Human Factors Assessment of Runway Status Lights and Final Approach Runway Occupancy Signal

FAA Operational Evaluations at Dallas Ft. Worth and San Diego International Airports

Maria Picardi Kuffner
Human Factors Specialist
MIT Lincoln Laboratory
Lexington, MA, USA
MariaKuffner@LL.MIT.EDU

Captain Robert Perkins
Air Safety Coordinator - Canada
Air Line Pilots Association, International
Ottawa, ON, Canada
robert.perkins@alpa.org

Abstract— Runway incursions have been a persistent problem in airport operations for decades, both in the National Airspace System (NAS) and worldwide. The deadliest accident in the history of commercial aviation occurred at Tenerife Airport in the Canary Islands. As commercial airliners become larger and airports more congested the potential for major accidents on the airport surface is expected to increase. Runway Status Lights (RWSL) have shown promise in precluding this potentiality through demonstrated operational suitability and measured reductions in runway incursions as cited independently in an audit by the US Inspector General. RWSL will be deployed to 22 airports in the near future. MIT Lincoln Laboratory has recently completed human factors assessments in support of the Federal Aviation Administration’s (FAA) ongoing operational evaluations of RWSL at Dallas/Ft. Worth International Airport (DFW) and RWSL at San Diego International Airport (SAN). The evaluations of RWSL at DFW and SAN began in 2004 and 2006, respectively. In addition, we have been assessing preliminary data from an ongoing operational evaluation of the Final Approach Runway Occupancy Signal (FAROS) at DFW that began four months ago. The assessments were developed to evaluate the effectiveness and operational suitability of RWSL and FAROS in reducing runway incursions and preventing accidents. The human factors assessments conducted to measure and record RWSL and FAROS operational suitability are presented here (with the FAROS data subject to change as the ongoing operational evaluation continues). The process established to include human factors research, development, and testing is specifically described.

Keywords- human factors; runway status lights; final approach runway occupancy signal

I. INTRODUCTION - RUNWAY INCURSION PROBLEM

In descending order of causation, errors committed by pilots, controllers, or vehicle operators - often because their situational awareness is lost – result in runway incursions. Recent Federal Aviation Administration (FAA) data (see figure 1) summarizes and analyzes the patterns and trends in runway incursions [1]. The data indicate that the most severe runway incursions can develop quickly and without warning from perfectly safe and routine traffic situations on the airport surface. Severe runway incursions leave little time for corrective action such as a tower controller responding to a conflict alert; e.g., from the Airport Movement Area Safety System, (AMASS) and verbally issuing conflict resolution instructions in the time available. A layered approach to runway safety must be employed that includes surveillance-based situational awareness and conflict alerts for the tower controller and runway status information directly presented to flight crews whenever and wherever such conflicts may develop, as recommended by the National Transportation Safety Board (NTSB). Two safety systems currently under development and test by MIT Lincoln Laboratory for the FAA, Runway Status Lights (RWSL) and Final Approach Runway Occupancy Signal (FAROS), provide this direct presentation with surveillance-driven lights that indicate when it is unsafe to enter the runway via runway entrance lights (RELs), when it is unsafe to depart via takeoff hold lights (THLs), when it is unsafe to cross a runway intersection via runway intersection lights (RILs), or when it is unsafe to land via FAROS.
The RWSL and FAROS indications are an automatic back up to air traffic control (ATC) clearances. Pilots and vehicle operators at the test airports have been trained to know that when they see illuminated red RELs or THLs or flashing precision approach path indicators (PAPIs) for FAROS, the runway is unsafe. To date, RELs, THLs, and FAROS have been evaluated in the field. A recent report on runway safety published by the United States Government Accountability Office (GAO) stated that experts have found RWSL (RELs and THLs) to be a promising technology for reducing runway incursions [2]. Note that RILs will be evaluated for the first time later this year (work in progress).

Human factors assessments conducted during operational evaluation demonstrate that RELs and THLs do not interfere with normal, safe operations and do have the potential for reducing runway incursions, as judged by the users on site. Similar early findings have been found for FAROS during the ongoing operational evaluation at DFW although the data are to be considered preliminary since more users could respond, as the evaluation is ongoing. The users include air traffic controllers, pilots, and vehicle operators. During the operational testing, we iterate design changes based on user feedback with feasible refinements until the system is shown to be operationally suitable for air traffic management (ATM).

The field studies described below comprise the operational evaluation phase of the RWSL at DFW and SAN, and FAROS at DFW, to date. The FAA permitted commencement of the operational evaluation phases for each of these systems only after the prerequisite phase of shadow operations was passed in the field and an engineering phase was completed in the laboratory [3]. DFW is undergoing extended operational evaluations of RELs and THLs and SAN is undergoing an extended operational evaluation of RELs. The extension is predicated on the successfully completion of three-month operational evaluation periods. Human-system integration issues are identified via user discussions and surveys administered throughout. The process begins with the operational concept, and continues with training, testing, and analyzing events to insure minimal interference with operations while increasing safety for ATM users.

The operational concept of RWSL and FAROS is simple and straightforward, users understand that “red means stop.” RWSL and FAROS indications both turn on automatically driven by surveillance from available sources at the airport. There is no human input in the 24/7 operation of the lights. They turn on when detected traffic indicates that proceeding is not safe. They turn off when the condition(s) no longer exists. Turning off is not clearance to proceed. Clearance remains a verbal instruction from ATC to pilots or vehicle operators, as done today. For the RELs to illuminate, there must be an aircraft landing or departing. For the THLs to illuminate, there must be an aircraft or vehicle “on” the runway whilst an aircraft is landing or departing. FAROS must sense an aircraft or vehicle “on” the runway and an aircraft landing in order to flash the existing PAPIs. Per the National Transportation Safety Board’s recommendation to the FAA for preventing runway incursions, the system provides “immediate warnings of probable collisions (or) incursions directly to flight crews in the cockpit.”[4]

**Configuration of RWSL and FAROS**

There are four different types of runway status lights shown in the operational concept (see figure 2). They comprise RELs, THLs, FAROS, and RILs. The number, placement, and direction of the lights is carefully selected to provide optimum warning in any given potential conflict situation. Human factors assessments included study of the light configuration resulting in a placement unique from existing airport lights and conspicuous enough to serve their intended purpose.

The RELs are placed longitudinally along the taxiway centerline to be distinct from the active Surface Movement Guidance and Control (SMGCS) red stop bar that is located...
along the taxiway hold line at some airports and used during low visibility operations. This is an important distinction since the operational concept of RWSL is different from SMGCS. While there has been some concern that a transverse configuration is more intuitive to some, the longitudinal configuration allows for last second situational awareness by pilots taxiway on the centerline onto a runway. In fact, that is why there is one REL placed directly on the runway centerline itself.

Currently, RELs are operating on RWY 9/27 at SAN and RELs and THLs are operating on RWY 18L/36R at DFW with combined operations of well over two hundred thousand to date. More recently, FAROS is operating on the three major arrival runways at DFW, 18R/36L, 17R/35L, and 17C/35C. An earlier version of FAROS that uses in-ground loops to sense surface traffic is operational at Long Beach (LGB) airport in California. The first test of RILs is planned for BOS later this year (autumn of 2009). Similar to the RELs and THLs, the RILs are configured longitudinally and, like the THLs, will be a double row of lights installed on either side of the runway centerline. Figure 3 is from the FAA’s draft advisory circular on THLs that specifies the number, spacing, and placement of the new light fixtures on the runway.

Similarly, the THLs are configured longitudinally along the runway centerline. Again, this allows for pilots’ situational awareness of perhaps a developing conflict whilst on departure roll. The existing THLs at DFW on 18L/36R are a single row of 11 lights. However, through pilot feedback it was determined that the conspicuity and uniqueness from end-of-runway lights could both be improved to acceptable levels by the addition of five lights at the beginning of the array (especially for low visibility operations) and the introduction of a second row.

The double-row THL configuration (with two rows of 16 lights each) is being used going forward at DFW, Los Angeles International Airport (LAX), and Logan International Airport in Boston (BOS) as shown in figures 4, 5, and 6 respectively. The RELs are currently planned to remain as a single row, as at SAN (see figure 7).
RWSL and FAROS system description

A high-level block diagram of the RWSL and FAROS systems, along with photographs of the lights and surveillance sources (primary radar and secondary beacon) at the airport, and a snapshot of the air traffic controller supervisor’s RWSL test display placed in the control tower cab, is shown in figure 8. The display is not for operational use.

Note the red bars on the display turn on and off in accordance with the lights on the surface. The PAPIs flashing to arriving pilots is depicted by a long red bar in the location of the PAPI lights on the surface. This bar begins to flash red and white if the arrival has reached a set distance, currently .5 nautical miles (nmi), from the landing threshold and an audio alarm is simultaneously sounded in the control tower stating “FAROS runway one seven center” (for example). The idea for the audio advisory alarm arose during the operational concept development phase and originated from tower controllers. It serves to raise their situational awareness of an impending go-around situation. It is a female voice (distinct from the male voice used for the existing AMASS mandatory go-around alert).

In addition to the situation display with red bars, there is a window available only on the supervisor’s display that allows for command and control of the RWSL and FAROS systems (see figure 9). The window includes functions such as turning all lights (or some lights) off immediately, plus adjusting the power level of the lights and changing the airport flow (although the system senses both and changes automatically to reduce workload).

Operational Protocol for RWSL and FAROS

One of the human factors challenges faced at the beginning of each phased implementation for RWSL and FAROS was to, in conjunction with the subject matter experts, establish appropriate operational protocol and develop training materials to reflect and disseminate it. The latter was done by typical methods such as NOTAMs and Jeppesen inserts along with more comprehensive efforts such as delivering training briefings to all stakeholders on CDs and presenting to all involved (controllers, supervisors, tower managers) at FAA air traffic control facilities as well as to pilots at airlines and pilot union forums.

The protocol that has been established states that “RWSL has two states, ON: lights are illuminated red, indicating the runway is not safe to enter or cross, RED MEANS STOP! And OFF: lights are EXTINGUISHED, conveying no meaning. — THE SYSTEM NEVER CONVEYS APPROVAL OR CLEARANCE TO PROCEED ONTO A RUNWAY. Pilots remain obligated to comply with all ATC
clearances, except when compliance would require crossing an illuminated red REL. In such a case, the crew should hold short of the runway (if possible), contact ATC, and await further instructions.

However, if the pilots notice an illuminated red REL and remaining clear of the runway is impractical for safety reasons, then crews should proceed according to their best judgment of safety (understanding that the illuminated REL indicates the runway is unsafe to cross or enter) and contact ATC at the earliest opportunity. ATC may disable RWSL at any time if in their judgment the system is interfering with normal, safe operations.”

For FAROS the protocol is stated as “When the FAROS acquisition point of approximately 500 ft AGL is reached with flashing PAPIs, attempt to see traffic on the runway. If seen, evaluate the situation, then proceed with caution. If not seen, prepare to contact ATC at contact point. When FAROS contact point of approximately 300 ft AGT is reached with flashing PAPIs, attempt to see traffic on the runway. If seen, evaluate the situation, then proceed with caution. If not seen, contact ATC to verify landing clearance and prepare for an immediate go-around. If ATC does not verify landing clearance, go around. If ATC cancels the landing clearance, go around.” It is anticipated that the training challenge will be more acute when RWSL and FAROS are tested with international pilots or pilots who may not frequent the airports where the systems will be deployed. The newly established pilot protocol that is currently being tested with FAROS at DFW is meant to prevent a “land-over” accident such as occurred at LAX in 1981 (shown in figure 10).

Operational Feedback and Analysis

Operational feedback was the primary focus during the operational evaluation. This information comprised responses to questionnaires from pilots, and vehicle operators, as well as, comments, notes, and observations made by controller supervisors, voluntary controller participants, and test team members. The operational feedback determined when and to what extent RWSL affects the normal operation of the airport and served as a measurement of the operational suitability of RWSL in actual operational use.

Operational Feedback Measures

The RWSL and FAROS operational feedback resulting from the conduct of the operational evaluations is ongoing and initial results are reported here. The data for RELs and THLs at DFW and RELs at SAN is robust since there are hundreds of responses included over the past few years. Although the surveys are still open there have been no substantially different findings to date. The data for FAROS at DFW is early information and subject to change as the operational evaluation at DFW continues. The feedback gives us insights regarding impacts to system capacity, allows in depth assessment of controller supervisor and pilot communications with respect to the new lights provided as a safety back-up to ATC, and helps assess pilot and vehicle driver situational awareness.

Elicited observer feedback included suggestions for system tuning and safety enhancements. The pilots were asked to confidentially answer survey questions to assess the operational suitability, safety, and effectiveness of the runway status lights. Both paper and on-line surveys were provided with the majority of responses submitted using the project website on-line at www.RWSL.net.

In addition, voice transmissions between air traffic controllers and pilots and vehicle drivers over the local and ground frequencies were recorded for confidential post hoc analyses.

Pilot Surveys

The pilot surveys comprised a number of yes/no response statements or bipolar Likert scales presented in a positive and negative counterbalanced order with additional comments encouraged. We have employed three different survey methods: web site (at RWSL.net), telephone, and paper (placed near posters in Airlines Operations Centers and Fixed Base Operators at the airports). Most pilots used the website method to respond to the survey; the phone method was rarely used and has since been abandoned.

Overall reaction to the RWSL systems in the field has been very favorable among the participants who chose to respond to the
surveys. Early information received on the FAROS system at DFW also reveals an overall favorable response. An overwhelming majority of the pilots felt that RELs at both DFW and SAN and THLs at DFW will help reduce runway incursions, and would recommend that they be installed in other airports. Preliminary data for FAROS also shows agreement with the supposition that flashing PAPIs will help to reduce runway incursions. About one quarter of the respondents to the RELs survey felt that the system needs some fine tuning in such areas as the configuration of the lights relative to the taxi way hold line, the timing of the lights (especially at SAN), and the intensity of the lights (especially at DFW). These REL issues have been addressed in system upgrades. Less than ten percent of the respondents were expressly negative about the concept and/or its implementation.

Pilots Comments about RWSL and FAROS

In the surveys administered during the operational evaluations, over half of the total respondents elected to add unstructured and open-ended comments to the surveys. These comments, for the most part, reflected the pilots’ personal attitude toward and concerns about the RWSL and FAROS systems. This is a relatively high percentage of added comments indicating the general interest and overall enthusiastic attitude that pilots felt about this system (typically only 15–20 percent of the respondents add free form comments to such surveys). The majority of comments were quite positive and consistent with the given ratings.

Pilot Survey Statement Aggregated Results

To summarize the survey results in the post-hoc analysis, responses to specific statements were aggregated into four categories: comprehension, effectiveness, acceptance, and suitability. These aggregated results are shown in figure 12 for DFW and SAN RELs (combined due to their similarity in favorability ratings at the two airports) and in figure 13 for DFW THLs only (since there are not yet any THLs at SAN). Similar initial data are shown in figure 14 for FAROS at DFW. Only DFW airport has the advanced version of FAROS under evaluation to date and the results reported here are preliminary.

During the first operational evaluation of runway status lights, involving RELs at DFW, we formed these categories once the survey results were analyzed and found significant correlations between the responses to each survey statement within a given category. This verified the logical groupings and credibility of aggregating responses into these four categories.

Also, a learning curve and increased favorability is evident in all categories as more data are gathered and more pilots are exposed to the lights (see figure 13 with data presented in bins of no exposure, one to five times exposure, and over five times exposure to the lights in the field).

The sample size is an inherent limitation of field studies with volunteer respondents. However, with the aggregated data each category contains at least 60 data points for FAROS (started only three months ago) and well above that for RELs and THLs that have been in the field undergoing extended operational evaluations for two to four years.

Comprehension, of course, is essential so that pilots recognize risk indicators (red illuminated REL or THL or flashing PAPIs). Also, just as or perhaps more importantly (given the circumstances) they must understand that they are not to proceed to cross, enter, take off from, or land on a runway simply because there is not red lights or flashing lights when they have not received verbal clearance from ATC.

One of the primary concerns is that a pilot will misconstrue a light turning from red to off as clearance to cross or enter a runway or to take off from a runway upon the extinguishment of red RELs and THLs respectively. However, to our knowledge and best efforts at detecting such an event through timing analysis, this has not happened.

Comprehension is also the foundation that must be secure in order for measurements of effectiveness, acceptance, and suitability to be valid. As shown in the figures of survey results, comprehension received over 90 percent favorability for all of the runway status lights and FAROS responses analyzed to date from both field sites, DFW and SAN. Complimentary technical assessments of the systems that analyze false activations and missed detections indicate that they are working at near optimum (above 99.5 percent). Therefore, the system information is accurate and the users understand it. Thus we can move on to evaluate its fit into their operational environment by looking more closely at the other categories.
Acceptance is assessed from responses to queries on situational awareness, potential for reducing runway incursions, and recommendation for additional installations at other airports. Effectiveness is based on ratings of accuracy (lights were on and off when they should have been), conspicuity, and consistency with ATC clearances. Finally, suitability considers the impact of RWSL and FAROS on workload and whether or not it is a distraction to normal duties and scans, as well as the parameters used in tuning the lights to the tempo of operations (such as the acquisition and contact points for pilots on final approach to landing who observe flashing PAPIs with FAROS).

Overall, pilots who responded to the surveys have rated RELs and THLs quite favorably. The large majority of the pilot respondents comprehended the operating procedures associated with RELs (93%) and THLs (96% for those with over 5 exposures). The perceived operational effectiveness category was also high with responses reaching a favorability of near or above 90% for RELs and THLs. Early data for FAROS is indicating a similar favorable overall rating with the exception of suitability.

The overall acceptance of the system based on the survey was 90% of pilots for RELs and THLs. So far the acceptance of FAROS is initially showing a rating of 95%. Operational suitability was rated highly for RELs at 92% and even higher for THLs at 99%. However, suitability has received the lowest score of 82% by pilots responding to the ongoing FAROS survey. The relatively low suitability score for FAROS (as shown segregated into the five point scale ratings in figure 15) is attributed to the higher levels of disagreement on the existing operational concept which calls for PAPIs to flash fairly close in to the landing threshold for pilots on final approach (when they are typically busy with relatively high workloads in preparation for landing). As with the other warning lights, the presentation of the indication is a delicate balance between providing a potentially life saving safety benefit to pilots and yet not interfering with the flow of traffic being efficiently orchestrated by the air traffic controllers.

The pilot feedback to date from the ongoing operations of RELs, THLs, and FAROS indicates that these systems are well understood, accepted, effective, suitable (with more data needed to establish a reliable reading on the suitability of FAROS), and should be implemented.
due to false tracks that resulted in false activations of the RELs and THLs, although one event during the first week was an actual runway incursion with a valid red illumination of RELs. That event is by its nature sensitive, however the pilots who crossed the red RELs reported that they did not see them. Such incidents have ceased with the help of refresher training, diligent follow up with the pilots and air traffic controllers, improvement of the surveillance and safety logic algorithms that reduced false activations, and increased exposure to the lights.

There have been a number of pilots who questioned a clearance when they observed red lights (both RELs and THLs) and at least three documented “saves” by the lights as follows with snapshots of the RWSL test display showing aircraft involved and red bars indicating lights (except for FAROS event where pilot going around has already been given the alert by flashing PAPIs).

**Actual events demonstrating benefit of RWSL and FAROS**

The following synopses describe actual events that have occurred at DFW during the ongoing extended operational evaluations of RWSL and FAROS. A screen snapshot from the RWSL test display is shown for each event.

**Event One: DFW airport THL save, February 2008**

Synopsis: EGF301 cleared for intersection takeoff on 36R. About 26 seconds later tower cleared AAL1116 to cross runway 36R. During EGF301’s departure, THLs illuminated as AAL1116 crossed. EGF301 rejected the takeoff because of red THLs. EGF301 was cleared for takeoff again 25 seconds later. The pilot of the departing aircraft said that he was very familiar with runway status lights and has learned to “Scan right, scan left, check for red lights, good to go.”

**Event Two: DFW airport THL save, May 2008**

Synopsis: AAL379 was cleared for departure on 36R and 20 seconds later MES3675 crossed 36R during AAL379’s takeoff roll. THLs illuminated and AAL379 aborted. After exiting the RWY, AAL379 was cleared for takeoff on 36R four minutes later. The pilot’s company report of event stated: “After cleared for take-off, we began to roll and I noticed the RWSL lights turn red. I looked down the runway and saw an aircraft crossing the runway left to right (Mesaba regional jet) and aborted the takeoff (max speed below 80 knots). The RWSL worked awesome. I noticed that BEFORE I saw the intruding regional jet.”

**Event Three: DFW airport FAROS save, Dec 2008**

Synopsis: EGF5152 did not exit 36L as cleared by the local controller. Tower requested EGF5152 expedite down the runway and exit at the next taxiway due to traffic (AAL1300) on short final. EGF5152 slowed to take E4. Tower received a FAROS audio alert when AAL1300 was approximately 0.5 nmi from the runway threshold and EGF5152 was beginning their turn onto E4. Four seconds later tower issued a go-around to AAL1300 (approximately 140 ft and 0.29 nmi from the runway threshold). Additional communications post go-around between AAL1300 and tower included a traffic and wake turbulence advisory for a B777 Heavy which had just departed the parallel runway 36R. The pilot who went around reported that he saw the lights (flashing PAPIs) and that he had decided he would go around at the same time as the local controller cleared him to do so.

**CONCLUSION**

The primary goal of RWSL and FAROS is to reduce the number of runway incursions and thus prevent runway accidents while not interfering with normal, safe and efficient airport operations. These advisory systems improve crew and vehicle operator situational awareness through accurate and timely indication of runway occupancy. In all situations, RWSL provides advisory information that must never be construed as an ATC clearance. The systems have been subjected to extended operational evaluations that are ongoing and will continue anew at different airports with different human factors and other technical challenges. These evaluations address key requirements set forth for the RWSL development program including participation of air traffic controllers and pilots in all phases of development, demonstration of system acceptance at each phase of testing, and determination of operational suitability for end users.

The human factors challenges that have been met include training pilots and vehicle operators to understand that illuminated red lights or flashing PAPIs are used to raise situational awareness and advise of unsafe conditions. However runway status lights turning from red to off or from FAROS flashing PAPIs reverting to their typical non-flashing, steady appearance never imply a clearance since that is still provided verbally by air traffic control. After having briefed RWSL and FAROS human factors results to the Aerodrome Ground Environment (AGE) group of both the Airline Pilots
Association (ALPA) and the International Airline Pilots Association (IFALPA), the former wrote a white paper [5] on runway incursions that has recommended the deployment of these systems at all major airports and the latter has submitted a proposal to the International Civil Aviation Organization (ICAO) lighting panel to standardize the message the “red means stop” and to change the end-of-runway lights (that are currently red) to a different color thereby avoiding any (remotely) possible confusion with red THLs. Human factors assessments of such issues and challenges will be explored and evaluated as we test the prototypes of RWSL and FAROS at new sites to be chosen by the FAA in cooperation with the respective airport authorities. We are also continuing to work with the community of pilots and air traffic controllers, both national and international, as the RWSL and FAROS technologies are transferred to industry for deployment to major airports in the NAS and worldwide.

REFERENCES


[2] “FAA has increased efforts to address runway incursions” GAO Testimony Before the Subcommittee on Aviation, Committee on Transportation and Infrastructure, House of Representatives, Aviation Safety, page 1.


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AUTHOR BIOGRAPHY

Maria Picardi Kuffner was born in Boston, Massachusetts and was awarded a Masters Degree in Cognitive/Experimental Psychology from Arizona State University, Tempe AZ, USA sponsored by a Regents scholarship in 1983 after completing graduate courses at Harvard University, Cambridge, MA, USA in Psychology and Law in 1981, and a Bachelors Degree in Psychology at Regis College, Weston, MA, USA in 1978.

She is currently employed at MIT Lincoln Laboratory in Lexington, MA, USA, as a Human Factors Specialist. Before joining MIT Lincoln Laboratory in 1989, she was a Senior Engineer at Raytheon Company for five years. Prior to Raytheon, she was a Member of Technical Staff at GTE Laboratories Incorporated. She was a Research Assistant at the Psychophysics Laboratory of Harvard University for five years and a Programmer/Analyst for the Air Force Geophysics Laboratory for four years while an undergraduate student.

Ms. Kuffner is a past president of the Human Factors and Ergonomics Society's New England Chapter, was recognized by the FAA for contributions to the National Plan for Aviation Human Factors, and holds a private pilot's license.

Captain Robert Perkins was born in Toronto Canada in 1951. He left formal schooling after High School to pursue a career in aviation.

After obtaining his private and commercial pilot’s licenses, he instructed for five years at Toronto, Ontario, and was the assistant Chief Flying Instructor at the time he left the flight school in 1973. Since then he has been employed by JAZZ Air LP, through various mergers and buyouts, today Air Canada Jazz, the regional arm of Air Canada and has over 26,000 flight hours.

Captain Perkins currently sits on the ICAO (International Civil Aviation Organization) Aerodromes Panel as the IFALPA (International Federation of Air Line Pilot Associations) member. He is also the Chair of the Airports and Ground Environment Committee at both IFALPA and ALPA (Air Line Pilots Association) in the United States and was the recipient of the ALPA Air Safety Award in 2007. He currently resides in Welland, Ontario, Canada.