
Crossed hold short line	159	118
Entered Runway	1120	104
Crossed Runway	149	107
Took Off	34	28
Landed	61	36