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# Human-in-the-Loop Simulation of an Integrated Ground Movement Safety System

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# Abstract

This document describes a human-in-the-loop simulation evaluating the effectiveness of an integrated ground movement safety system for improved runway safety. The evaluated ground movement safety system contained technologies to enhance pilot awareness as well as warn pilots about runway safety risks and had been proposed by Andrews, Dorfman, Estes, Jones, and Olmos (2005). Strengths and limitations of this integrated system as well as possibilities to address these limitations were determined. Pilots experienced the integrated safety system that enhanced pilot awareness (passive runway awareness technologies) and provided visual warnings about surface traffic to pilots (active warning system). In addition pilots experienced simulation scenarios in a baseline condition. The passive runway awareness system consisted of enhanced airport surface markings, modified lead-on lights, and runway guard lights. The active warning components consisted of airport surface lights including take-off hold lights and runway entrance lights. Two additional warning systems were designed in this simulation to fill runway safety gaps that the proposed solution set did not address. Arrival occupancy lights warned arriving aircraft that it was unsafe to land on a runway. In addition AMASS alerts were directly displayed via auditory channel to pilots in the cockpit. Results indicate that active pilot warning technologies reduced the occurrence of simulation incursions.

KEYWORDS: runway safety, direct pilot warning, runway guard lights, runway entrance lights, runway status lights, take-off hold lights, arrival occupancy lights, AMASS, direct AMASS alerting, human error induction methodology, runway guard lights, enhanced airport surface markings, modified taxiway centerline lead-on lights, airport surface simulation, runway conflicts, runway collisions, human-in-the-loop simulation

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# Executive Summary

A human-in-the-loop simulation was performed to evaluate the effectiveness of an integrated ground movement safety system for improved runway safety. The evaluated ground movement safety system was proposed by Andrews, Dorfman, Estes, Jones, and Olmos (2005) and contained technologies to enhance pilot awareness of the runway environment as well as warn pilots about potential runway safety risks. Strengths and limitations of this integrated system as well as possibilities to address these limitations were determined. Pilots operated an aircraft simulator under three different conditions representing three technological safety levels. The simulation scenarios contained potential runway conflicts. The effectiveness of the integrated safety system was assessed by comparing the occurrences of safety incidents between the three technology levels. At the first level, pilots operated the aircraft on an airport that approximated current operational safety levels without added awareness or warning technologies. At the second level, pilots experienced an integrated safety system that enhanced pilot awareness and provided visual warnings about surface traffic to pilots (active warning system). The runway awareness technologies were passive and consisted of enhanced airport surface markings, modified lead-on lights, and runway guard lights. The active warning component consisted of airport surface lights including take-off hold lights and runway entrance lights. Two additional new warning technologies were designed and evaluated in this simulation to fill safety gaps that the solution set as defined by Andrews et al. (2005) did not address. Arrival occupancy lights warned arriving aircraft that it was unsafe to land on a runway. In addition AMASS alerts were directly displayed via auditory channel to pilots in the cockpit.

The results of the simulation indicate that the integrated ground movement safety system, as proposed by Andrews et al. (2005), increased runway safety by significantly reducing the likelihood of simulation incursions. Specifically:

- Runway entrance lights eliminated all unsafe runway crossings.
- Take-off hold lights reduced unsafe take-off maneuvers by 86%.
- Passive runway awareness technologies increased self-perceived runway awareness of pilots; runway guard lights and enhanced markings in the hold-short environment were seen as the most mature and effective passive warning technologies.
- Overall, according to the pilots' comments, the integrated ground movement safety system resulted in increased situation awareness and increased performance, without increased pilot workload.

The solution set, as proposed by Andrews et al. (2005), did not provide protection against unsafe landings. For this purpose, Arrival Occupancy Lights were evaluated that resulted in a 63% reduction of unsafe landings.

In addition, a prototypical auditory warning system that communicated Airport Movement Area Safety System (AMASS) alerts directly in the cockpit reduced simulation incursions by an additional 80 %.

Based on the results of this simulation, the following improvements and research are recommended:

- Some pilots missed the activation of the THL lights; therefore, different lighting arrangements (e.g., transverse rather than longitudinal lights) should be considered. Guidance about desired pilot behavior after the lights deactivate is also required.
- The implementation of arrival occupancy lights should be improved because the chosen implementation (PAPIs that are flashing triggered by AMASS alerts) did not gain sufficient attention by pilots. Alternative concepts could include other runway lightings such as THLs, or runway approach lights. the predictive logic of the alerting system should also be improved to provide earlier alerts.
- The auditory warning system provided significant safety benefits in this simulation; therefore, additional research is recommended to develop such a system. Additional research should outline technological solutions with performance characteristics that consider false and missed alerts. For the purpose of this simulation the warning technologies had been assumed to be perfect. The volume of the warning message should be increased and the length of the message should be shortened if possible. The effectiveness of direct auditory warnings to prevent runway incursions should be evaluated in isolation from other safety systems.

# Acknowledgments

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Also acknowledged is the support for the coordination and organization from Alisia Quickel, Beth Bird, Sandra Carlough, as well as for editing this document. The author wishes to thank James Eggert and Maria Kuffner (MIT Lincoln Laboratory) for their cooperation for the runway status lights implementation. The contribution of Blake Roberts for categorizing and organizing the comments from pilots is specifically acknowledged. Also acknowledged is Ron Nichol for coordinating a visit of the runway status light system at Dallas-Fort Worth Airport. Special thanks go to Cheryl Andrews for organizing the test plan and technology demonstrations for this project.

**Section 1**

# Introduction

The safety service of the Air Traffic Organization (ATO) of the Federal Aviation Administration (FAA) is tasked to determine the feasibility of a system to mitigate runway incursions (RIs) at airports that have scheduled passenger service in order to address National Transportation Safety Board (NTSB) recommendation A-00-66 (NTSB, 2000). NTSB recommends that any implemented ground movement safety system should provide a direct warning to the flight crew. Additionally, simulations should demonstrate that the system prevents RIs.

The FAA is researching a prototype ground movement safety system per the NTSB recommendation, and initial phases of system planning were completed in Fiscal Year 2004 (FY04) (Andrews, Dorfman, Estes, Jones & Olmos, 2005). This phase included RI risk ranking of airports (prioritized needs assessment), identification of possible near-term technologies applicable to RI mitigation, and establishment of recommended solution sets. The initial set of possible technologies included the Airport Movement Area Safety System (AMASS), Runway Status Light System (RWSLs), and a set of technologies to enhance pilot awareness about the runway, here referred to as Passive Runway Awareness System (PRAS). This set of technologies is referred to as "solution set" in this document. A simulation study was required to assess the completeness of the recommended solution and identify modifications if needed. The results of this simulation are reported in this document. The following sections outline the prototype ground movement safety system.

The integrated ground movement safety system is designed to reduce the risk of runway incursions using two types of components. First, the integrated system contains passive technologies that support pilots' awareness about the runway environment. Second, the integrated system consists of active systems that inform pilots about current traffic and warns pilots about potential conflicts[1]. Whereas all these technologies had been previously researched and described in some detail, a new set of "enhanced" technologies was added to fill remaining safety gaps. These safety gaps emerged from an analysis of historic runway incursions and the construction of simulation scenarios, as described in this document. These systems are described next.

[1] The term "warning" in this document is used in a general sense and refers to any communication with the intent to improve safety. It does not imply any Air Traffic Control clearance except at places where it is specified as such. In Air Traffic Control terminology, the term "alert" is used to describe a notification to a position that there is an aircraft-to-aircraft conflict or aircraft-to-airspace conflict, as detected by Automated Problem Detection (see FAA Order 7110.65).

## 1.1 Airport Movement Area Safety System

AMASS is a runway collision alert system that provides air traffic tower controllers at some Airport Surface Detection Equipment-3 (ASDE-3)-equipped airports with automated aural and visual conflict warnings to reduce the risks of runway collisions.

AMASS does not provide direct warnings to pilots, but alerts controllers. AMASS is included in the integrated ground movement safety system because AMASS is currently operational at several National Airspace System (NAS) airports and provides protection against certain types of runway incursions. It therefore represents a layer of protection with an integration opportunity with other systems for a comprehensive runway safety solution and avoid conflicting alerting between pilots and controllers. It could also serve as the technology base for development of a system that can provide direct warnings to pilots.

AMASS generates alerts for situations such as when an aircraft or vehicle is occupying the runway while an arriving aircraft is closer than at a specific distance (e.g., approximately 0.5 miles) from the runway threshold or when a departing aircraft is moving faster than a minimum speed threshold (e.g., 45 knots) and is predicted to conflict with another aircraft occupying the same runway. Converging runway coverage is possible but not implemented in current site adaptations and may be a future capability.

The AMASS system receives raw radar data from the ASDE-3 and airborne approach targets from the Terminal Automation Interface Unit (TAIU). The TAIU receives target data from the Surveillance Communications Interface Processor (SCIP) and aircraft tag data from the Automated Radar Tracking System (ARTS). It tracks this data and sends the appropriate position, vector, and a predicted approach runway to AMASS. Targets are then processed by the AMASS Safety Logic to determine if any targets have the potential to create a hazardous situation (Dellmyer 2000).

The AMASS alerting logic that was implemented in this simulation was adapted based on the description of Hershey (1998) and the AMASS baseline document FAA (1995). (See Figure 1-1 for an engineering display of AMASS.)

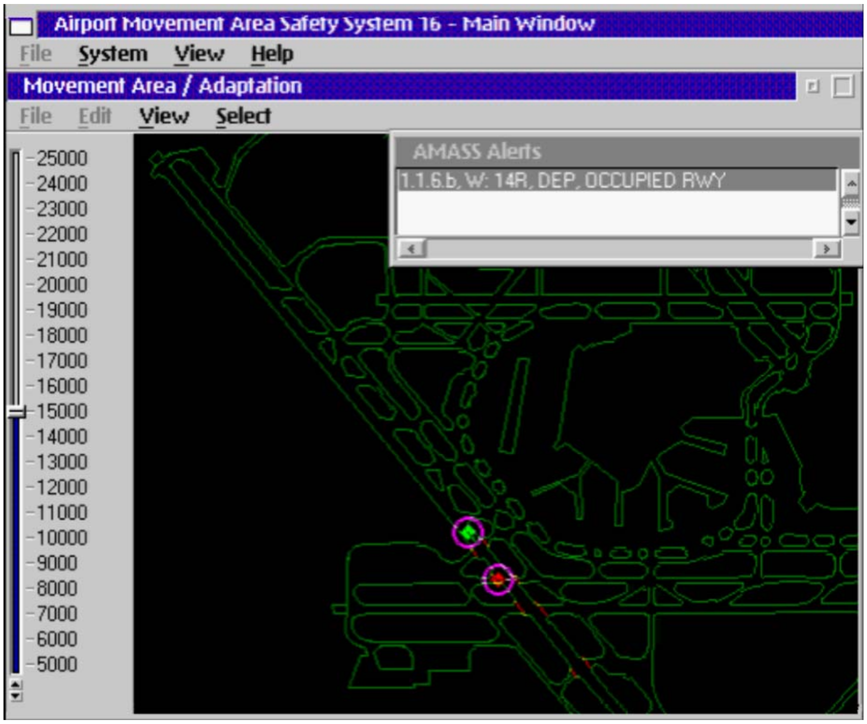


**Figure 1-1. Capture of AMASS Display and Runway Incursion Alert for Two Aircraft**
**(From: http://www.ntsb.gov/events/2000/incursion/incur_video)**

## 1.2 Runway Status Lights

The RWSL system is currently being researched by MIT Lincoln Lab (Thompson and Eggert, 2001) and is not operational in the NAS. It is designed to reduce the risk of runway incursions by visually warning pilots and ground vehicle operators when the potential for a runway incursion exists. RWSLs provide this advisory in the form of steady red lights at the runway holding position marking (Runway Entrance Lights or RELs, see Figures 1-2 and 1-3) and on the runway (Take-off Hold Lights or THLs). The current RWSL concept does not include any warnings for arrivals. When the RWSL system, driven by a surveillance network (e.g., ASDE-X), detected an aircraft in the process of taking off, landing, and/or crossing the runway, the RELs or THLs illuminated. The REL and THL systems in this simulation were based on specifications by Thompson and Eggert (2001) as well as the RWSL site adaptation at DFW and as specified by the RWSL website at http://www.rwsl.net/.

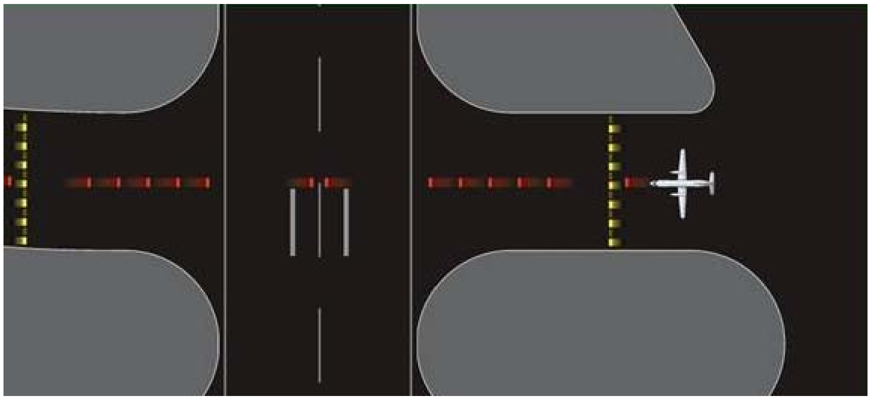

**Figure 1-2. Illustration of Runway Entrance Lights**

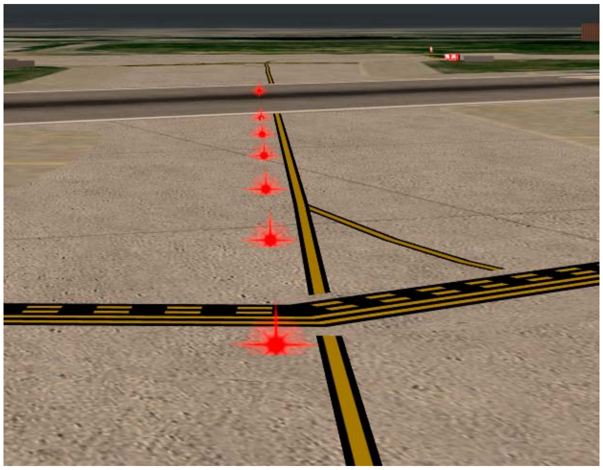

**Figure 1-3. Runway Entrance Lights as Seen From the Cockpit**

RELs are intended to warn pilots who approach the runway hold-short environment that another aircraft is either landing (within 0.75 NM of the landing threshold) or departing on the runway and is currently located prior to that runway intersection at a speed higher than 20 knots. RELs consist of red in-pavement fixtures that are installed longitudinally along the taxi path, beginning just prior to the taxiway/runway hold position marking and extending to the runway edge, with one additional REL installed near the runway centerline on the line extended from the last two lights on the taxiway. The longitudinal spacing for the lights was between 12.5 feet to 50 feet so that four lights were positioned between the hold line and the runway edge. A final light was placed at the straight extensions of the lights at the runway centerline.

THLs are intended to warn pilots who are about to initiate a take-off that another aircraft is on the runway or is predicted to enter the departure runway. THLs consist of a 1000 foot longitudinal array of in-pavement red lights, aligned with the runway, and aimed back along the approach path to the runway[2]. (See Figures 1-4 and 1-5.) For this simulation THL's illuminated if an aircraft was located in the departure region of a runway or in process of taking off and another aircraft was on the runway or was predicted to enter that departure runway within 30 seconds.

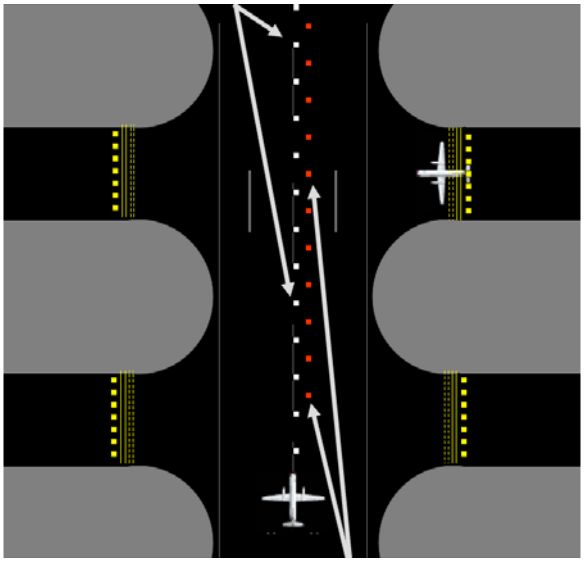

**Figure 1-4. Take-Off Hold Lights**

[2] For this simulation, THL's began at 875 ft. from the threshold at runways that were longer than 10000 feet and at 525 ft. for shorter runways. They were displaced laterally 2 ft. from the centerline lights on the same side of the centerline marking as the centerline lights. The THLs were offset longitudinally 25 ft. from the centerline lights, and placed every 100 ft., so that for 50 ft. spaced centerline lighting, the THLs were placed in between the centerline lights in every other space. There was a minimum of 1000 ft. of lights (i.e. 11 lights in the array)

**Figure 1-5. Take-Off Hold Lights as Seen From the Cockpit**

## 1.3 Passive Runway Awareness System

PRAS consists of technologies to support pilots' runway awareness by providing visual information about the runway, prior to, at, and beyond the hold-short environment. These technologies are passive and do no provide active alerts to pilots or air traffic controllers.

### 1.3.1 Modified Taxiway Centerline Lead-On Lights

Current taxiway centerline lead-on lights consist of green lights beginning at the holding position marking and leading to the runway centerline. In this simulation, a proposed modification of taxiway centerline lead-on lights was evaluated that consisted of alternating yellow and green lights (see Figure 1-6). The proposed modification is currently not implemented in the NAS but has been previously been evaluated, see Moertl et al. (2005). This pattern mimics the current lead-off light pattern for taxiway centerline lights. The modification was designed to improve flight crew's awareness of the runway environment by providing an additional visual cue that indicates the runway environment. The simulation implementation followed FAA advisory circular AC 150/5340-30.

**Figure 1-6. Modified Taxiway Centerline Lead-On Lights**

### 1.3.2 Enhanced Surface Markings

Enhanced Surface Markings (Figure 1-7) consist of runway holding position markings that are extended onto the shoulder beyond the taxiway edge lines, modified taxiway centerline markings, and dual surface painted holding position signs. The enhanced surface markings are currently not implemented in the NAS.

The FAA updated the Standard for Airport Markings, Advisory Circular AC 150/5340-1H during the conduct of this simulation and included a subset of these marking features. In this study, the enhanced surface markings consisted of the features as listed above. Enhanced markings are illustrated in Figure 1-8 and described in detail in Moertl and Andrews (2005).


**Figure 1-7. Enhanced Surface Markings**

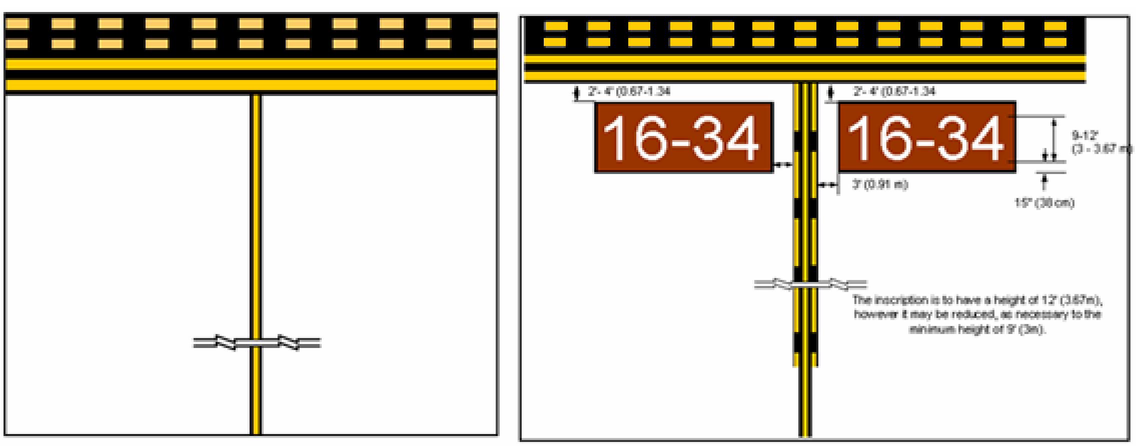

**Figure 1-8. Illustration of Current (Left) and Enhanced Surface markings (Right)**

### 1.3.3 Runway Guard Lights

Runway Guard Lights (RGLs), commonly referred to as "wig-wags," consist of flashing yellow lights located at each edge of the runway holding position marking (Figure 1-9) and are currently implemented in the NAS. These lights may also be in-ground fixtures, installed in front of and parallel to the holding position marking. RGLs are presently required for operations less than 1200 runway visual range (RVR) and are intended to enhance pilot awareness of the runway environment, particularly under conditions of reduced visibility. RGLs are controlled by Air Traffic Control (ATC) and may be activated at any time. Runway Guard Lights are either elevated (see Figure 1-9) or installed in the pavement (see Figure 1-10); The FAA lighting standard FAA AC 150/5340-30) requires in pavement RGLs for the intersections in this simulation.

**Figure 1-9. Elevated Runway Guard Lights**

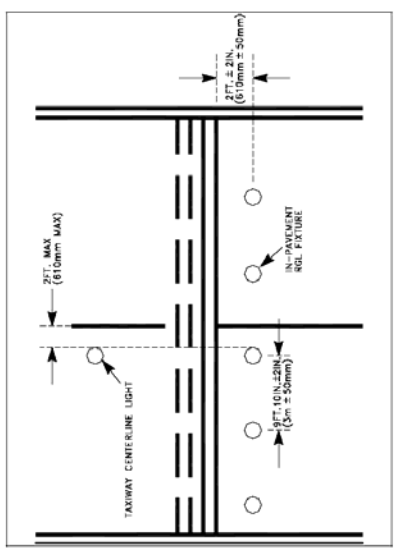

**Figure 1-10. In-Pavement Runway Guard Lights**
**(From AC 150/5340-30)**

## 1.4 Prototype Warning Systems

The above described safety systems provided protection against most but not all simulated runway incursion. During the process of constructing the simulation scenarios, as described in more detail in the following section, it was determined that the ground movement safety system as proposed by Andrews et al. (2005) did not provide sufficient warnings to arrival aircraft. Specifically, AMASS collision prediction performance provided alerts to controllers that were too late to prevent incursions in these scenarios. Therefore, two additional prototype technologies were added.

### 1.4.1 AMASS Direct to Cockpit

An extension of the currently existing AMASS consists of displaying AMASS alerts directly to the cockpit. Currently a time delay between AMASS alert and controller response is introduced by the necessity of the controller to first assess the situation, formulate an appropriate response, and then relay an alert to the pilots. A direct relay of AMASS alerts to the cockpit could represent an improvement in terms of safety because of decreased warning delay. In this simulation, an initial evaluation of the effectiveness of direct AMASS alerts was conducted as one of the three experimental warning levels. For this purpose, AMASS warnings were presented directly via an auditory channel to the cockpit. Also, the Air Traffic Control Tower (ATCT) controller received an auditory and visual warning about the conflict situation. For this simulation, it was assumed that alerts could be communicated to the cockpit via sideband frequency of the marker beacon and be played on the Enhanced Ground Proximity Warning System (EGPWS). Only the alerted aircraft and ATCT received the warning.

The warning that the pilot received was different from the one that the ATCT controller received. ATCT controller received the same AMASS alert as under current operations. The pilot received a simpler message that was independent from the type of alert conflict. This message was:

> "CAASD 49, Warning: Runway Unsafe, Warning: Runway Unsafe"

The message was relayed via computer generated voice. Pilots were instructed to immediately initiate appropriate action upon hearing this warning message and inform the air traffic controller who then issued a clearance to resolve the conflict. The pilot warning message was independent of the conflict situation and the pilot was required to determine appropriate action.

The AMASS direct-to-cockpit warning concept was developed solely for use in this simulation and does not represent a system currently planned for implementation.

### 1.4.2 Arrival Occupancy Lights

The Arrival Occupancy Light (AOL) system is intended to warn landing aircraft that a runway conflict is predicted while they are approaching the runway. The AOL system is a prototype that has been developed for this study and has not been previously specified in detail. AOLs consist of Precision Approach Path Indicator (PAPI) lights that are flashing when a conflict on the runway was predicted by the AMASS alerting logic. PAPI lights are installed in a single row of either two or four light units. PAPI lights have an effective visual range of about five miles during the day and up to 20 miles at night. The conflict predictions were calculated by the AMASS alerting logic that provided a visual and an auditory alert to the controller when a collision was predicted and triggered the PAPI's to flash on the runway. PAPI's flashed in two second cycles with the lights being on for 1.33 seconds and off for 0.66 seconds. (See Figures 1-11 and 1-12).

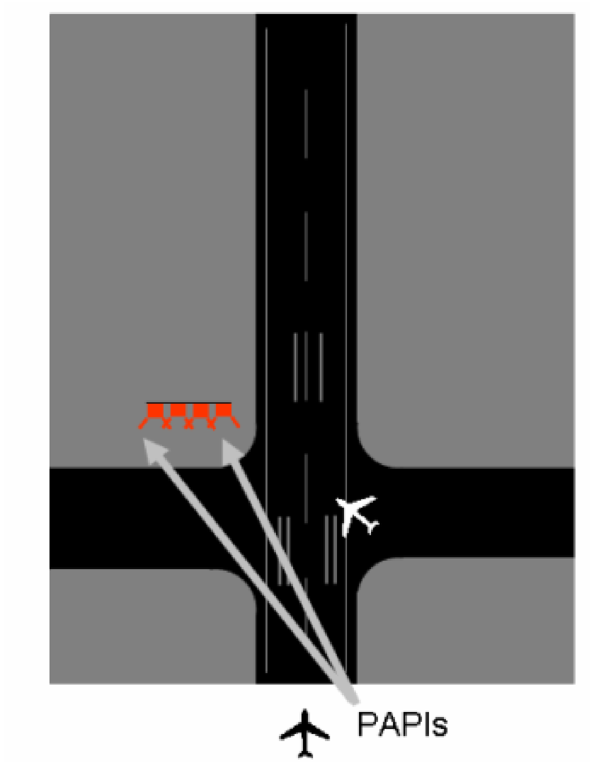


**Figure 1-11. Arrival Occupancy Lights Consisting of PAPIs that Flashed Upon Being Triggered by an AMASS Arrival Alert**

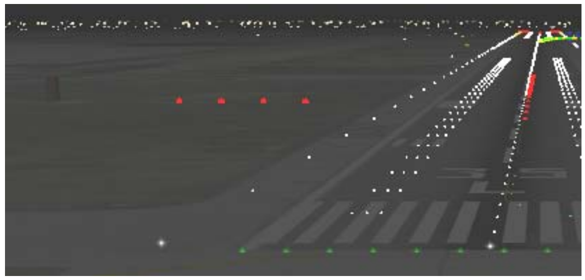

**Figure 1-12. Arrival Occupancy Lights as Seen From the Cockpit, Indicating a Low Approach Path**

**Section 2**

# Study Objectives and Method

The objective of this simulation study was to evaluate the effectiveness of an integrated ground movement safety system as specified by Andrews et al. (2005). Also, system strengths, limitations, and strategies to address these limitations should be identified.

The study objective was addressed in an airport surface simulation. In this simulation, pilots were exposed to scenarios with pilot error opportunities. The effectiveness of the ground movement safety system was assessed by measuring how well the system mitigated or prevented pilot errors leading to an incursion or a collision. Because runway incursions at major air carrier airports are relatively infrequent events, it could not be expected that pilots committed such incursions during a few simulation runs. For this purpose, error opportunities were embedded in the simulation scenarios. Pilots always had opportunities to detect these error opportunities. Such error opportunities were induced by:

- Taxi-instructions that contain an error
- Difficult environmental factors such as low visibility and night conditions
- Unexpected events
- Continuous radio communication
- Increased pilot workload through performance of secondary tasks

Pilots were asked to complete flying and taxiing tasks on the simulated airport surface without assistance of a second pilot. They communicated via radio with an ATCT controller from whom they received taxi instructions. They heard background radio communication with simulated airport surface traffic and saw the simulated traffic while performing their task. Background radio communication was produced by one simulation "pseudo-pilot" and an ATCT controller.

The effectiveness of the integrated ground movement safety system was measured by comparing safety benefits of two safety levels with a baseline condition. The baseline condition approximated current airport surface operations. Safety benefits were conceptualized as mitigation of safety hazards such as runway incursions, increased situation awareness of pilots, decreased pilot workload, and perceived increases in runway safety.

## 2.1 Participants

Thirty-six pilots participated in this simulation. Twenty-nine pilots had experience flying transport category aircraft, seven pilots were General Aviation pilots[3]. Their average flight experience was 5887 (median 5250) flight hours and they had on average 119 flight hours (median 105 hours) logged during the last 6 months. The minimum flight experience was 500 flight hours, and the maximum was 23,600 flight hours. All participants, regardless of their experience, operated the same simulator.

## 2.2 Simulation Environment

The MITRE Center for Advanced Aviation System Development's (CAASD) Air Traffic Management (ATM) laboratory hosts an integrated terminal area and flight simulation (Oswald and Bone, 2002). This medium fidelity simulation environment supports end-to-end evaluations from both flight deck and ATC perspectives. The main simulation functions that were used in this study included a cockpit simulator with external visual scene, a ground traffic generator, and an airport surface traffic display. All applications ran on networked Linux workstations. The simulation was customized to the Louisville International Standiford Field (SDF) terminal and airport surface movement area.

The cockpit was an enclosed, fixed base, mid-fidelity transport aircraft simulator (see Figure 2-1). It was configured as a generic twin-engine, large weight category, jet aircraft with an auto-throttle system. Though configured as transport aircraft, General Aviation pilots provided with appropriate training have effectively used that simulator in previous CAASD studies. The simulation included audio capabilities supporting aircraft environmental sounds (e.g., slipstream noise) and ATC communication. The cockpit provided two standard flight crew positions and an observer position. For aircraft control, both the left and right seat positions were equipped with side-stick controllers. The center pedestal houses the throttle quadrant, flap handle, and speed brake lever. Twenty-one inch touch-screen displays were located in front of the left and right seat positions and display the

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[3] The active safety technologies that were evaluated in this simulation are intended mainly for airports with primary commercial transport operations. Therefore, more commercial pilots than general aviation pilots were selected for participation approximate the distribution of pilot experience at these airports.

Primary Flight Display (PFD) instruments and Navigation Display (ND). A nineteen inch display occupied the center instrument panel and displays engine and flap status and landing gear status information.

**Figure 2-1. MITRE CAASD's Cockpit Simulator**

The cockpit out-the-window (OTW) view was projected via three large scale high-resolution projectors on a 130-degree field-of-view curved screen providing pilots with a virtual three-dimensional representation of the simulated airport surface and its environment. Various visibility conditions such as night, dusk, and haze were approximated as appropriate. The main OTW elements were aircraft, airport surface structures, surrounding terrain, various environmental features including weather (e.g., haze). Airport surface signage, enhanced markings, and lighting were implemented as appropriate.

The surface simulation controls/displays aircraft within a definable approach or departure airspace. Each aircraft managed by the surface simulation had a flight path that was either automatically assigned based on the aircraft identification or specified by a pseudo-pilot (Figure 2-2 depicts the pseudo-pilot interface). The same applied for the taxi paths. The ground traffic generator produced airport surface ground traffic such as aircraft and/or vehicles that the participating pilot saw through the cockpit window. The ground traffic movement was initiated and timed dependent on the participants' aircraft movements to provide the desired encounter geometries.

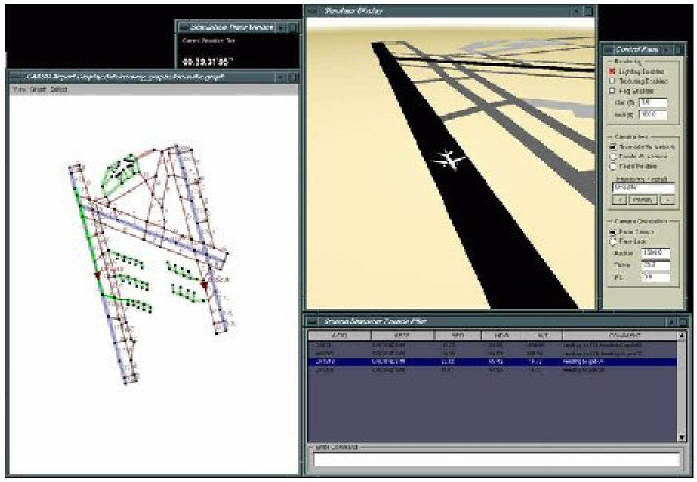


**Figure 2-2. Screen Capture of the Ground Traffic Generator**

## 2.3 Simulation Scenarios

Pilots were exposed to a total of 15 simulation scenarios. Twelve simulation scenarios contained runway conflicts; an additional set of three scenarios did not contain a conflict. Each of the conflict scenarios consisted of a specific conflict type, specific aircraft movement characteristics, as well as conditions in which a human error was likely to occur.

### 2.3.1 Conflict Types

Conflict types were down-selected from an initial list of 196 combinations that resulted from the combinations of 14 possible aircraft states (see Table 2-1) on the airport surface to 12 conflict types (see Table 2-2).

- Non-relevant conflict types were eliminated, reducing the number of conflict types to 161. For example, the combination of target states “Stopped on runway” (target state 2), were eliminated because the two aircraft would not be in conflict and therefore not be addressed by a warning system.
- Redundant conflict types with different orderings of the aircraft were eliminated, reducing the number of conflict types to 86.
- Conflict types with aircraft moving in the opposite direction were combined, resulting in 42 conflict types.
- Conflict types consisting of taxiing or stopped aircraft were combined, resulting in 33 conflict types.
- Conflict types consisting of simultaneous departures, and arrivals on a runway and a taxiway were eliminated, resulting in 15 conflict types.

- Conflict types that contained arrivals and landings at the same time were combined, resulting in 9 conflict types.
- Intersecting runway conflict types were added (departure – departure, departure – arrival, arrival – arrival), resulting in 12 conflict types.

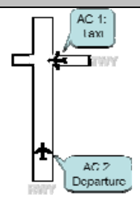
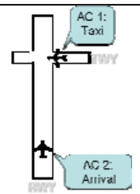
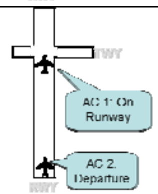
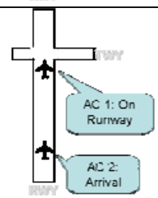
Additional information can be found in Moertl (2005).

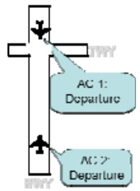
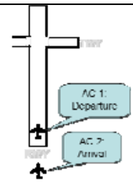
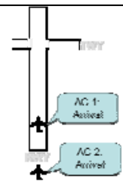
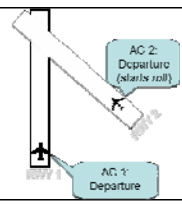
**Table 2-1. Initial List of 14 Aircraft States**

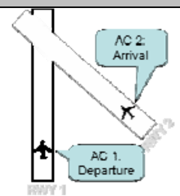
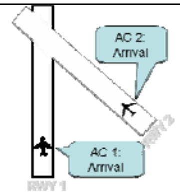
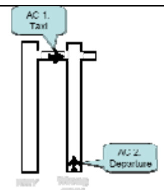
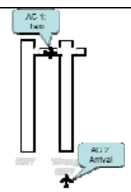
| |
|---|
| No target |
| Stopped on runway |
| Arrival to runway - correct direction |
| Landing on runway - correct direction |
| Departure on runway - correct direction |
| Taxi on runway - correct direction |
| Arrival to runway - opposite direction |
| Landing on runway - opposite direction |
| Departure on runway - opposite direction |
| Taxi on runway – opposite direction |
| Arrival to wrong runway |
| Landing on wrong runway |
| Departure on wrong runway |
| Taxi on wrong Runway |

Table 2-2 gives an overview of the 15 simulation scenarios. Column “Runways” displays a schematic depiction of the runway conflict. Column “Aircraft 1” and “Aircraft 2” describe the operations of the conflicting aircraft. The pilots’ aircraft is indicated in bold. The column “error induction” describes the process of how a pilot error was induced. The next column describes the simulations’ environmental conditions. The following four columns describe the applicability of the warning systems that were included in condition II (provision of traffic and conflict information via airport surface lighting); an X and grey shading indicates that the warning system was not provided in the scenario. The last column indicates the enhanced warning solution set for condition III (auditory warning in the cockpit).

## Table 2-2. Overview of Simulation Scenarios

| Conflict Number | Runways | Aircraft 1 (AC1) | Aircraft 2 (AC2) | Error Induction | Visibility | REL | THL | AMASS | AOL | Direct AMASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 |   | **Taxi to Rwy** | Departure | Follow traffic on active runway | Night, clear$^{*}$ | *Warning* | x | x | x | *Warning* |
| 2 |   | **Taxi to Rwy** | Arrival | Controller gives erroneous crossing clearance | Day, clear | *Warning* | x | x | x | *Warning* |
| 3 |   | Taxi / stopped on Rwy | **Departure** | Controller erroneously clears take-off | Day, very low$^{+}$ | X | *Warning* | *Warning* | x | *Warning* |
| 4 |   | Taxi / stopped on Rwy | **Arrival** | Controller does not inform pilot about occupied runway | Night, low$^{o}$ | X | x | *Warning* | *Warning* | *Warning* |

| Conflict Number | Runways | Aircraft 1 (AC1) | Aircraft 2 (AC2) | Error Induction | Visibility | REL | THL | AMASS | AOL | Direct AMASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 |  | Departure | **Departure** | Vehicle is on the runway, is in radio communication but provides incorrect runway | Day, clear | X | *Warning* | *Warning* | x | *Warning* |
| 6 |  | Departure | **Arrival** | Controller “forgets” AC 1, Taxi in Position and Hold (TIPH) | Day, low layer of clouds | X | x | *Warning* | *Warning* | *Warning* |
| 7 |  | Arrival | **Arrival** | Unexpected slow down of AC 1, and controller fails to contact participant | Night, low layer of clouds | X | x | *Warning* | *Warning* | *Warning* |
| 8 |  | Departure | **Departure** | Simulated erroneous take-off due to similar callsigns, and lack of pilot read-back | Day, clear | X | *Warning* | *Warning* | x | *Warning* |

| Conflict Number | Runways | Aircraft 1 (AC1) | Aircraft 2 (AC2) | Error Induction | Visibility | REL | THL | AMASS | AOL | Direct AMASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 9 |   | **Departure** | Arrival | Controller error and unexpected departure event | Day, clear | x | *Warning* | *Warning* | *Warning* | *Warning* |
| 10 |   | Arrival | **Arrival** | Simulated pseudo-pilot does not follow speed instructions, resulting in spacing conflict | Day, clear | x | x | *Warning* | *Warning* | *Warning* |
| 11 |  | Taxi to Rwy | **Departure on wrong Rwy** | Explicit instruction to pilot to depart on “wrong” runway; pilot finds himself on incorrect runway | Nigh, very low | x | *Warning* | *Warning* | x | *Warning* |
| 12 |  | Taxi to Rwy | **Arrival on wrong Rwy** | Aircraft is lined up for arrival on incorrect runway, measured: time for correction | Dusk, low hanging cloud | x | x | *Warning* | *Warning* | *Warning* |
| 13 | No conflict | **Taxi** | Arrival | No Conflict | Day, low | *Warning* | *Warning* | x | x | *X* |

| Conflict Number | Runways | Aircraft 1 (AC1) | Aircraft 2 (AC2) | Error Induction | Visibility | REL | THL | AMASS | AOL | Direct AMASS |
|---|---|---|---|---|---|---|---|---|---|---|
| 14 | No conflict | **Departure** | Arrival | No Conflict | Day, clear | x | x | x | x | *x* |
| 15 | No conflict | Departure | **Arrival** | No Conflict | Day, clear | x | x | x | x | *x* |

**Note: Bold font indicates the aircraft that is controlled by the simulation participant**

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* Clear refers to RVR > 1200 RVR

+ Very low refers to visibility < 300 RVR

° Low refers to visibility < 1200 RVR and > 300 RVR

The simulation scenarios are described in detail in Appendix A.

## 2.4 Experimental Design

The experiment followed a within-subject design, with three levels of safety technology such that each participant was exposed to each safety technology. An in-house ATCT controller served as a confederate and issued control instructions to the pilot.

In the first condition (I), airport safety technologies consisted of current airport marking and lighting systems that approximated an "average" NAS airport. Taxiway centerline lighting was included in this condition but no runway guard-lights or lead-on lights were implemented. Condition I served as baseline.

In the second condition (II), the following passive runway awareness technologies were added to the baseline: enhanced airport surface markings, modified taxiway centerline lead-on lights, runway guard-lights. As active warning systems runway entrance lights (RELs), and take-off hold lights (THLs) were included. These systems represented the solution set as proposed by Andrews et al. (2005). Because this solution set did not provide warnings for arrivals, arrival occupancy lights (AOLs) were added to this condition.

In the third condition (III), all of the technologies in Condition II were present and in addition pilots received auditory runway incursion warnings in the cockpit.

The scenario runs are indicated in Appendix B. Each pilot was exposed to 15 scenarios, five in each experimental condition. Twelve of the 15 scenarios contained possibilities for traffic conflicts, the remaining three did not. The three non-conflict scenarios were intended to decrease the expectation of pilots that conflicts occur in every scenario. Also, the non-conflict scenarios served as "warm-up" trials and therefore were presented as first trial in each condition. Scenario 13 provided a warm-up for condition I, scenario 14 for condition II or III. Scenario 14 also familiarized participants with the warning technologies. Scenario 15 was always shown after scenario 14 in condition II or III, dependent on the order of the conditions. The simulation runs were randomized within each experimental condition and the order of the three conditions was randomized and counterbalanced across pilots so that all of them together experienced the sequence of warning conditions about an equal number of times.

The simulation design attempts to alleviate some of the differences between simulated and real world operations. Because of differences in the light sources between physical environment and the simulator, the implementation of lightings in a simulator deviates from the physical environment. For this purpose the effect of lighting needs to be determined by a comparison to the performance in the simulated baseline condition, not to the real world operations.

## 2.5 Procedure

Members of the experiment team briefed each participant individually concerning the experimental procedure (see Appendix C). The briefing covered the following topics:

- Participant rights and informed consent
- Participants' role in the study
- Study objectives
- Study methodology
- Training on the safety technologies that include RWSL, enhanced markings, modified lead-on lights, runway guard lights
- Cockpit familiarization
- Training on flying the simulator

Following the briefing, the participant was requested to sign the informed consent document and to complete the demographics questionnaire.

### 2.5.1 Training Procedure

The purpose of training was to familiarize pilots with the simulation environment and the runway safety technologies that they would later experience in the simulation. Specifically, the training procedure was intended to be realistic in the way that it approximated how pilots learned about new airport systems in the real world. At the end of the evaluation, pilots evaluated the effectiveness of their training.

The training procedure familiarized pilots with the following warning technologies:

- Runway Entrance Lights
- Take-off Hold Lights
- Arrival-Occupancy Lights
- Auditory Conflict Warning System
- Lead-on Lights
- Enhanced Markings
- Runway Guard Lights

Participants received information about the systems in two training sessions.

First, pilots learned about the runway safety technologies by reading textual and viewing pictorial material about the technologies. The training material is contained in Appendix C.

To increase the validity of the training procedure, the training material was constructed similarly to material that had been used for technology evaluations by the FAA Airport Surface Technology program office. Pilots were instructed to thoroughly read and understand the material that informed them how to use to the technology. Pilots were also encouraged to ask any questions to help them understand the technologies.

Second, pilots saw a brief movie showing the technologies from the simulator view in the cockpit. This was intended to approximate field experience.

Finally, pilots were reminded about each of the technologies prior to conditions II and III while they were sitting in the simulator cockpit. For this purpose pilots received a simulated Notice to Airmen (NOTAM) message providing information about the safety systems for the following simulation trials.

Pilots were afforded a familiarization with the flight simulator that included normal ATC communications for up to 30 minutes. The pilot was asked to taxi on the airport surface, take off and fly an approach to the simulated airport. More familiarization was provided if needed and as determined by the experimenter.

#### 2.5.2 Scenario Runs

Once the pilot was deemed comfortable operating the cockpit simulator, the testing began. Prior to each block of five scenarios, pilots were informed which warning level would be presented next. Each scenario lasted approximately five minutes. Dependent on the scenario, the pilot initiated a radio call to the simulation air traffic controller to request a taxi, landing, or departure clearance. The controller provided the pilot with a clearance. At this point the radio communication between controller and other airport traffic started and airport surface traffic was simulated. There was a short break between each scenario to prepare the simulator for the next run. During this break the pilot, observer, and controller each completed the post-run survey.

#### 2.5.3 Debriefing

At the end of the simulation, a post-simulation questionnaire and a brief interview was administered and the pilot was informed about the purpose of the simulation

#### 2.5.4 Simulation Controller and Simulation Pilot Training

The controller and one “pseudo- pilot” were trained to provide consistent and timely communications. Pseudo-pilots used a communication script for each of the scenarios to provide the same communications for each of the pilot participants. The communication scripts were correlated with the airport surface traffic so that what the pilots saw on the airport surface matched what they heard via radio.

## 2.6 Data Collection

Pilots completed a demographics questionnaire during the initial briefing session. The demographics questionnaire solicited information related to pilot experience (Appendix D). During each scenario, a video camera recorded the pilots gaze orientation. Aircraft ground movement were recorded directly from an AMASS display of traffic information. In addition, aircraft positions and speeds were recorded digitally. Pilots indicated their workload by pressing an illuminated button on a workload assessment keypad (WAK) on the cockpit center screen in the cockpit. The buttons illuminated at 45 second intervals and stayed illuminated for 15 seconds. See Stein (1985) for specifications of the WAK. Pilots also rated their situation awareness using SART (Situation Awareness Rating Technique, Taylor, 1990).

At the end of each scenario run, the pilots completed a post-run questionnaire. The post-run questionnaire consisted of questions concerning the simulation quality and the experienced safety systems. In addition, the experimenter and controller recorded their observations and estimated pilot workload (NASA Task Load Index see Hard and Staveland 1988) and estimated situation awareness. At the end of the simulation, the pilots completed a post-simulation questionnaire and were debriefed by the experimenter.

The collected data are summarized in Table 2-3.

**Table 2-3. Data Measurements**

| Data | Type |
|---|---|
| Number of taxiing errors | Frequency count |
| Number of runway incursions | Frequency count |
| Pilot workload | NASA-TLX survey<br>Workload Assessment Keypad |
| Pilot situation awareness | SART survey |
| Taxi speed | Simulation recording |
| Radio communication | Audio recording |
| Pilot gaze direction | Video recording |
| In cockpit communication | Audio recording |
| Pilot interactions with flight controls | Video recording |
| Aircraft position and timing information | Simulation recording |

**Section 3**

# Results

The first subsection reports the safety effectiveness of the active pilot warning systems. The second subsection reports the passive runway awareness technologies. Subsections three and four report workload and situation awareness. Subsection five reports the pilots' safety related perceptions about the integrated safety system as well as each safety technology. Subsection six reports the comments that pilots provided for each safety technology and subsection seven summarizes the pilot's perception of simulation realism and training effectiveness.

## 3.1 Safety Effectiveness of the Active Pilot Warning System

The safety effectiveness of the safety system was measured by comparing the number of unsafe system states that occurred in each experimental condition. Unsafe states were defined as completed take-off maneuvers, landings, or runway crossings that in real life, would have resulted in runway incursions or collisions. These unsafe states are referred to as simulation incursions. The safety effectiveness of the active warning systems was determined by the reduction in incursions compared to the baseline.

A total of 71 simulation incursions occurred in the three simulation conditions. Fifty-eight of these incursions occurred in condition I, 11 occurred in condition II, and 2 occurred in condition III. This indicates a statistically significant decrease in simulation incursions between conditions I and II as measured by the McNemar test ($z=3.96$, $p < 0.01$). The additional decrease in the number of simulation incursions between conditions II and III was not statistically significant.

All but one pilot committed at least one simulation incursion, one pilot committed five incursions. Commercial pilots were as likely to commit a simulation incursion as General Aviation (GA) pilots: the 29 commercial pilots committed on average 1.9 simulation incursions whereas the seven GA committed on average 2.0 incursions.

Figure 3-1 indicates the frequencies of simulation incursions for arrivals, departures, and crossing operations. All differences between conditions I and II, as well as I and III are statistically significant. In the five arrival and departure scenarios, pilots committed significantly fewer incursions in condition II than in condition I ($z = 2.21$, $p < 0.05$; $z=4.62$, $p < 0.01$ respectively). In the two runway crossing scenarios, pilots committed statistically significantly fewer incursions under condition II than in condition I ($z=7$, $p < 0.01$). None of the differences between conditions II and III are statistically significant.

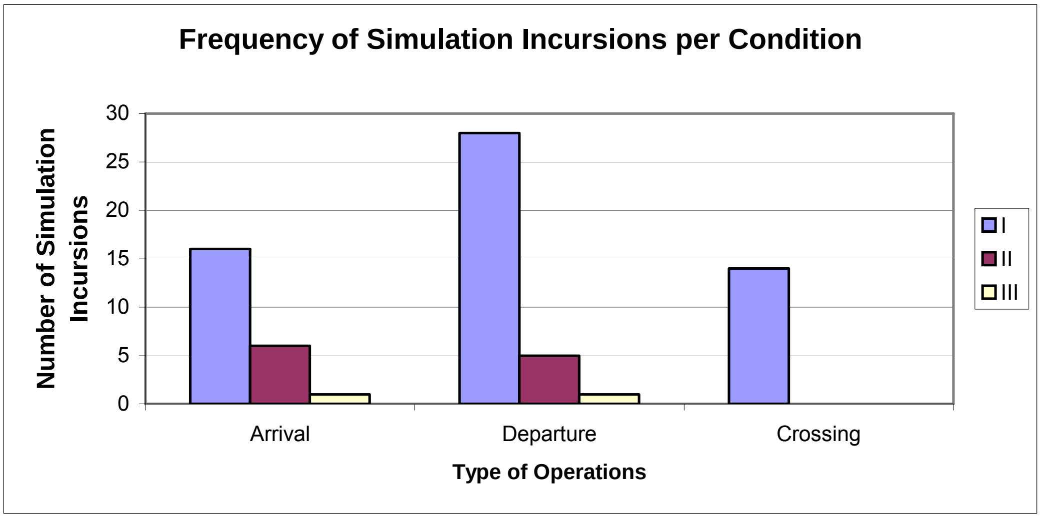


**Figure 3-1. Simulation Incursions per Condition and Type of Operation**

Based on the simulation results, the most effective safety technologies were REL's, reducing the number of simulation incursions from 14 to 0 (100% improvement). THL's reduced the number of simulation incursions from 28 to 5 (82 % improvement). AOL's reduced the number of simulation incursions from 16 to 6 (63 % improvement). Auditory warnings reduced the number of incursions from 6 to 1 for arrival operations and from 5 to 1 for departure operations. This indicates a combined improvement of about 80 % for arrivals and departures.

Table 3-1 indicates the frequencies of simulation incursions per condition for 12 of the 15 scenarios that contained possibilities for traffic conflict. In two of these 12 scenarios, no conflicts were actually encountered because pilots detected the conflicts early enough and were able to avoid them.

**Table 3-1. Frequency of Simulation Incursions per Simulation Condition**

| Operation | Scenario Number | Incursions in Condition I | Incursions in Condition II | Incursions in Condition III | Evaluated Active Technology |
|---|---|---|---|---|---|
| **Arrival** | 4* | **0** | **0** | **0** | AOL |
| **Arrival** | 6* | **0** | **0** | **0** | AOL |
| **Arrival** | 7 | **5** | **0** | **0** | AOL |
| **Arrival** | 10 | **8** | **5** | **1** | AOL |
| **Arrival** | 12 | **3** | **1** | **0** | AOL |
| **Departure** | 3 | **7** | **2** | **0** | THL |
| **Departure** | 5 | **9** | **0** | **0** | THL |
| **Departure** | 8 | **3** | **1** | **0** | THL |
| **Departure** | 9 | **1** | **0** | **0** | THL |

| | | | | | |
|---|---|---|---|---|---|
| **Departure** | 11 | **8** | **2****  | **1** | THL |
| **Twy Crossing** | 1 | **5** | **0** | **0** | REL |
| **Twy Crossing** | 2 | **9** | **0** | **0** | REL |
| | **Total** | **58** | **11** | **2** | |

**Note: * No simulation incursions were observed.**
**** One additional simulation incursion was prevented by the passive runway awareness system**

## 3.2 Safety Effectiveness of Passive Awareness Technologies

The safety effectiveness of the passive runway awareness system was assessed in scenario 11. The purpose of the passive runway awareness system is to enhance pilots' awareness about the runway environment. Though increased pilots' runway awareness is an indirect safety benefit and does not per se prevent incursions, under certain conditions runway awareness systems could help prevent incursions. For example, pilots with incorrect expectations about their current location could proceed onto an incorrect runway. Passive awareness systems such as enhanced runway hold-short markings and lighting could help correct pilots' incorrect expectations and thereby prevent incursions. This hypothesis was tested in scenario 11.

In scenario 11, pilots expected to be located on the North-end of taxiway B, heading North (heading 350) and expected a departure clearance for runway 17R, see Figure 3-2. However, in contrast to their expectation, they were located on taxiway Delta, facing South (heading 170). Pilots could determine that they were actually at an unexpected location by using heading information from their primary flight display, taxiway signage, runway signage, enhanced hold-short markings, and runway markings. Safety risk was defined by pilots initiating a take-off maneuver on the incorrect runway.

From 36 pilots, 22 pilots initiated a take-off maneuver on the incorrect runway, see Figure 3-3. From the remaining 14 pilots who corrected their incorrect expectation, five pilots used the heading information on their primary flight display. Three pilots used runway and taxiway signage, one pilot used the white runway labels on the runway and one pilot used the enhanced surface markings. For four pilots it was not possible to determine what information they used, see Figure 3-4. Seven of these errors occurred in condition I, and 7 occurred in conditions II and III[4]. Note, that the active warning systems (conditions II and III) prevented the development of a simulation incursion in 4 out of the 7 cases.

[4] Conditions II and III are combined for this purpose because no active technologies were presented to pilots before the initiation of the take-off maneuver.

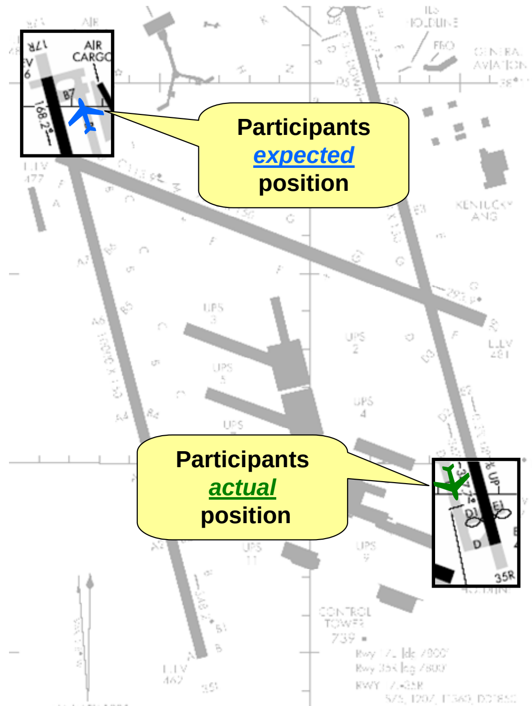


**Figure 3-2. Expected and Actual Location of Pilot in Scenario 11**

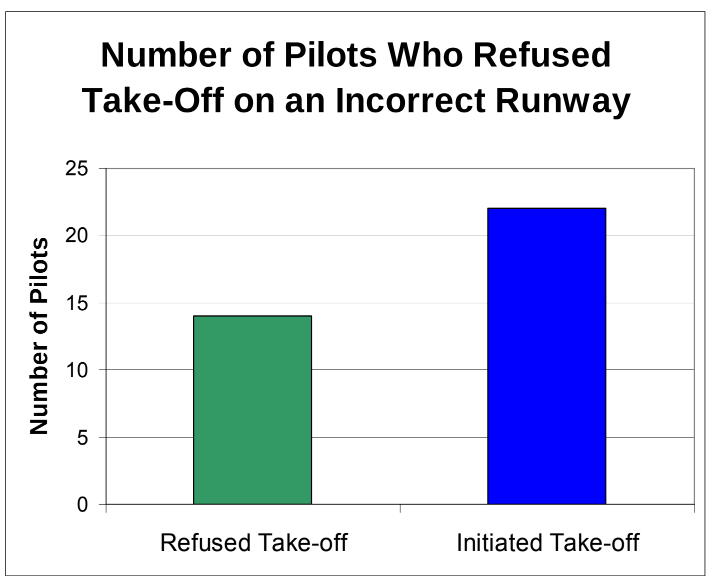


**Figure 3-3. Number of Pilots Correcting an Incorrect Runway Expectation in Scenario 11**

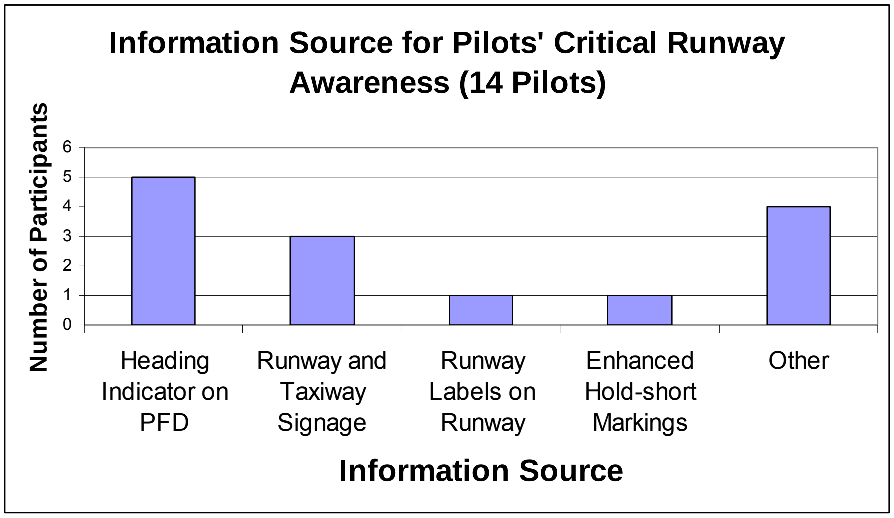


**Figure 3-4. Information Source From Which 14 Pilots Obtained Critical Information to Prevent an Incursion**

## 3.3 Pilot Performance and Workload (NASA-TLX)

Overall, pilots reported their own performance to be higher when exposed to the integrated safety systems (conditions II and III) and compared to the baseline condition. Pilots did not report increased workload when exposed to the integrated safety system in conditions II and III, see Figure 3-5. Highest performance was reported for the auditory warning system (condition III). Pilots indicated their workload and performance using the NASA-TLX rating scale after each scenario run. Performance, one subscale of the NASA TLX, was significantly higher for the integrated safety system in condition II and III than in condition I[5]. On two of the workload subscales, mental workload and frustration, workload was significantly reduced when pilots used the integrated safety system (conditions II or III)[6].

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[5] Statistically significant effect using a repeated measures Analysis of Variance (ANOVA), df = 2,68, $p < 0.01$ and statistically significant differences between conditions I and II using a dependent t-test (df = 35, $p < 0.05$).

[6] Statistically significant effect using a repeated measures ANOVA, df=2,68, $p < 0.05$ and statistically significant differences between conditions I and II using a dependent t-test (df = 35, $p < 0.05$).

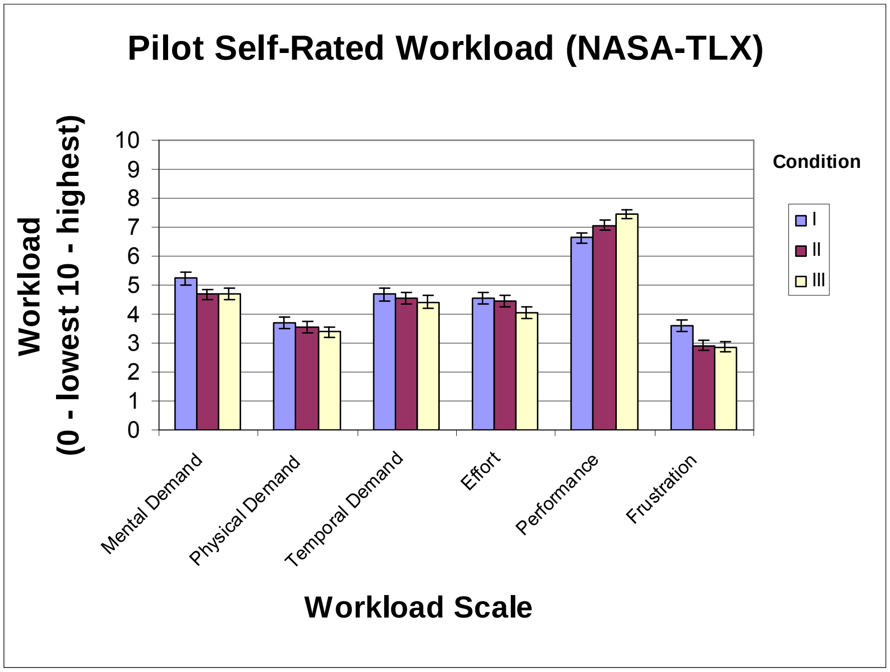


**Figure 3-5. Overall NASA-TLX Ratings**

A similar pattern of increased performance without apparent difference in reported workload for the integrated safety system was visible for each type of these performed operations: taxiing, departure or arrival scenarios, see Figure 3-6 and Figure 3-7.

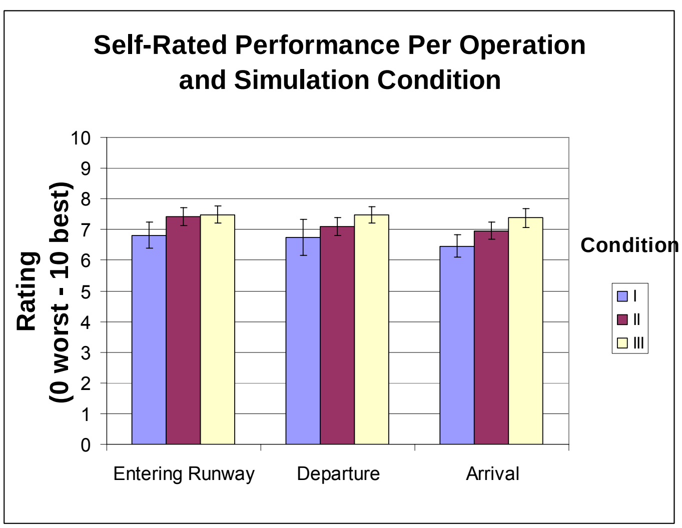


**Figure 3-6. Pilot Rated Performance per Scenario Operations and Condition**

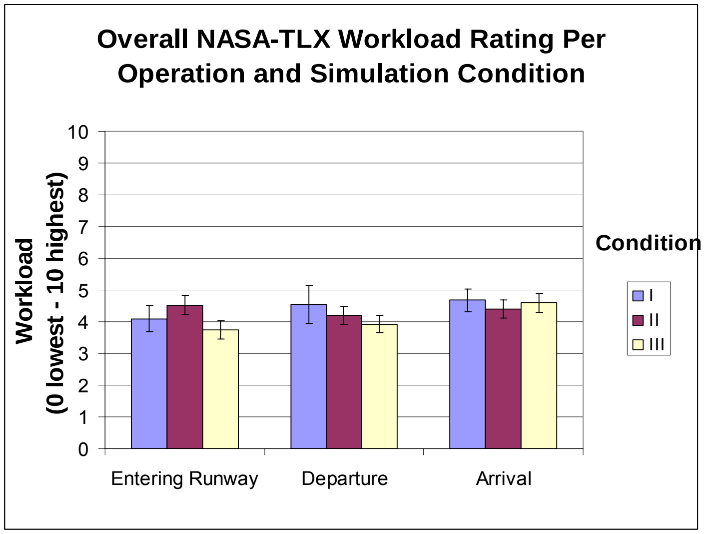


**Figure 3-7. Pilot Rated Overall Workload per Scenario Operation and Condition**

## 3.4 Pilot Situation Awareness

Overall, pilots reported increased situation awareness in conditions II and III, when compared to the baseline condition. After each scenario run, pilots indicated their situation awareness during the scenario using the Situation Awareness Rating Technique (SART, Taylor, 1990; see appendix D). Overall, pilots felt that the auditory warnings in conditions III provided a significant improvement in their understanding of the situation in comparison to the baseline condition[7]. They also indicated that the quality of the available information in each scenario was improved in conditions II and III[8]. Overall situation awareness was perceived to be increased between condition II and III when compared to condition I[9], see Figure 3-8.

[7] Statistically significant effect using a repeated measures ANOVA, df=2,68, $p < 0.05$ and statistically significant differences between conditions I and III using a dependent t-test (df = 35, $p < 0.05$).

[8] Statistically significant effect using a repeated measures ANOVA, df=2,68, $p < 0.05$ and statistically significant differences between conditions I and II as well as between conditions II and III using a dependent t-test (df = 35, $p < 0.01$).

[9] Statistically significant effect using a repeated measures ANOVA, df=2,68, $p < 0.05$ and statistically significant differences between conditions II and III and I using a dependent t-test (df = 35, $p < 0.01$).

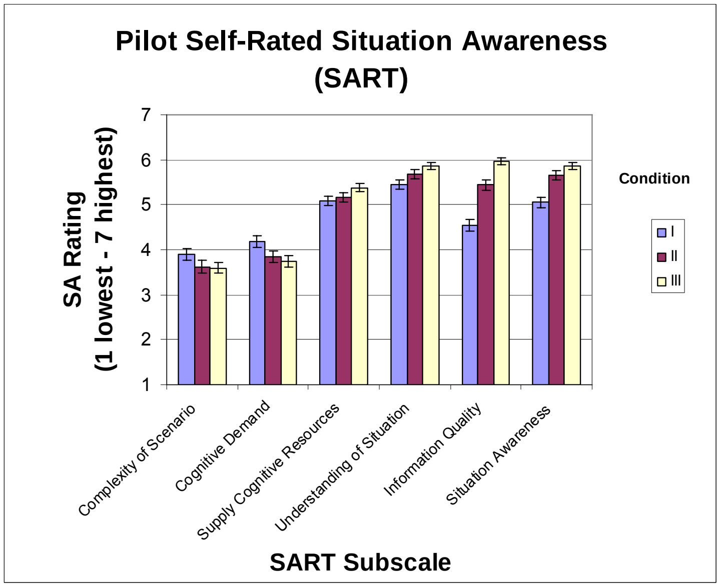


**Figure 3-8. Overall Situation Awareness Ratings**

During taxi and arrival scenarios, pilots reported situation awareness to be higher for the integrated safety system in conditions II and III than in the baseline condition, see Figure 3-9. However pilots found that for departure scenarios, the integrated warning system in condition II was related to reduced situation awareness.

This indicates that though THL's increased safety and resulted in fewer simulation incursions, pilots did not perceive increased situation awareness compared to the baseline condition.

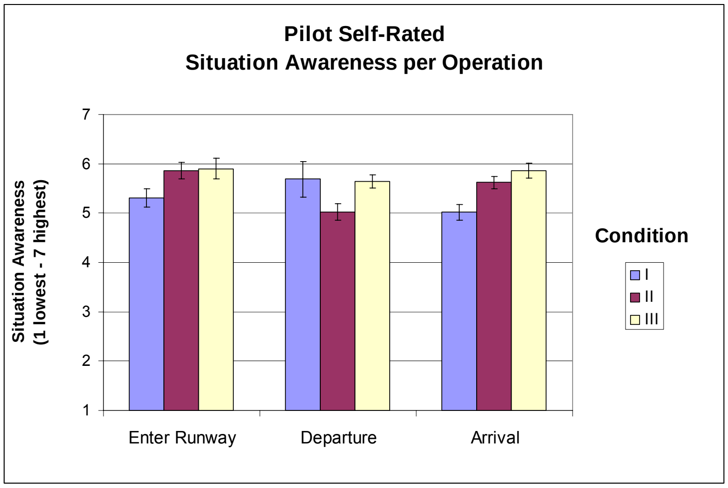


**Figure 3-9. Situation Awareness Ratings per Type of Operation**

## 3.5 Perceived Runway Safety

Pilots generally perceived runway safety to be higher when exposed to the integrated safety system (conditions II and III) than in the baseline condition. Pilots reported their safety perceptions on a survey after each scenario by agreeing or disagreeing to seven statements on a scale from 1 (strongly disagree) to 5 (strongly agree). Figure 3-10 shows that pilots felt runway safety was generally higher in conditions II and III than in the baseline condition. Specifically, pilots thought they were more aware of aircraft[10], had more information available[11], felt that runway safety was sufficient[12], and that conflicts were less likely[13] and more avoidable[14] than for level I. Pilots did not feel that their awareness about the runway was improved between level II and level I.

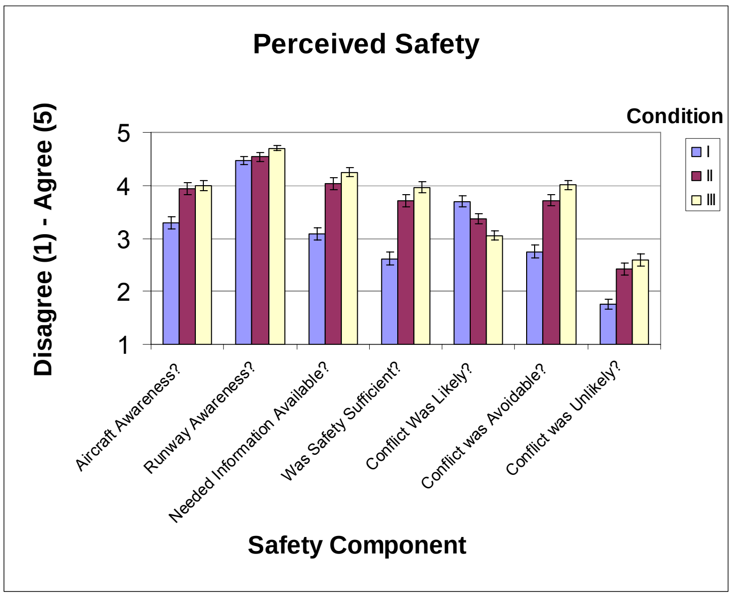


**Figure 3-10. Perceived Runway Safety**

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[10] Statistically significant difference between the averaged responses per participant between level I and II using a repeated t-test, df = 35, $p < 0.01$.

[11] Ibid.

[12] Ibid.

[13] Ibid.

[14] Ibid.

Figure 3-11 shows how pilots evaluated the contribution of each of the safety technologies to runway safety. Pilots evaluated the contribution after the completion of all scenarios, see Figure 3-11. Overall, more than 80 % of pilots thought the evaluated technologies increased runway and traffic awareness.

When asked about passive awareness technologies, 94 % of pilots felt that the enhanced markings increased runway awareness (pilots either somewhat or strongly agreed), followed by runway guardlights (91%), and lead-on lights (84 %).

When asked about active warning technologies, 93 % of pilots thought that RELs increased traffic awareness, followed by THLs (91 %) and AOLs (83 %). Overall, a majority of pilots indicated that the active warning technologies increased runway safety, see Figure 3-12. About 94 % of pilots felt that THLs increased runway safety, 89 % felt that RELs increased runway safety, 92 % felt that direct auditory warnings increased runway safety, and 85 % felt that AOLs increased runway safety.

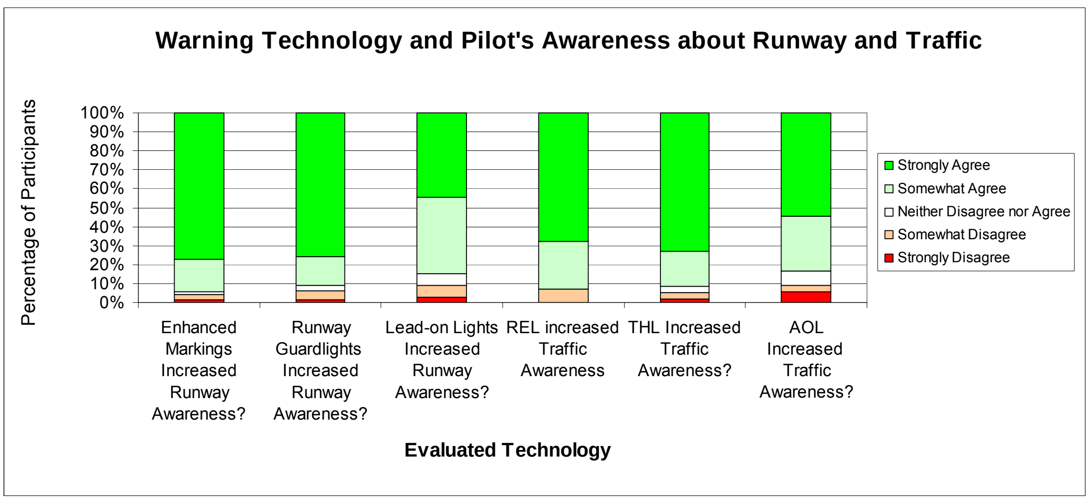


**Figure 3-11. Percentage of Pilot-Perceived Contributions of Warning Technology to Increased Runway and Traffic Awareness**

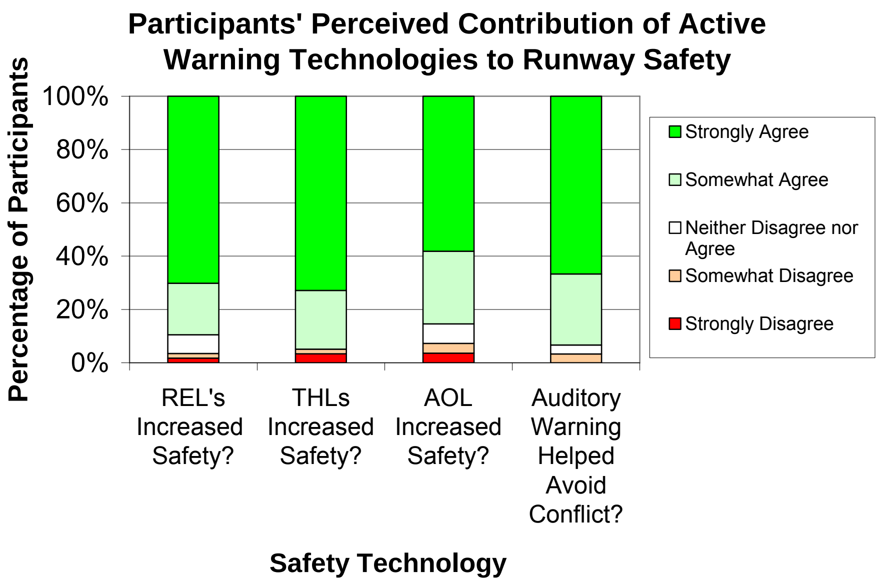


**Figure 3-12. Participants' Perceived Contributions of Warning Technology to Runway Safety**

Pilots also ranked the perceived safety contributions for each technology, see Table 3-2. These results also indicated that THL's were ranked the highest, followed by REL's, runway guardlights, and AOL's. Auditory alerts, enhanced markings, and lead-on lights were ranked having the lowest safety cotnribution.

**Table 3-2. Average Ranking of Safety Contribution of Technology**

| Rank / Technology | Average Rank* |
|---|---|
| 1. Take-off hold lights | 2.5 |
| 2. Runway entrance light | 2.9 |
| 3. Runway guard lights | 3.5 |
| 4. Arrival occupancy lights | 4.0 |
| 5. Auditory alerts | 4.5 |
| 6. Enhanced markings | 5.1 |
| 7. Lead-on lights | 5.8 |

**Note: *Low numbers indicate that the technology was ranked as providing a higher safety contribution.**

There were three different lighting systems installed at the runway hold-short line and pilots were asked if they had experienced problems with the integrated lights. Eighty-three percent of pilots found the combination of lead-on lights and RGLs appropriate, eighty percent found the combination of modified lead-on lights and RELs appropriate, see Figure 3-13. In addition pilots provided comments that are summarized in the following subsection.

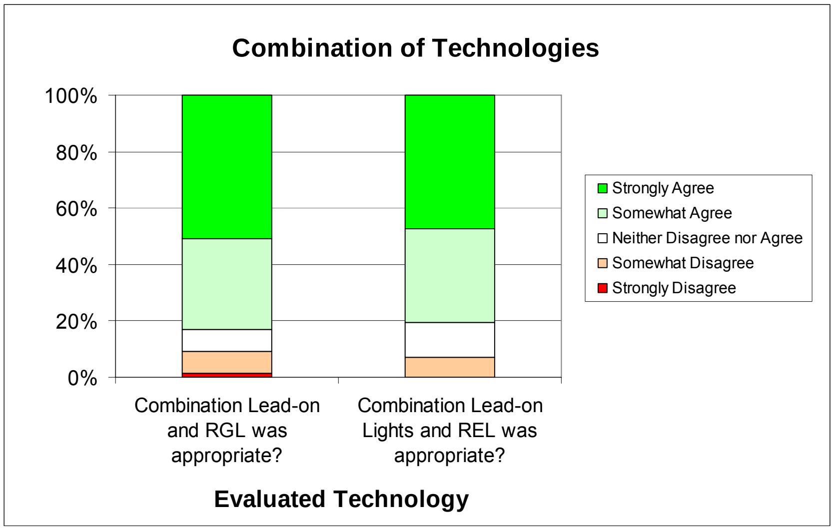


**Figure 3-13. Appropriateness of Combination of Technologies**

## 3.6 Comments About Safety Technologies

Pilots had opportunities to provide comments after each experimental scenario and at the end of the simulation. Most pilot comments addressed the safety technologies as seen on Figure 3-14. The comments provided insight about perceived limitations of the technologies and are useful to explore the potential problems linked to these technologies.

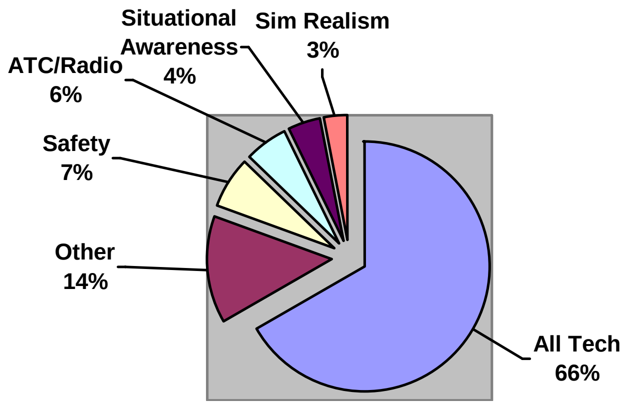


**Figure 3-14. Distribution of Comment Topics**

### 3.6.1 Runway Entrance Lights

Pilots generally referred to runway entrance lights as mature technologies with generally positive comments that they increased runway safety and increased pilot situation awareness (80 % of provided comments). Two pilots mentioned the combination of runway lead-on lights and runway entrance lights undesirable because of causing too many lights on the taxiway centerline. (See Figure 3-15.)

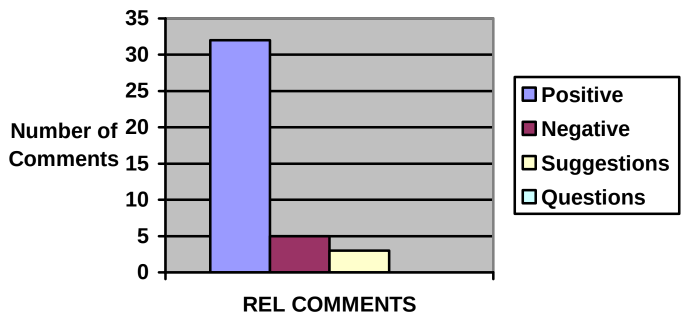


**Figure 3-15. Categorized Comments for Runway Entrance Lights**

### 3.6.2 Take-Off Hold Lights

Pilots generally positively commented on the concept for take-off hold lights (60 %) but pointed out implementation issues. Two pilots had concerns about the timing of the conflict predictions because neither aircraft weight or engine characteristics are considered in the THL conflict prediction logic. Five pilots mentioned concerns about the arrangement of the lighting that could either lead to confusion with runway end lights or have too short a string of lights that should preferably start closer to the threshold. One pilot found THL's useful for intersecting runway operations. Another pilot suggested the white runway centerline lights should extinguish when the red lights illuminated to improve the warning. Another pilot commented that he found it hard to interpret what to do when the lights extinguished after an aborted take-off maneuver. Another pilot mentioned a concern about false alarms, and suggested the lights should flash to attract pilot's attention. Finally, one pilot suggested a combined transverse and parallel arrangement of THLs along the runway centerline. (See Figure 3-16.)

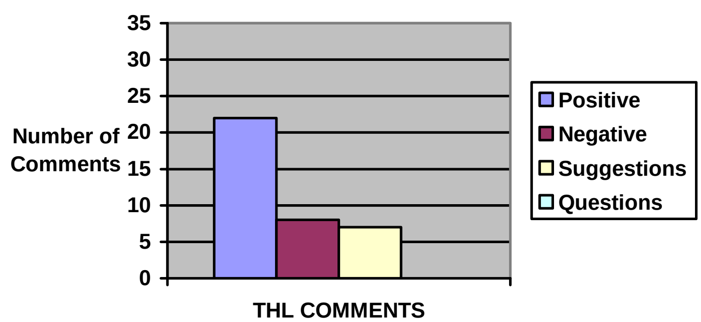


**Figure 3-16. Categorized Comments for Take-off Hold Lights**

### 3.6.3 Arrival Occupancy Lights

Pilots generally positively commented on the concept for Arrival Occupancy lights (43%) but pointed to implementation limitations. AOLs seemed not to attract enough of pilot's attention. Eight pilots believed that the AOL flash rate was too low to attract the attention of pilots. Nine pilots felt that they would not notice the lights, either because they looked somewhere else while the AOLs illuminated or because the warning came too late. These pilots suggested that AOLs required training for pilots to include PAPIs in their runway scan. One pilot suggested including additional lights on the beginning of the runway to display a warning together with AOLs. One pilot also commented that the use of PAPIs varied dependent on pilot experience, aircraft equipage, and airport, therefore limiting the usefulness of AOLs as warning against runway incursions. (See Figure 3-17.)

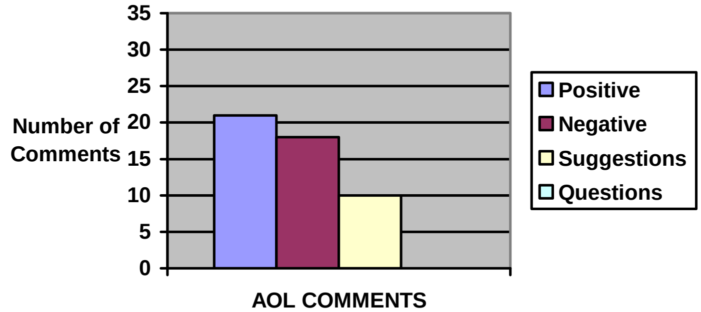


**Figure 3-17. Categorized Comments for Arrival Occupancy Lights**

### 3.6.4 Direct Auditory Warning in Cockpit

Pilots generally positively commented on the concept of auditory warnings in the cockpit (59%) but identified some severe implementation issues. The main concern was that the warnings came on too late (10 pilots) and four pilots mentioned that the warning should have been louder. One pilot mentioned that the warning would be more efficient and faster when the identifier would be left off the warning, whereas one pilot appreciated the inclusion of the flight identifier in the warning message. (See Figure 3-18.)

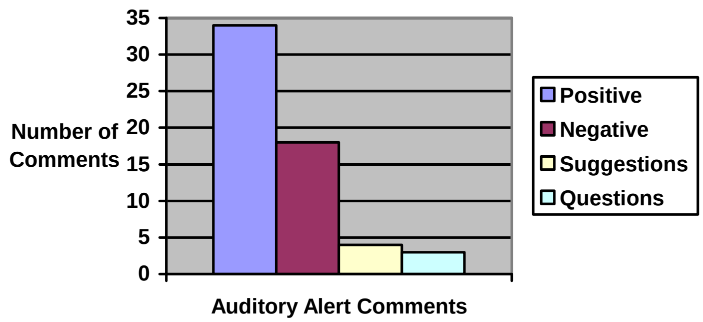


**Figure 3-18. Categorized Comments for Auditory Alerts**

### 3.6.5 Runway Guard Lights

Pilots generally commented positively on in-pavement runway guard lights lights (84%) and did not have major implementational issues. Runway Guard Lights were regarded as highly visible and one pilot found the in-pavement RGLs an improvement over above-ground runway guard lights. Three pilots regarded the RGL lights as being distractive from the air, one of them citing experience from Cleveland International Airport. One pilot questioned if in-pavement RGLs would be visible under snow. (See Figure 3-19.)

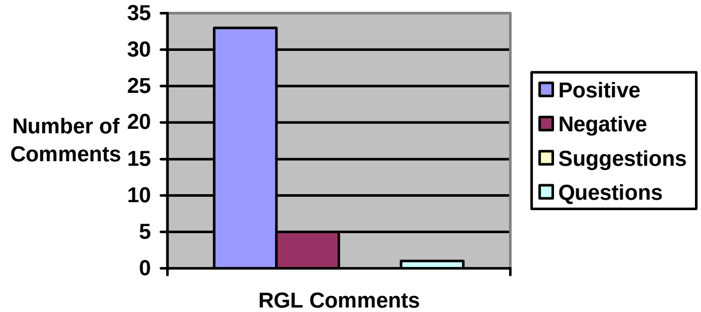


**Figure 3-19. Categorized Comments for Runway Guard Lights**

### 3.6.6 Enhanced Markings

Pilots generally positively commented positively on the marking enhancements in the hold-short environment (64%). Two pilots stated that they experienced no change in their runway awareness and one pilot mentioned that the enhanced markings did not provide a benefit under high workload because they would not attract pilots' attention. Two pilots mentioned that under low visibility or snow the safety contribution of markings would be reduced. (See Figure 3-20.)

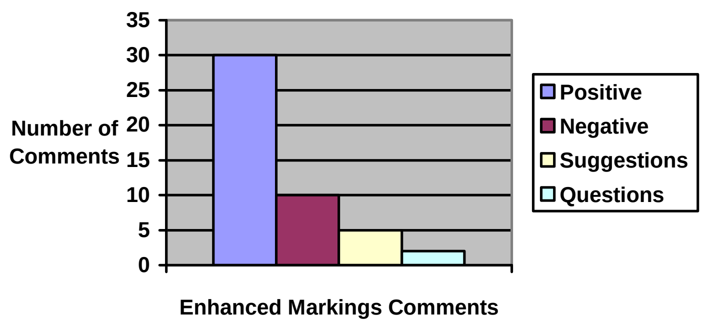


**Figure 3-20. Categorized Comments for Enhanced Markings**

### 3.6.7 Modified Lead-On Lights

The modification of lead-on lights received relatively fewer positive comments than any of the other evaluated technologies (41%). Other technologies that were presented in combination with modified lead-on lights, such as runway guard lights, were seen as more effective safety technology. Twenty out of 30 pilots disagreed with the implementation and preferred other methods of warning, "They increase alertness but I believe they are not as beneficial as runway guard lights." Pilots found the lead-on lights to be simple and easy to follow but not as effective in increasing runway awareness than other safety technologies. (See Figure 3-21.)

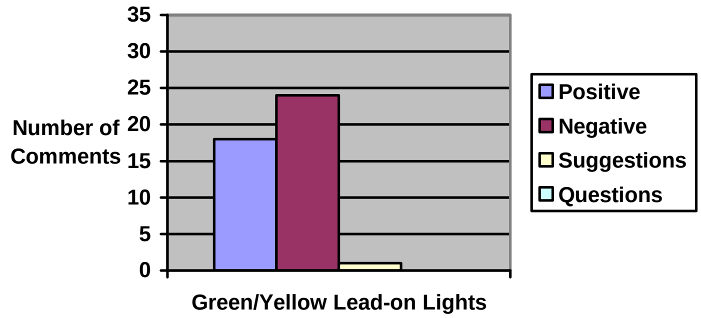


**Figure 3-21. Categorized Comments for Green/Yellow Lead-On Lights**

## 3.7 Simulation Realism and Training

Pilots generally felt the simulator experience was realistic, see Figure 3-22. Most pilots generally agreed about the realism of the flight simulator (88%), simulation scenarios (100%), lighting (91%), traffic (93%), and radio communication (96%). Mentioned simulation deficiencies included one pilot who felt that controlling the simulator through the side-stick interfered with his ability to operate the aircraft. There was some criticism concerning the simulation lighting such as too prominent lights (2 pilots), not low enough levels of darkness (1 pilot), blurry taxiway signs (1 pilot), too low display resolution (1 pilot). One pilot mentioned that combining the radio frequencies felt unrealistic.

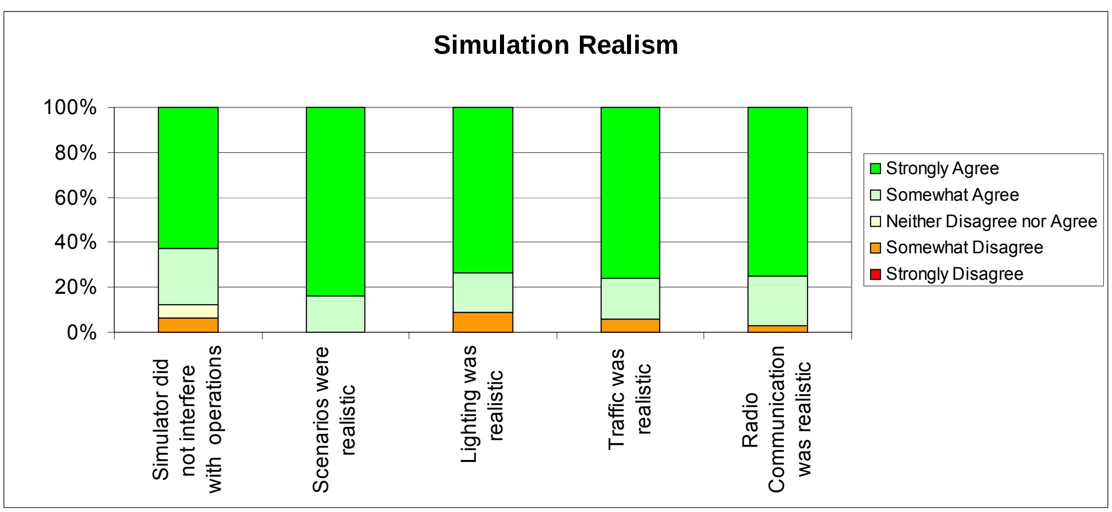


**Figure 3-22. Pilot Assessment of Simulation Realism**

When evaluating the training they experienced in preparation of using the safety technologies in the simulator, pilots generally indicated that they had received sufficient information about the warning technologies, see Figure 3-23. Two pilots (somewhat) disagreed with aspects of the training. One pilot mentioned that different technology names might help to disambiguate systems from each other (runway stop lights instead of runway entrance lights) and another pilot mentioned that having a "cheat-sheet" in the cockpit would have helped to disambiguate the various safety systems.

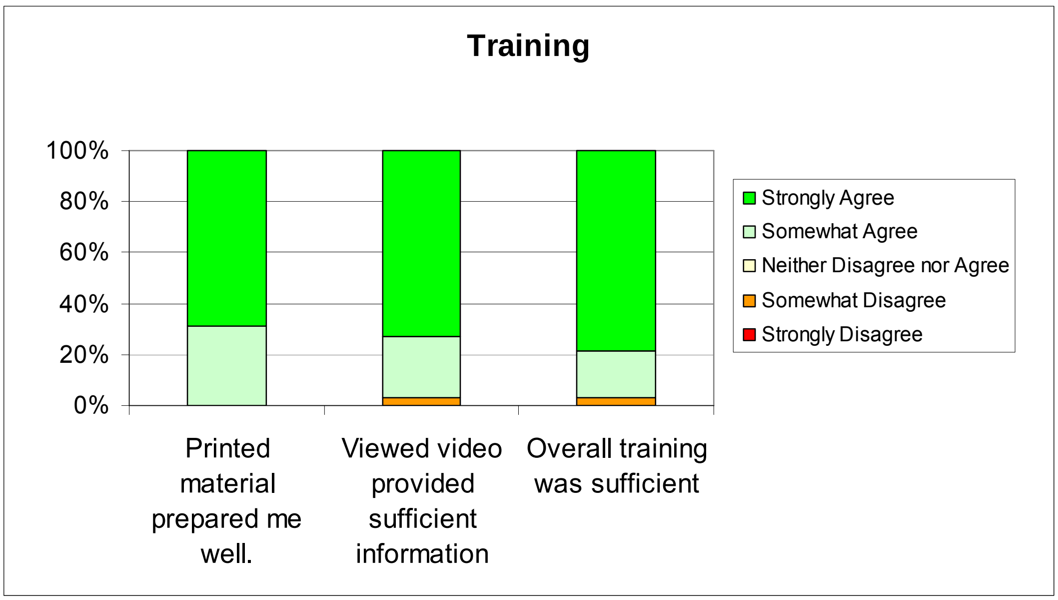


**Figure 3-23. Pilot Evaluations of Training Effectiveness**

## 3.8 Discussion and Recommendations

The simulation evaluation of the integrated ground movement safety system, as proposed by Andrews et al. (2005), demonstrated a reduced likelihood of simulation incursions. Specifically:

- Runway entrance lights eliminated all unsafe runway crossings.
- Take-off hold lights reduced unsafe take-off maneuvers by 86%.
- Passive runway awareness technologies increased runway awareness of pilots; guard lights and enhanced markings in the hold-short environment were seen as the most mature and effective passive warning technology.
- Overall, according to the pilots' comments, the integrated ground movement safety system resulted in increased situation awareness of pilots, increased self-rated performance, without increasing pilot workload.

The solution set, as proposed by Andrews et al. (2005), did not provide protection against unsafe landings. For this purpose, Arrival Occupancy Lights were evaluated that resulted in a 63% reduction of unsafe landings.

In addition, a prototypical auditory warning system that communicated AMASS alerts directly in the cockpit reduced simulation incursions by an additional 80 %.

Note that extensive pilot training might have increased the effectiveness of the evaluated technologies in comparison to real world operations. In this simulation, pilots were extensively trained and prepared for using these technologies. In real world operations, pilots might not have received such thorough preparation or might have received it long time before encountering a situation requiring its use. This might reduce training effectiveness in the field compared to the simulation setting. This is in particular true for RELs, THLs, and AOLs that all required appropriate pilots' attention allocation on a sometimes visually complex airfield as well as signal interpretation prior to initiation of an action. For this reason, the simulator results should be taken as an upper boundary for the effectiveness of the safety technologies in the field.

Based on the results of this simulation, the following improvements and research are recommended:

- Because some pilots missed the activation of the THL lights, different lighting arrangements (e.g. transverse in addition to, or instead of longitudinal lights) should be considered. Also, guidance about desired pilot behavior after the lights deactivate is required.

- The implementation of arrival occupancy lights should be improved because the chosen implementation (PAPIs that are flashing triggered by AMASS alerts) did not gain sufficient attention by pilots. Alternative concepts could include other runway lightings such as THLs or runway approach lights. Also, the predictive logic of the alerting system should be improved to provide earlier alerts.

- The auditory warning system should be improved to provide earlier warnings in the cockpit. The volume of the warning message should be increased and the length of the message should be shortened if possible. The effectiveness of the direct auditory warnings to prevent runway incursion should be determined in isolation from other safety systems.

- Additional research should evaluate the effectiveness of the warning technologies with performance characteristics that include false and missed alerts. For the purpose of this simulation the warning technologies had been assumed to be perfect.

- The methodology of evaluating the effectiveness of runway safety systems by simulating safety hazards could be applied to measure runway safety in the NAS. This could be achieved by building a general model of runway safety hazards.

Whereas in this study, the runway safety hazard of failures in auditory communication between operators (pilots, controllers, and ground vehicle operators) via radio was used as basis for opportunities of pilot errors. However, in real world operations, various other runway safety hazards contribute to operator errors which need to be captured to allow an externally valid evaluation of NAS safety benefits. Therefore, a general model of runway safety hazards would be useful to statistically estimate the occurrence of pilot errors in the NAS. Such a model could then be used to derive simulation scenarios that are representative for runway safety incidents in the NAS and be used as “standardized NAS runway safety test scenarios”. Subsequent simulations can use such scenarios to allow generalization of the evaluated safety system effectiveness across the NAS.

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**Appendix A**

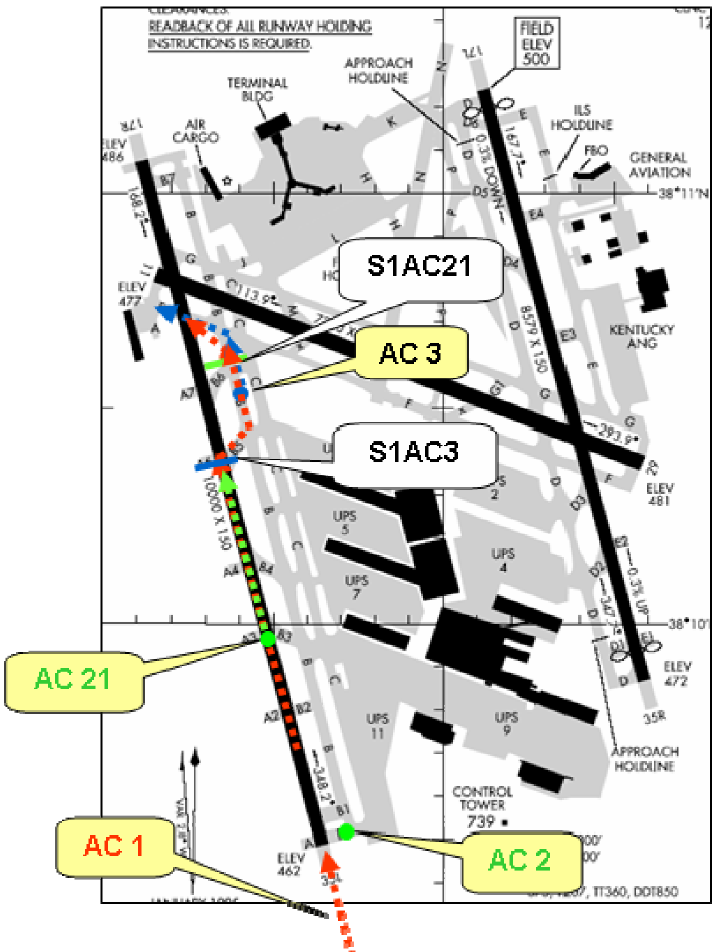
# Simulation Scenarios

This section contains descriptions of the simulation traffic, layout, and communication scripts. The participant's aircraft and its surface movement are indicated on the following airport diagrams. Also additional surface traffic is indicated. The movement of these additional aircraft is either initiated automatically upon start of the scenario or initiated by the participant crossing predefined lines which are referred to as triggers on the airport diagrams. The names of the aircraft (AC 1 to AC 3) are derived from Table 2-2 and defined therein. Next, the communication scripts and alerting behavior of the direct warning systems are listed for each scenario. The communication scripts also include communication of additional aircraft that are not modeled in the surface simulation but are used to increase communication realism for the participants.

**Scenario 1 - Layout**

**Taxi to Rwy (participant) – Departure; Single Runway** **ILS 35L: 109.35**

**Visibility:** night, clear

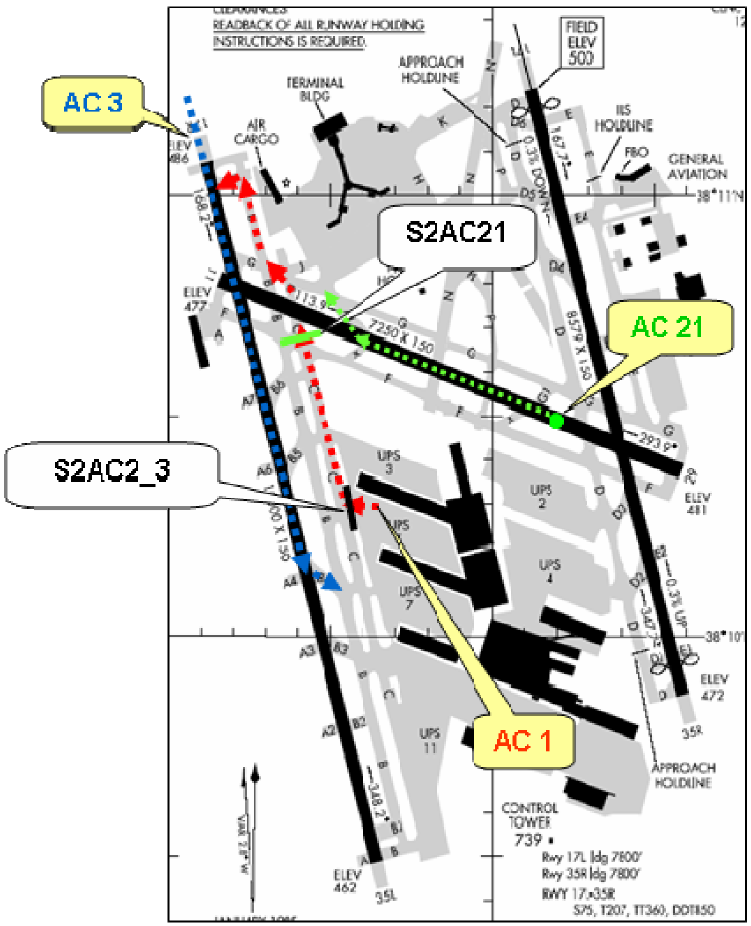



| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Lands on 35L and erroneously turns left on F onto 35L | Participant | – |
| AC 2 | Hold short of 35L | Simulated | Start of scenario, no movement |
| AC 21 | Take-off on 35L | Simulated | S1AC21 |
| AC 3 | Start taxi B, between B5 and F, turn left on F, cross 35L and stop prior to Rwy 11 | Simulated | S1AC3 |

| | Speed | Altitude |
|---|---|---|
| AC1 | 150 knots | 8 miles lined up for 35L, 2300 feet MSL |
| AC 21 | 120 knots | On runway at B4 |

**Triggers are actuated by participant aircraft.**

**Scenario 2 - Layout**
**Taxi to Rwy (participant) – Arrival; Single Runway**
**Visibility:** day, clear



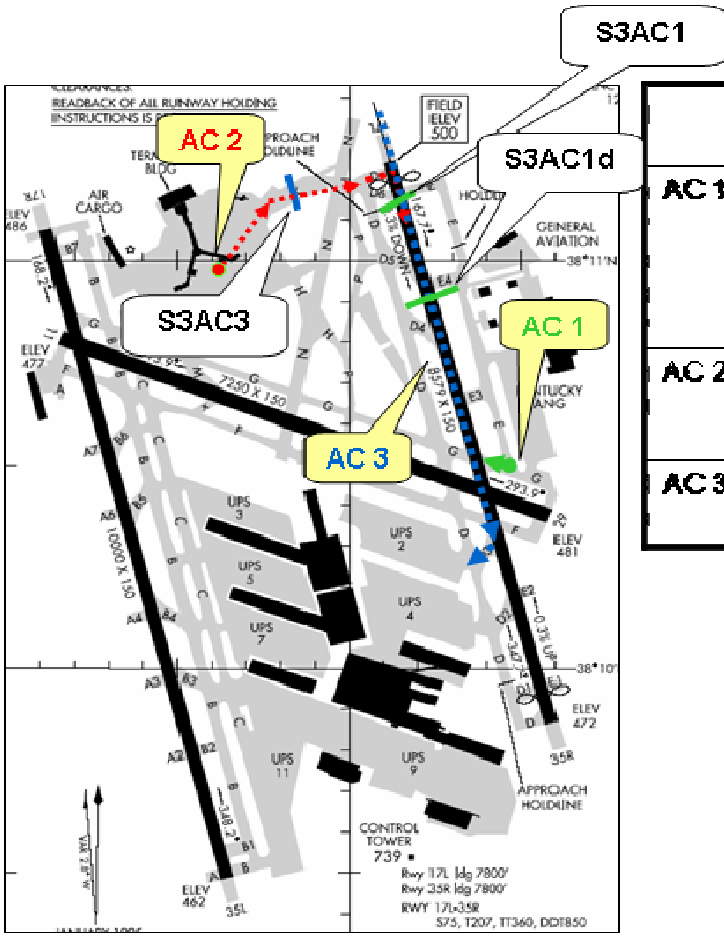

| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Cleared to cross runway 29 | Participant | – |
| AC 2 | Arrival to Rwy 29 | Is not created in simulator only radio communication | – |
| AC 21 | Landed on Rwy 29 | | S2AC21 |
| AC 3 | Lands on Rwy 17R | Simulated | S2AC2_3 |

AC 2 (not created)

| | Speed | Altitude |
|---|---|---|
| AC2 | -- | -- |
| AC3 | 150 knots | 4 miles out, lined up for 17R, 2000 feet MSL |
| AC21 | 120 knots | On runway |

Triggers are actuated by participant aircraft.

**<u>Scenario 3 - Layout</u>**
**On Rwy – Departure (participant); Single Runway**
**Visibility:** day, very low




| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Taxies from E onto Rwy 17L is deleted when participants crosses the 2nd trigger | Simulated | S3AC1 S3AC1d |
| AC 2 | Taxi for departure on 17L, hold short of 17L | Participant | – |
| AC 3 | Lands on Rwy 17L while AC 2 taxies | Simulated | S3AC3 |

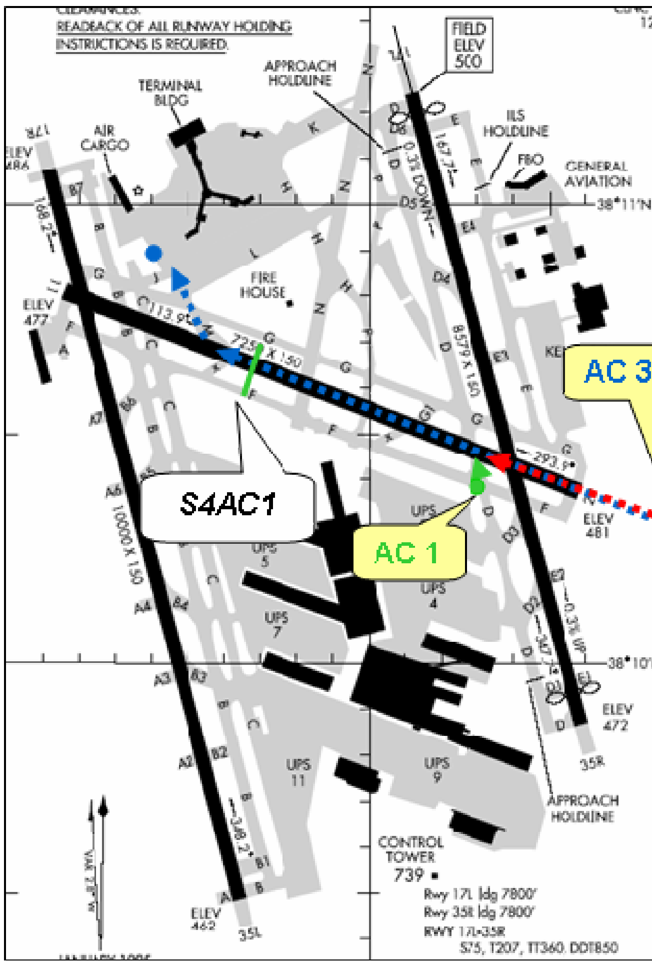
| | Speed | Altitude |
|---|---|---|
| AC3 | 150 knots | 3 miles, lined up for 17L, 1000 feet |

**Triggers actuated by participant aircraft.**

**<u>Scenario 4 - Layout</u>**
**On Rwy – Arrival (participant); Single Runway**

**ILS 29: 109.10**

**Visibility:** night, clear,

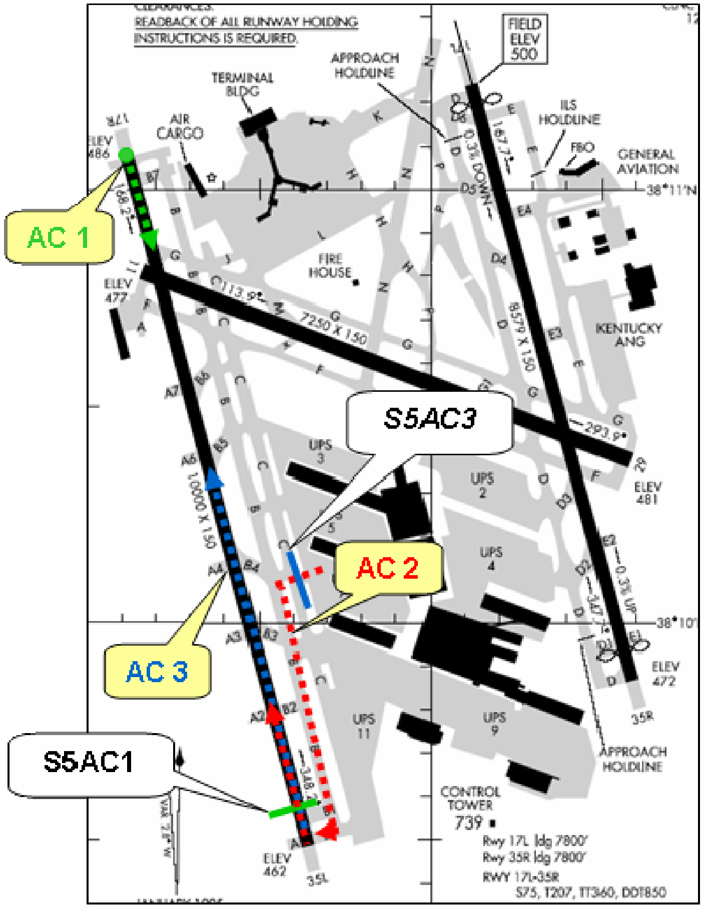



| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Taxies onto Runway 29 at D | Simulated | S4AC1 |
| AC 2 | Cleared for arrival on 29, following AC 3 that is also cleared for arrival on 29 | Participant | – |
| AC 3 | Cleared for arrival on 29 | Simulated | On start |

| | Speed | Altitude |
|---|---|---|
| AC 3 | 150 | 3 miles lined up for 29, 1500 feet MSL |
| AC 2 | 150 | 8 miles lined up for 29, 3100 feet MSL |

Trigger actuated by AC 3.

<u>**Scenario 5 - Layout**</u>
**Departure (participant) - Departure; Single Runway**
**Visibility:** day, clear



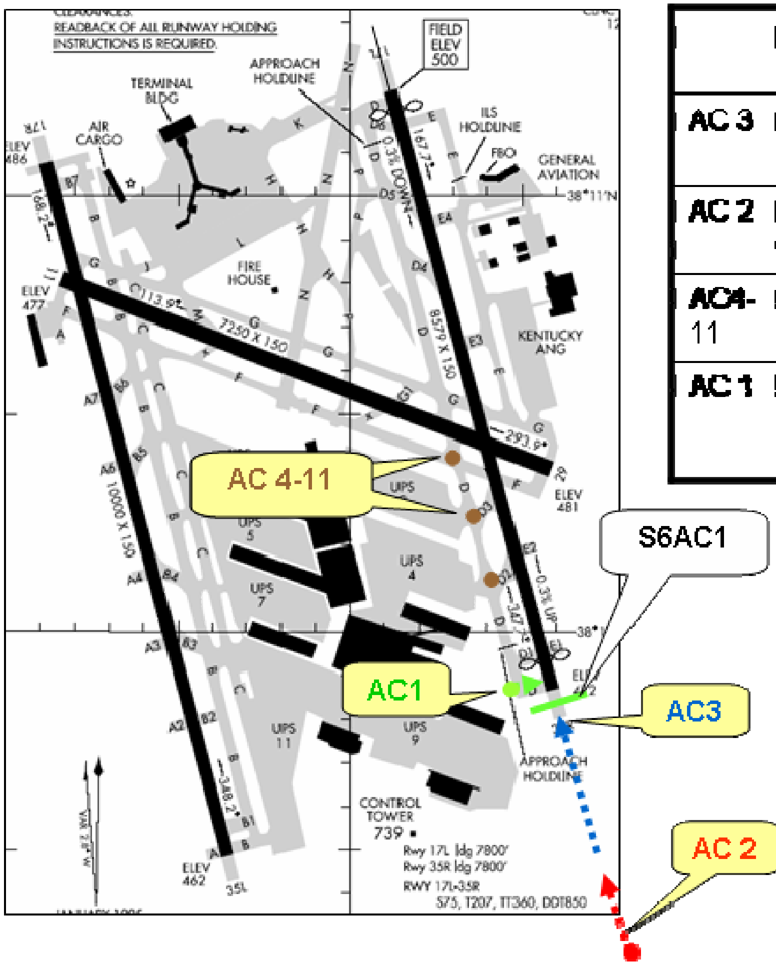

| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Vehicle driving on the runway in direction of departing aircraft | Simulated | S5AC1 |
| AC 2 | Taxies toward runway 35L, in position and hold, starts departure for Rwy 35L | Participant | – |
| AC 3 | Aircraft takes off on 35L while participant taxies | Simulated | S5AC3 |

| | Speed | Altitude |
|---|---|---|
| AC1 | 40 knots | On runway |

**Triggers are actuated by participant aircraft.**

**<u>Scenario 6 - Layout</u>**
**Departure – Arrival (participant); Single Runway**
**Visibility:** day, clear

**ILS 35R: 110.55**




| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 3 | Lands on runway 35R | Simulated | On start |
| AC 2 | Follows AC3 for arrival on Rwy 35R. | Participant | – |
| AC4-11 | Stationary aircraft | Simulated | On start |
| AC 1 | Created at hold-line, does not depart | Simulated | S6AC1* |

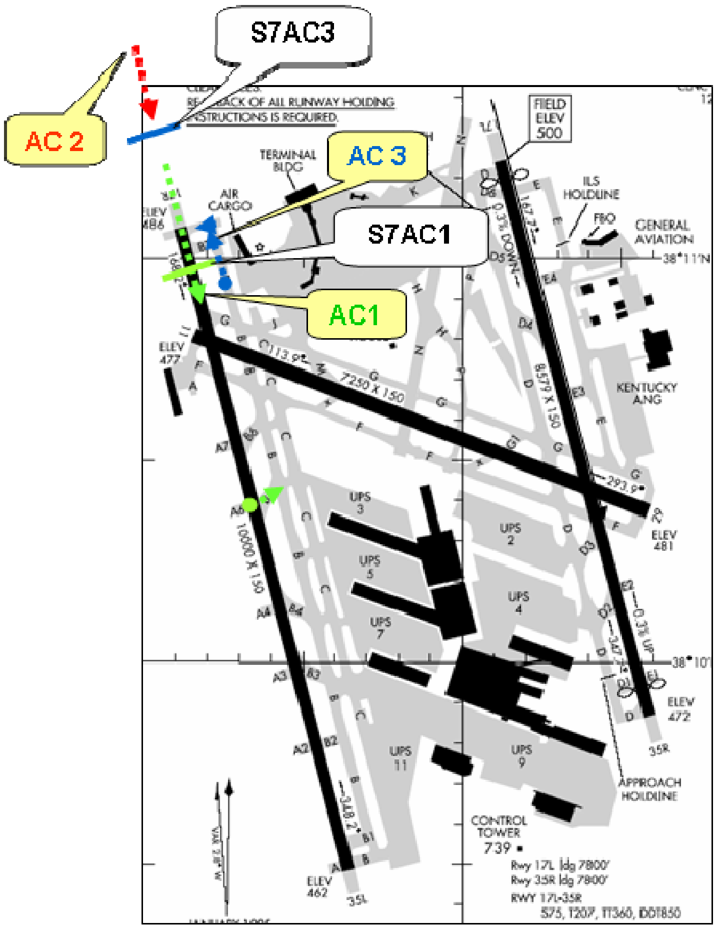
| | Speed | Altitude |
|---|---|---|
| AC3 | 150 knots | 3 miles lined up for 35R at 1500 feet MSL |
| AC2 | 150 knots | 8 miles lined up for 35R at 3100 feet MSL |

*Triggers are actuated by AC3

## Scenario 7 - Layout

**Arrival – Arrival (participant); Single Runway** **ILS 17R: 110.30**

**Visibility:** night, layer of clouds close to ground (1200 MSL)




| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Arrival on Rwy 17R; however, flight slows significantly down after landing, stops at B5 and start again at trigger | Simulated | S7AC1 |
| AC 2 | Follows AC1 for arrival on Rwy 17R | Participant | – |
| AC 3 | Holdshort on Twy B7 and 17R intersection | Simulated | S7AC3 |

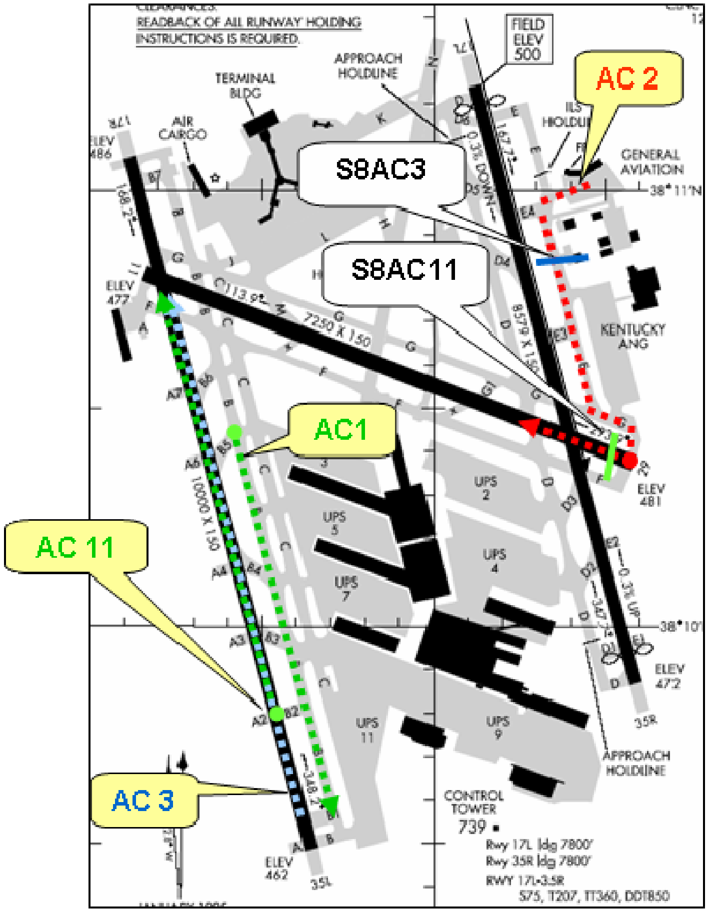
| | Speed | Altitude |
|---|---|---|
| AC1 | 135 knots | 3 miles lined up for 17R at 2100 feet MSL |
| AC2 | 200 knots | 5 miles lined up for 17R at 2600 feet MSL |

**Trigger is actuated by participant aircraft.**

## Scenario 8 - Layout

**Departure (participant) - Departure; Intersecting Runways**

**Visibility:** day, clear

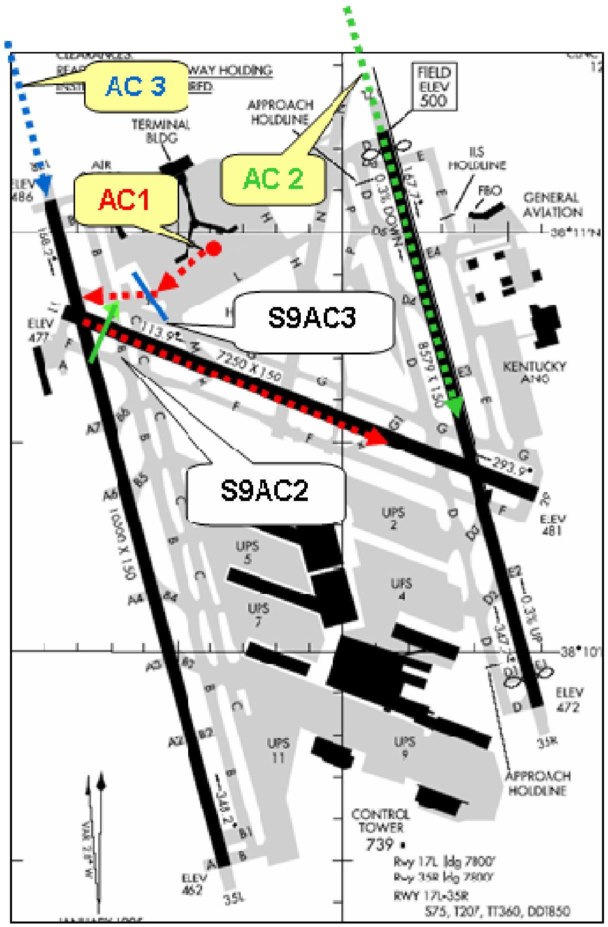



| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Taxi from B5 on B to twy B1, cleared in position and receives departure clearance. | Simulated | On start |
| AC11 | Has initiated take-off maneuver | Simulated | S8AC11 |
| AC 2 | Cleared for departure on rwy 29 as AC 1 moves on rwy 35L | Participant | – |
| AC 3 | Departure starts roll | Simulated | S8AC3 |

| | Speed | Altitude |
|---|---|---|
| AC11 | 40 knots | On runway |

**Triggers are actuated by participant aircraft.**

<u>**Scenario 9 - Layout**</u>
**Departure (participant) – Arrival; Intersecting Runways**
**Visibility:** day, clear

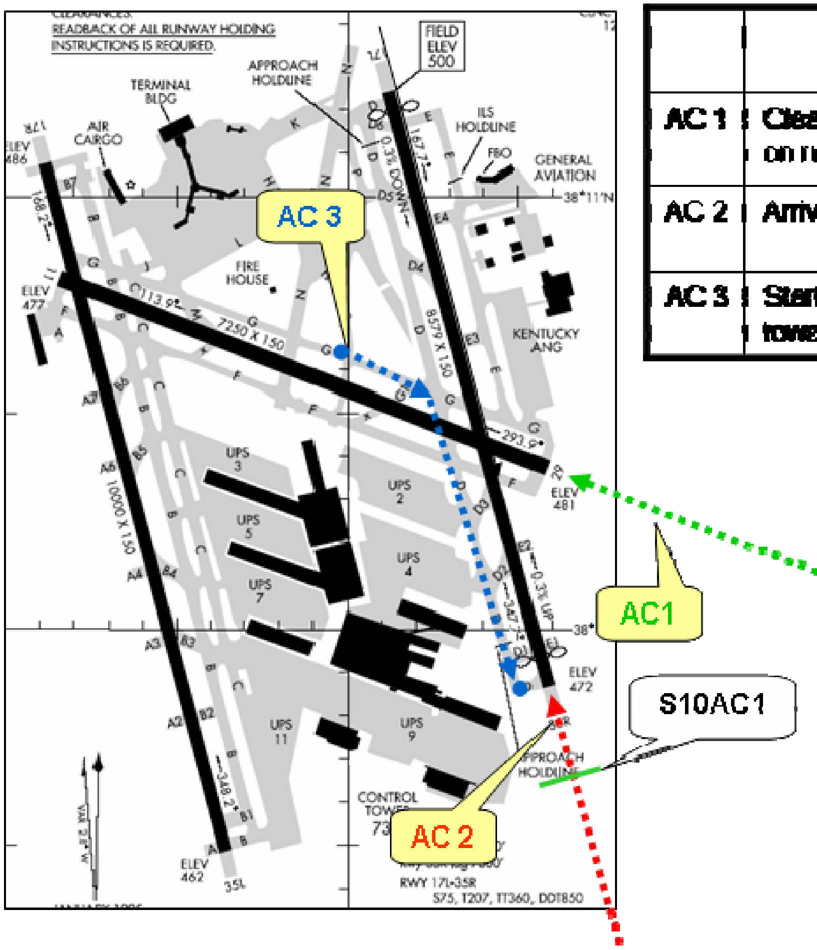



| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Taxies from North Ramp via J and B to Rwy 11 for departure | Participant | – |
| AC 2 | Arrival on 17L | Simulated | S9AC2 |
| AC 3 | Arrival on 17R | Simulated | S9AC3 |

| | Speed | Altitude |
|---|---|---|
| AC2 | 150 knots | 0.3 mile lined up for 17L at 650 foot MSL |
| AC3 | 150 knots | 0.1 mile lined up for 17R at 500 feet MSL |

**Triggers are actuated by participant aircraft.**

**<u>Scenario 10 - Layout</u>**
**Arrival – Arrival (participant); Intersecting Runways** **ILS 35R: 110.55**
**Visibility:** day clear




| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Cleared for arrival on runway 29 | Simulated | S10AC1 |
| AC 2 | Arrival on 35R | Participant | – |
| AC 3 | Starts taxiing toward rwy 35R | Simulated | On start |

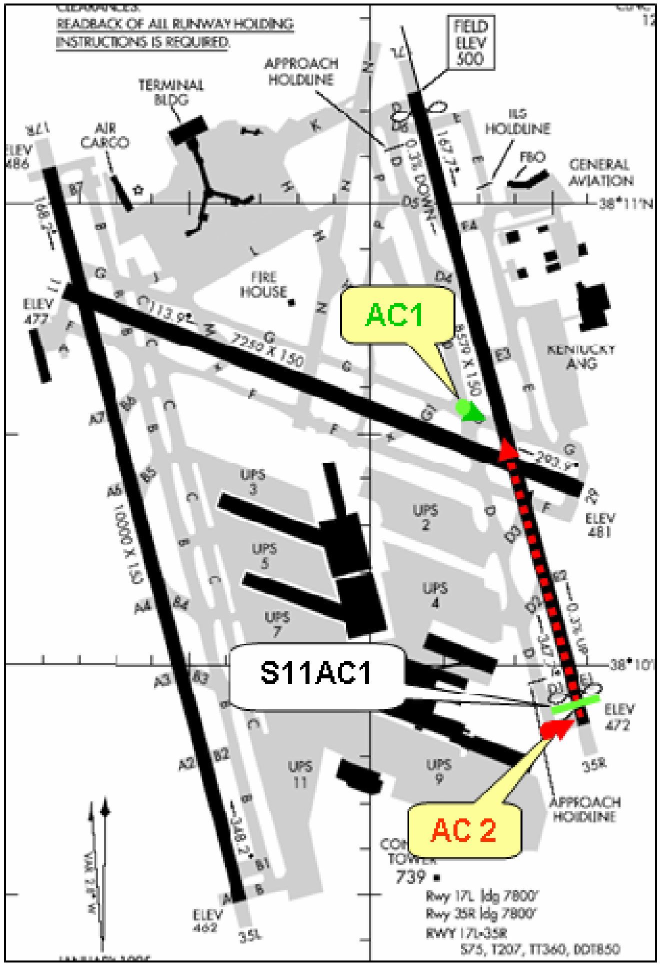
| | Speed | Altitude |
|---|---|---|
| AC1 | 150 knots | 5.5 miles lined up for 29 at 1800 feet MSL |
| AC2 | 150 knots | 5 miles lined up for 35R at 1700 feet MSL |

**Trigger is actuated by participant aircraft.**

__Scenario 11 - Layout__

**Taxi to Runway - Departure on Wrong Runway (participant); Single Runway**

**Visibility:** night, very low



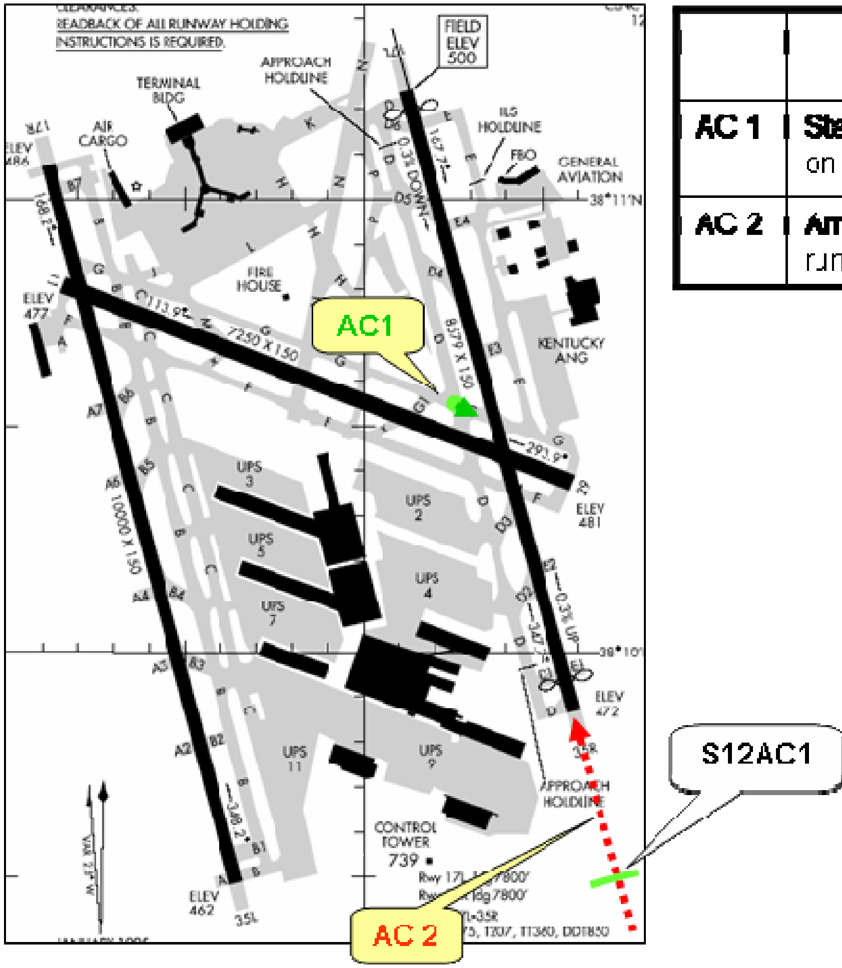

| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Starts crossing 35R on G | Simulated | S11AC1 |
| AC 2 | Departure on Rwy 35R | Participant | – |

**Trigger is actuated by participant aircraft.**

**<u>Scenario 12 - Layout</u>**

**Taxi to runway - Arrival on Wrong Runway (participant); Single Runway** **ILS 35R: 110.55**

**Visibility:** dusk, low hanging cloud

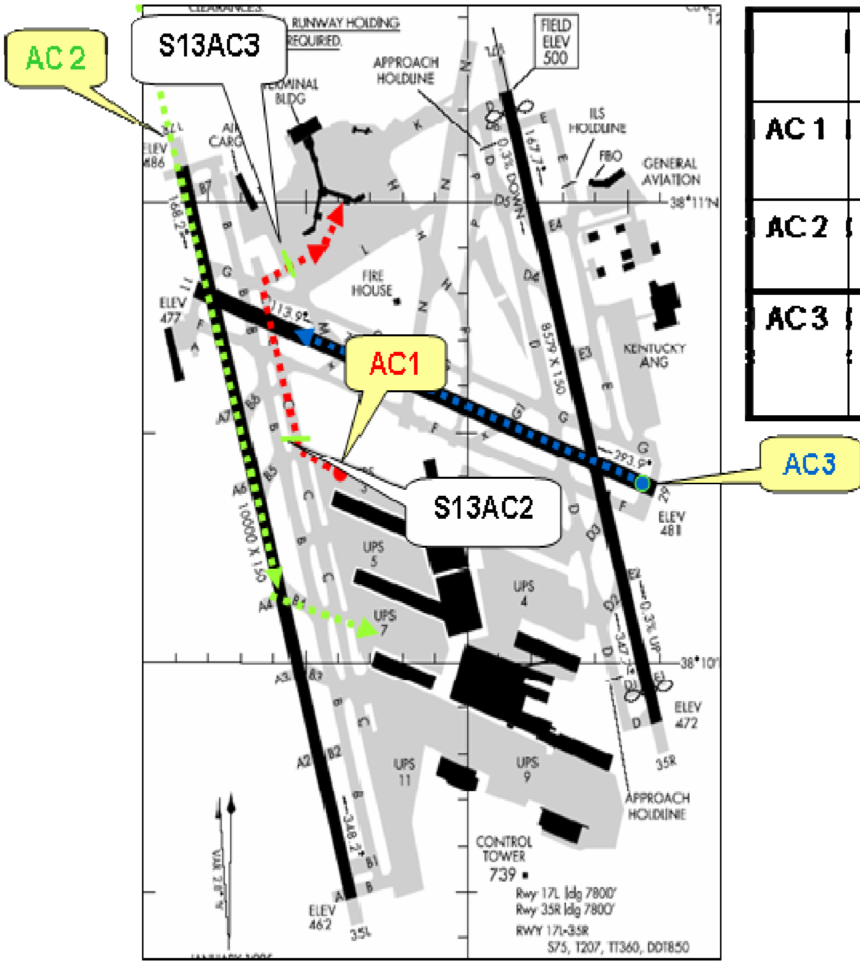



| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Starts crossing 35R on G | Simulated | S12AC1 |
| AC 2 | Arrival on incorrect runway 35R | Participant | – |

| | Speed | Altitude |
|---|---|---|
| AC2 | 150 knots | 5 miles out to runway 35R, 1650 feet MSL |

**Trigger is actuated by participant aircraft.**

**<u>Scenario 13 – Layout (no conflict)</u>**
**Taxi to Runway (participant) - Arrival; Single Runway**
**Visibility:** day, low visibility



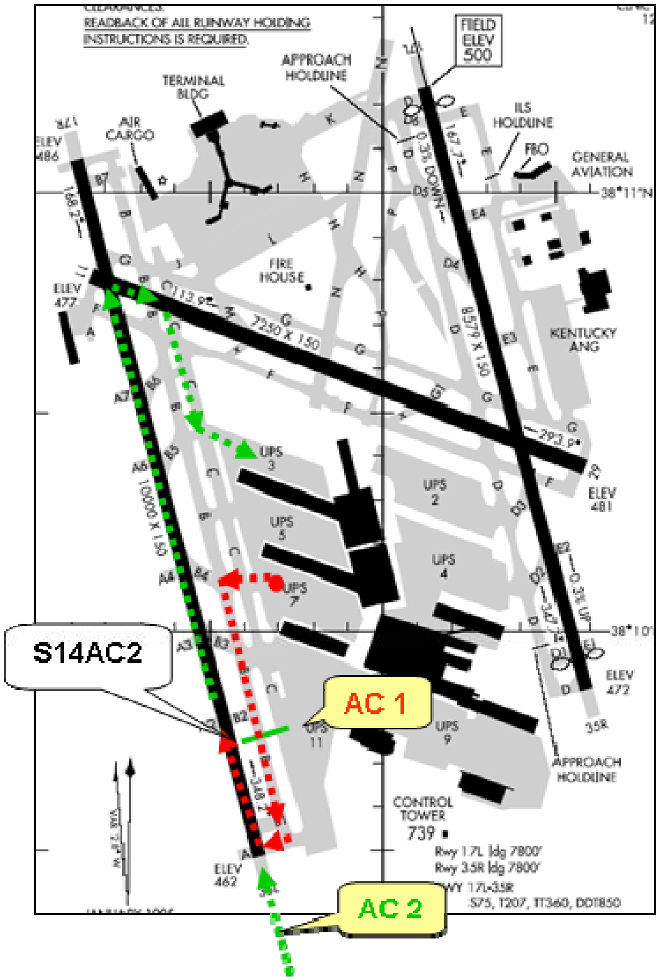

| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Starts taxiing at UPS 3 | Participant | – |
| AC 2 | Arrival on runway 17R | Simulated | S13AC2 |
| AC 3 | Stopped on rwy 29; departs when triggered | Simulated | S13AC3 |

| | Speed | Altitude |
|---|---|---|
| AC2 | 150 knots | 1 mile to runway 17R, 700 feet MSl |

**Trigger is actuated by participant aircraft.**

**<u>Scenario 14 – Layout (no conflict)</u>**
**Arrival (participant) – Taxi on Runway ; Single Runway**

**Visibility:** day, clear

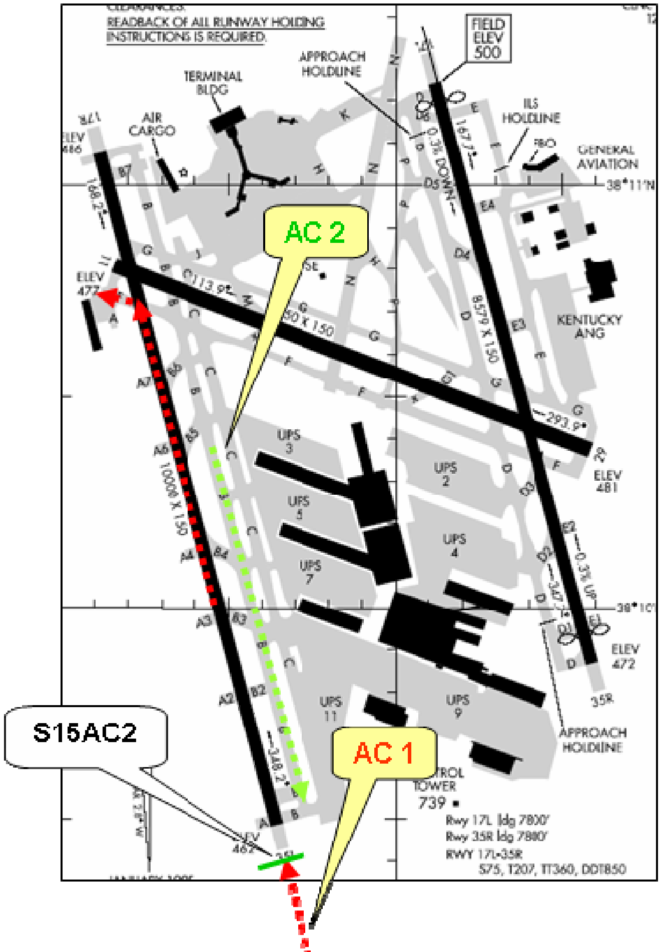



| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Departure on 35L | Participant | – |
| AC 2 | Arrival on 35L | Simulated | S14AC2 |

| | Speed | Altitude |
|---|---|---|
| AC2 | 150 knots | 2 mile out to runway 35L, 1200 feet MSL |

**Trigger is actuated by participant aircraft.**

**<u>Scenario 15 – Layout (no conflict)</u>**
**Arrival (participant) - Departure; Single Runway**
**Visibility:** day, clear




| | Action | Controlled by | Trigger |
|---|---|---|---|
| AC 1 | Arrive on 35L | Participant | – |
| AC 2 | Starts moving on B direction 35L and holds short of 35L | Simulated | S15AC2 |

| | Speed | Altitude |
|---|---|---|
| AC1 | 150 knots | 8 miles lined up for 35L, 2500 feet MSL |

**Trigger is actuated by participant aircraft.**

Scenario Script 1 (**Crossing** – Departure)

The designators AC1, AC2, and AC3 refer to the aircraft as outlined in the layout graphs.

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Participant (AC1 / CAASD 49) starts at about 8 NM lined up for Rwy 35L* | Approach: CAASD 49, contact Louisville tower on 124.2 | | | | | | | | | | |
| *2* | | | | | | | | "Tower on 124.2 for CAASD 49. So long" | | | | |
| *3* | | | | | | | | "Louisville Tower, CAASD 49 , 8 out for 35L" | | | | |
| *4* | *Participant calls tower controller* | "CAASD 49, Runway 35L, cleared to land, wind calm" | | | | | | | | | | |
| 5 | | | | | | | | "Cleared to land, CAASD 49" | | | | |
| 6 | *Additional traffic (not relevant to actual conflict)* | | | | | | | | | | "Louisville Tower, CAASD 86 , pushed off gate B19, requesting taxi with information Alpha" | |
| 7 | | CAASD 86, Louisville Tower, Roger, taxi via Mike, Foxtrot and Delta for Runway 35R, altimeter two-niner, niner-two" | | | | | | | | | | |
| 8 | | | | | | | | | | | "Roger, via Mike, Foxtrot and Delta for Runway 35R, 2-9-9-2, CAASD 86" | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | | | | | | | | | | | Louisville Tower, CAASD 1026, Pushed off B9 behind the company 757, requesting taxi. Information alpha” | |
| 10 | | CAASD 1026, Louisville Tower, Roger, follow the 757 to Runway 35R, altimeter 2-9-9-2” | | | | | | | | | | |
| 11 | | | | | | | | | | | “CAASD 1026, following the 757 for Runway 35R, 2-9-9-2” | |
| 12 | Prior to participant (AC1, CAASD 49) landing | “CAASD 43, cross runway 29 on Bravo and continue via Juliet to the Ramp” | | | | | | | | | | Setup for Error induction: AC 3 is cleared to cross 29 to reach the ramp |
| 13 | | | | | | | | | | “Roger, we’ll cross 29 on Bravo then taxi to the ramp, CAASD 43” | | |
| 14 | | | | | | | | | | | “Louisville Tower UPS Tug 5, request towing a 767 From UPS Ramp 2 to UPS Ramp 7 | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | | "UPS Tug 5, Roger , After an outbound 757, tow via Delta, Foxtrot and Charlie to Ramp 7" | | | | | | | | | | |
| 16 | | | | | | | | | | | UPS Tug 5, roger, we'll wait for the 757, the tow via Delta, Foxtrot and Charlie to Ramp 7" | |
| 17 | | | | | | | | | "Louisville tower, CAASD 1047, ready for take-off, 35L" | | | |
| 18 | AC1(CAASD 49) touch-down | "CAASD 1047, Runway 35L, Taxi in position and hold" | | | | | | | | | | |
| 19 | | | | | | | | | "Roger, CAASD 1047, position and hold" | | | |
| 20 | | "CAASD 49, turn right at next high-speed, that's B5, follow Boeing 737 to the ramp." | | | | | | | | | | |
| 21 | | | | | | | | "Right at B5 and follow to the ramp" | | | | |
| 22 | As AC1/CAASD 49 exits the runway | "CAASD 1047, turn left heading 320 degrees, maintain 3,000, Runway 35L, cleared for take-off" | | | | | | | | | | |
| 23 | | | | | | | | | "CAASD 1047, heading 320, maintain 3,000 feet, cleared for takeoff" | | | Error induction: confusing surface lighting and traffic to follow |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | Immediately after previous conversation | | | | | | | | | | Louisville Tower, CAASD 22 Heavy, 8 miles for Runway 35L” | |
| 25 | | CAASD 22 Heavy, Louisville Tower, cleared to land Runway 35L, wind calm” | | | | | | | | | | |
| 26 | | | | | | | | | | | “ CAASD 22 Heavy is cleared to land 35L” | |
| 27 | AC21 is created at REL alerting threshold | | illuminate | | Alert | | “CAASD 49, warning, runway unsafe” | | | | | AC21 is created at the spot that makes the REL turn on |
| 28 | | **Respond as appropriate to CAASD 49, if he questions whether to follow the other aircraft.** | | | | | | | | | | |
| *29* | *7 seconds after AMASS alert, if timing appropriate* | “CAASD 49, clear runway” | | | | | | | | | | |
| *30* | *Scenario ends after participant has crossed the runway and does not learn about the incursion* | | | | | | | | | | | |

Scenario Script 2 (**Crossing** – Arrival)

Pilot receives information that airport is operated on one frequency.

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC 2 (21) | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Participant (AC1 / CAASD 49) calls up ATC that he/she is ready for taxiing* | | | | | | | "Louisville Tower, CAASD 49, at UPS ramp 5, ready to taxi" | | | | |
| *2* | *ATC responds to AC1 / CAASD 49* | "CAASD 49, Louisville Tower, Stand by."<br><br>"CAASD 1020, Runway 29, cleared to land, wind is calm" | | | | | | | | | | |
| 3 | | | | | | | | | "CAASD 1020, cleared to land on 29" | | | |
| 4 | | "CAASD 87, Runway 17R, cleared to land, wind calm" | | | | | | | | | | |
| 5 | | | | | | | | | | "CAASD 87 cleared to land on 17R. | | |
| 6 | Participant (AC1 / CAASD 49) waits until ATC comes back | "CAASD 49, taxi to runway 17R via Charlie, Golf, Bravo, and Bravo 7, altimeter 2-9-9-2" | | | | | | | | | | |
| 7 | | | | | | | | "CAASD 49, runway 17R via Charlie, Golf, Bravo, and Bravo 7, altimeter 2-9-9-2" | | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC 2 (21) | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | | | | | | | | | | | "Louisville Tower, CAASD 42 pushed off gate A14, ready for taxi with information Alpha" | |
| 9 | | "CAASD 42, Louisville Tower, taxi to Runway 17L via Kilo and Delta, altimeter 2-9-9-2" | | | | | | | | | | |
| 10 | | | | | | | | | | | "Roger, via Kilo and Delta for runway 17L, 2-9-9-2, CAASD 42" | |
| 11 | | | | | | | | | | | "Louisville Tower, CAASD 94, pushed off gate B 17 requesting taxi for Runway 17L, information Alpha" | |
| 12 | | CAASD 94, Louisville Tower, taxi to Runway 17L via Kilo and Delta, altimeter 2-9-9-2" | | | | | | | | | | |
| 13 | | | | | | | | | | | "Roger, Kilo and Delta for Runway 35R, altimeter 2-9-9-2, CAASD 94" | |
| 14 | | "CAASD 94, that's Runway 17L! via Kilo and Delta" | | | | | | | | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC 2 (21) | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | | | | | | | | | | | "Roger Kilo, Delta 17L, CAASD 94" | |
| 16 | | | | | | | | | | | Louisville Tower, CAASD 10-10, we're 9 out for 17L" | |
| 17 | | "CAASD 1010, roger, Runway 17L cleared to land, wind calm" | | | | | | | | | | |
| 28 | | | | | | | | | | | "Cleared to land 17L, CAASD 1010" | |
| 19 | AC3 / CAASD 87 has landed | "CAASD 87, turn left at B4, taxi to the ramp" | | | | | | | | | | |
| 20 | | | | | | | | | | "CAASD 87, left on B4, to the ramp" | | |
| 21 | | | | | | | | | | | "Louisville Tower, CAASD 1045 pushed back off Alpha 4 request taxi with information alpha" | |
| 22 | | "CAASD 1045, Louisville Tower, roger, taxi to Runway 17L via Hotel, Kilo and Delta, altimeter 2-9-9-2" | | | | | | | | | | |
| 23 | | | | | | | | | | | "Roger, via Hotel, Kilo and Delta for Runway 17L, 2-9-9-2, CAASD 1045" | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC 2 (21) | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | | **If participant questions crossing clearance of Runway 29 – GIVE CROSSING CLEARANCE regardless** | | | | | | | | | | |
| 25 | AC21 is created | | Illuminate | | | | | | | | | |
| 26 | Participant (AC1 / CAASD 49) crosses the rwy 29 threshold | | | | Alert | | "CAASD 49, warning runway unsafe" | | | | | Error induction: incorrect ATC clearance and pilot failure to visually check for traffic |
| 27 | Seven seconds after AMASS alert, if appropriate for situation | "CAASD 49, clear runway" | | | | | | | | | | |
| 28 | Participant continues until hold-short of rwy 17R | | | | | | | | | | | |
| *29* | *Scenario ends when participant holds short at the hold-short line at 17R* | | | | | | | | | | | |

Scenario Script 3 (On Runway – **Departure**)

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Participant (AC2 / CAASD 49) call ATC for taxi clearance* | | | | | | | | "Louisville Tower, CAASD 49 , pushed from gate A12, ready for taxi from the north ramp" | | | |
| *2* | | "CAASD 49, Louisville Tower, taxi to runway 17L via Kilo and Delta, altimeter 2-9-9-2" | | | | | | | | | | |
| *3* | | | | | | | | | "17L via Kilo and Delta, altimeter 2-9-9-2,, CAASD 49" | | | |
| *4* | AC2 / CAASD 49 taxies | | | | | | | | | "Louisville tower, CAASD 1047, 3 mile final for 17 left" | | |
| 5 | | "CAASD 1047, Louisville Tower Runway 17L, cleared to land, wind calm" | | | | | | | | | | |
| 6 | | | | | | | | | | "CAASD 1047 cleared to land on 17L" | | |
| 7 | | | | | | | | "Louisville Tower, this is Cessna N1234A at FBO, request taxi with information Alpha" | | | | |
| 8 | | "Cessna N1234A, Louisville Tower, taxi to Runway 29 via Echo and Golf, altimeter 2-9-9-2" | | | | | | | | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | | | | | | | | "Roger, Echo and Golf for Runway 29, altimeter 2-9-9-2, Cessna 34A" | | | | |
| 10 | After AC3 / CAASD 1047 crosses the threshold | "CAASD 49, Runway 17L, taxi into position and hold" | | | | | | | | | | |
| 11 | | | | | | | | | "Position and hold on 17L, CAASD 49" | | | |
| 12 | AC3 / CAASD 1047 has landed | "CAASD 1047, turn right on D3, taxi to the ramp" | | | | | | | | | | |
| 13 | | | | | | | | | | "CAASD 1047, right on D3, to the ramp" | | |
| 14 | Communication right after previous | | | | | | | "Tower, this is Cessna N34A, at Taxiway Echo proceeding to Taxiway Golf, should I turn left or right at this intersection? | | | | |
| 15 | ATC responds to AC1 / Cessna 123 | "Cessna 34A, turn right and hold on Runway 29, hold short of Runway 17L, traffic departing that runway" | | | | | | | | | | |
| 16 | | | | | | | | "Cessna 34A, we'll turn right and hold short of 17L" | | | | *Error: Incorrect clearance* |
| 17 | ATC issues take off clearance | " CAASD 49, fly runway heading, climb and maintain 3000 ft, Runway 17L, cleared for take-off" | | | | | | | | | | |
| 18 | | | | | | | | | "CAASD 49 rolling on 17L" | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | | | | | | | | | | | "Louisville Tower, CAASD 29, pushed off A 10, requesting taxi with information Alpha" | |
| 20 | | CAASD 29, Louisville Tower, taxi to Runway 17L via Kilo and Delta, altimeter 2-9-9-2" | | | | | | | | | | |
| 21 | | | | | | | | | | | "Kilo and Delta for Runway 17L, 2-9-9-2, CAASD 29" | |
| 22 | AC2 / CAASD 49 starts takeoff roll | | | Illuminate | | | "CAASD 49, warning runway unsafe" | Moves into position and hold on 17L | | | | |
| 23 | Seven seconds after AMASS alert | "CAASD 49, abort takeoff, runway unsafe" | | | | | | | | | | |
| *24* | *Pilot of AC2 / CAASD 49 either initiates takeoff or contacts tower; scenario ends* | | | | | | | | | | | |

Scenario Script 4 (On Runway– **Arrival**)

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC2 | AC3 | Other Aircraft | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Participant (AC2 / CAASD 49) flies an approach to rwy 29 and follows AC3 / CAASD 86; Approach contacts pilot* | Approach: "CAASD 49 contact Louisville tower on 124.2" | | | | | | | | | | |
| *2* | | | | | | | | | "CAASD 49 going over to 124.2" | | | |
| *3* | Pilot (AC2 / CAASD 49) initiates contact with tower | | | | | | | | "Louisville tower, CAASD 49 on final for 29" | | | |
| 4 | | "CAASD 49, Louisville tower, 5 miles behind a B757, cleared to land Runway 29, wind calm" | | | | | | | | | | |
| 5 | | | | | | | | | "Cleared to land Runway 29, CAASD 49" | | | |
| 6 | | | | | | | | | | | Louisville Tower, U-P-S 10-27 at Ramp 2 for taxi with information alpha" | |
| 7 | | "UPS 1027, Louisville Tower, taxi to runway 29 via Delta and Foxtrot, altimeter 2-9-9-2" | | | | | | | | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC2 | AC3 | Other Aircraft | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | | | | | | | | | | | "Roger, via Delta and Foxtrot to Runway 29, altimeter 2-9-9-2, U-P-S- 1027" | |
| 9 | | | | | | | | | | | Louisville Tower, this is CAASD 36, pushed off gate A6 for taxi, with information alpha and requesting runway 17L for departure" | |
| 10 | | CAASD 36, Louisville Tower, taxi to Runway 17L via Hotel, Kilo and Delta, altimeter 2-9-9-2" | | | | | | | | | | |
| 11 | | | | | | | | | | | "Hotel, Kilo and Delta for Runway 17L, altimeter 2-9-9-2, CAASD 36" | |
| 12 | AC3 / CAASD 86 has landed | "CAASD 86, turn right at Mike, taxi to the ramp | | | | | | | | | | |
| 13 | | | | | | | | | | "Roger, right on Mike and taxi to the ramp, CAASD 86" | | |
| 14 | Immediately after previous conversation | "Cessna 34A cross Runway 29, proceed to the ramp" | | | | | | | | | | |
| 15 | | | | | | | | "Cessna 34A cleared across 29" | | | | |
| 16 | As AC3 / CAASD 86 exits the | | | | | | | "Louisville Tower, this | | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC2 | AC3 | Other Aircraft | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | runway | | | | | | | is Cessna 34A, we have a slight problem and need to hold in present position, but I think we are clear of, umm runway 17R" | | | | |
| 17 | Immediately thereafter | "Cessna 34A, verify your position. You are not visible from the tower" | | | | | | | | | | |
| 18 | Cessna 34A responds to ATC | | | | | | | "Tower, Cessna 34A, we have a slight steering problem. I am not sure, it is hard to see; yes, we are clear of Runway 17R" | | | | Error induction: Pilot reads back incorrect runway; controller does not catch that error |
| 19 | | "Cessna 34A, hold position and advise when you're able to taxi" | | | | | | | | | | |
| 20 | | | | | | | | " Wilco, Cessna 34A" | | | | |
| 22 | *Immediately thereafter* | | | | | | | | | | "Louisville Tower, CAASD 26, off gate A9, request taxi with information alpha and requesting runway 17L" | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 | AC2 | AC3 | Other Aircraft | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | | "CAASD 26, Louisville Tower, follow company 757 to Runway 17L via Hotel, Kilo and Delta, altimeter 2-9-9-2" | | | | | | | | | | |
| 24 | | | | | | | | | | | "Roger following the company 757 to Runway 17L, 2-9-9-2, CAASD 26" | |
| 25 | | | | | AMASS | alert | "CAASD 49, warning runway unsafe" | | | | | |
| *26* | *7 seconds after AMASS alert* | "CAASD 49, go around, climb runway heading to 3000 feet" | | | | | | | | | | |
| *27* | *Pilot (AC2 / CAASD 49) either lands contacts ATC, initiates the go-around; scenario ends* | | | | | | | | | | | |

Scenario Script 5 (Departure – **Departure-Vehicle**)

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 (Vehicle) | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | | "CAASD 29, runway 35L, taxi into position and hold" | | | | | | | | | | |
| *2* | | | | | | | | | | "CAASD 29, Position and hold 35L" | | |
| *3* | *Participant (AC2 / CAASD 49) calls ATC for taxi clearance* | | | | | | | | "Louisville Tower, CAASD 49, Ramp 7 for taxi with information alpha" | | | |
| *4* | | "CAASD 49, taxi to runway 35L via Bravo, altimeter 2-9-9-2" | | | | | | | | | | |
| *5* | | | | | | | | | "CAASD49 to Runway 35L via Bravo, 2-9-9-2" | | | |
| 6 | | "Airport Five, cross Runway 35R" | | | | | | | | | | |
| 7 | | | | | | | | | | | "Airport Five, roger, we are crossing Runway 35R" | |
| 8 | AC3 / CAASD 29 on runway | CAASD 29, after departure fly runway heading, maintain 3,000, Runway 35L, cleared for takeoff | | | | | | | | | | |
| 9 | | | | | | | | | | "CAASD 29, cleared | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 (Vehicle) | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | for take off 35L” | | |
| 10 | | | | | | | | | | | Louisville Tower, CAASD 55, abeam gate B17 for taxi, information alpha” | |
| 11 | | “CAASD 55, Louisville Tower, taxi to runway 35L via Bravo, altimeter 2-9-9-2” | | | | | | | | | | |
| 12 | | | | | | | | | | | “Bravo for Runway 35L, 2-9-9-2, CAASD 55” | |
| 13 | | | | | | | | | | | Tower, Airport Five is clear of Runway 35R, proceeding via Golf to the north ramp” | |
| 14 | | “Airport Five roger, that’s approved” | | | | | | | | | | |
| 15 | Participant (AC2 / CAASD 49) reaches runway 35L, holds short | “CAASD 49 , runway 35L, taxi in position and hold | | | | | | | | | | |
| 16 | | | | | | | | | “CAASD 49, Position and hold 35L” | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 (Vehicle) | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | Immediately thereafter | | | | | | | "Tower, this is Airport One, Runway 35R is now closed for work in progress, works vehicles will be entering at taxiway B" | | | | Error induction: Error from AC2 not picked up ATC. (Taxiway B is not compatible with Runway 35R) |
| 18 | Responds to Airport 1 | "Airport One, Roger Runway 35R closed at XXXX" | | | | | | | | | | |
| 19 | | | | | | | | | | | Louisville Tower, CAASD 45, pushed off gate B15, for taxi with information alpha" | |
| 20 | | CAASD 45, Louisville Tower | | | | | | | | | | |
| 21 | | | | | | | | | | | "Roger Juliet and Charlie for Runway 35L, 2-9-9-2, CAASD 45" | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 (Vehicle) | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | | | | | | | | | | | "Louisville Tower, CAASD 1020, pushed off gate B5, behind the 757 for taxi with alpha" | |
| 23 | | "CAASD 1020, Louisville Tower, follow your company 757 to Runway 35L, via Juliet and Charlie, altimeter 2-9-9-2" | | | | | | | | | | |
| 24 | | | | | | | | | | | "Following company to Runway 35L, 2-9-9-2, CAASD 10-20" | |
| 25 | After about one minute after AC3 / CAASD 29 departs, AC2 / CAASD 49 is in position and holding | "CAASD 49, after departure turn left heading 320, climb and maintain 3,000 feet, Runway 35L, cleared for takeoff" | | | | | | | | | | |
| 26 | | | | | | | | | "Roger heading 320, maintain 3,000 feet, Cleared for take-off CAASD 49" | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 (Vehicle) | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | | | | | | | | | | | "Louisville Tower, CAASD 86, pushed off gate A 8, requesting taxi with information alpha, we can take Runway 29" | |
| 28 | | "CAASD 86, Louisville Tower. Can you take Runway 35L? | | | | | | | | | | |
| 29 | | | | | | | | | | | "That's affirm, CAASD 86" | |
| 30 | | "CAASD 86 taxi to Runway 35L via Juliet and Charlie, altimeter 2-9-9-2" | | | | | | | | | | |
| 31 | | | | | | | | | | | "Roger, Juliet and Charlie for Runway 35L,2-9-9-2, CAASD 86 | |
| 32 | | | | Illuminate | Alert | | "CAASD 49, warning runway unsafe" | Vehicle AC1 starts driving from North end of 17R direction South | | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC1 (Vehicle) | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | Seven seconds after AMASS alert | " Airport One, you are on an active runway – exit runway immediately, Boeing 757 is taking off" | | | AC2, warning traffic ahead on Foxtrott | | | | | | | |
| 34 | Car stops at Foxtrot, and remains on runwy 35L | | | | | | | Car stops | | | | |
| *35* | *Pilot either initiates the takeoff or aborts, scenario ends* | | | | | | | | | | | |

Scenario Script 6: Departure – **Arrival**

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Participant (AC2 / CAASD 49) is contacted by Approach control to contact SDF tower* | "CAASD 49, contact Louisville Tower on 124 point 2 | | | | | | | | | | |
| *2* | | | | | | | | | "Roger, Tower on 124point 2, CAASD 49" | | | |
| *3* | *AC2 / CAASD 49 contacts Louisville tower* | | | | | | | | "Louisville Tower, CAASD 49 on final for Runway 35R" | | | |
| 4 | | "CAASD 49, Louisville Tower, 5 miles behind B757, Runway 35R cleared to land, wind calm" | | | | | | | | | | Error induction: Radio frequency congestion and controller "forgets" about arrival aircraft |
| 5 | | | | | | | | | "Cleared to land on 35R, CAASD 49" | | | |
| 6 | | "CAASD 1020, are you number 2 or number 3 for Runway 35R?" | | | | | | | | | | |
| 7 | | | | | | | | | | | "CAASD 1020, we're number 3 Sir behind the 2 757's" | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | | "CAASD 1020 roger, thanks, can you accept a departure from Delta 1? , I need you out ahead of your company 757" | | | | | | | | | | |
| 9 | | | | | | | | | | | "CAASD 1020, we can accept the intersection departure from Delta 1" | |
| 10 | | "CAASD 42, Runway 35R, taxi in position and hold" | | | | | | | | | | |
| 11 | | | | | | | | "CAASD 42, Position and hold Runway 35R" | | | | |
| 12 | | "CAASD 1020, Roger, hold short of 35L at Delta 1, you will be number two to depart" | | | | | | | | | | |
| 13 | | | | | | | | | | | "CAASD 1020,understood, we'll hold short of 35L at Delta 1" | |
| 14 | | | | | | | | | | | | AC3 / CAASD 87 lands on 35R |
| 15 | | | | | | | | | | | Louisville Tower, CAASD 98, pushed off gate B17, ready for taxi with information alpha" | |
| 16 | | CAASD 98, Louisville Tower, Roger, taxi to Runway 35L via Juliet and Charlie, altimeter 2-9-9-2" | | | | | | | | | | |
| 17 | | | | | | | | | | | "Juliet and Charlie | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | for Runway 35L, 2-9-9-2, CAASD 98 | |
| 18 | | "CAASD 87, turn left at D4, taxi to the ramp" | | | | | | | | | | |
| 19 | | | | | | | | | | "CAASD 87, exiting at D4, cleared to the ramp" | | AC3 pulls off the runway |
| 20 | When CAASD 87 clears runway | "CAASD 42, Runway 35R, cleared for take off without delay, traffic one mile final, wind calm" | | | | | | | | | | |
| 21 | CAASD 42 does not roll | | | | | | | "CAASD 42, cleared for take-off 35R" | | | | |
| 22 | | | | | | | | | | | "Louisville Tower, CAASD 57, 9 miles out for Runway 35R" | |
| 23 | | "CAASD 57, Louisville Tower, number two behind a B757, Runway 35R, cleared to land, wind calm" | | | | | | | | | | |
| 24 | | | | | | | | | | | "Roger, cleared to land 35R, CAASD 57" | |
| 25 | | | | | | | | | | | "Tower, CAASD 98, just confirm we can cross Runway 29 at Charlie" | |
| 26 | | "CAASD 98, Affirm cross runway 29" | | | | | | | | | | |
| 27 | As AC2 / CAASD 49 gets in to alerting zone | | | | alert | alert | "CAASD 49, warning runway unsafe" | | | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | Seven seconds later | "CAASD 49, Go around, I say again, go around, runway occupied, climb runway heading to 3000 feet. Acknowledge" | | | Alert | | | | | | | |
| 29 | | | | | | | | | "CAASD 49, Going around, climbing runway heading to 3000 feet" | | | |
| 30 | After landing of AC2 / CAASD 49 | If AC2 / CAASD 49 lands - "CAASD 49 exit runway at D4 and taxi to the ramp" | | | | | | | | | | |
| *31* | *End of scenario* | | | | | | | | | | | |

Scenario Script 7:  Arrival – **Arrival**

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Participant (AC2 / CAASD 49) flies an approach to rwy 35R and follows AC1 / CAASD 22; Approach contacts pilot* | "CAASD 49, contact Louisville tower on 124 point 2" | | | | | | | | | | |
| *2* | | | | | | | | | " CAASD 49, contacting Tower 124 point2" | | | |
| *3* | | | | | | | | | "Louisville, CAASD 49 5 miles out for Runway 17R" | | | |
| 4 | | "CAASD 49, Louisville tower, reduce to minimum approach speed at this time, you're 3 miles behind B757, runway 17R cleared to land , wind calm" | | | | | | | | | | |
| 5 | | | | | | | | | "CAASD 49 roger, cleared to land Runway 17R" | | | |
| 6 | Immediately after previous communication | | | | | | | | | "Louisville Tower, CAASD 33 is ready for taxi, abeam gate B17 with information alpha" | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | | "CAASD 33, Louisville tower, taxi to runway 17R, via Juliette and Bravo, altimeter 2-9-9-2" | | | | | | | | | | |
| 8 | | | | | | | | | | "CAASD 33, Juliette, Bravo to runway 17R, altimeter 2-9-9-2" | | |
| 9 | After AC1 / CAASD 22 (NOT THE PARTICIPANT) lands on 17R (as displayed on AMASS display | | | | | | | "Tower, CAASD 22, can we exit at B5?" | | | | Error induction: due to the already close spacing, sharp turn on B5 causes extensive delay on runway |
| 10 | | "CAASD 22, B5 approved, expedite please, traffic short final" | | | | | | | | | | |
| 11 | | | | | | | | "Roger, turning left at B5 onto the parallel, CAASD 22" | | | | |
| 12 | | | | | | | | | | | Louisville Tower, CAASD 86, pushed off gate B16 for taxi, information alpha" | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | | "CAASD 86, Louisville Tower, follow your company 757 to Runway 17R, altimeter 2-9-9-2" | | | | | | | | | | |
| 14 | | | | | | | | | | | "Roger, following company to 17R, 2-9-9-2, CAASD 86" | |
| 15 | | | | | | | | | | | Louisville Tower, CAASD 23 Heavy is 9 out for Runway 17R" | |
| 16 | | "CAASD 23 Heavy, Louisville tower, six miles behind a company 757, Runway 17R, cleared to land, wind calm" | | | | | | | | | | |
| 17 | | | | | | | | | | | "Roger, copied the traffic, cleared to land Runway 17R, CAASD 23 Heavy" | |
| 18 | | | | | | | | | | | | Stops at B5 and waits until AC2 / CAASD 49 has landed |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | Participant (AC2 / CAASD 49) approaches landing threshold | | | | Alert | illuminate | "CAASD 49, warning runway unsafe" | | | | | |
| 20 | 7 seconds after AMASS | | | | "AC2 / CAASD 49, runway unsafe, traffic at B5" ???? | | | | | | | |
| *21* | *End of scenario* | | | | | | | | | | | |

Scenario Script 8: Departure - **Departure**

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 (11) | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Participant (AC2 / CAASD 49) calls up ATC that he/she is ready for taxiing.* | | | | | | | | "CAASD 49, ready for taxi clearance with information alpha" | | | |
| *2* | *ATC responds to AC2 / CAASD 49* | "CAASD 49, taxi to runway 29 via Echo and Golf, altimeter 2-9-9-2" | | | | | | | | | | |
| 3 | | | | | | | | | "CAASD 49, via Echo and Golf for Runway 29, altimeter 2-9-9-2" | | | |
| 4 | | "CAASD 86, turn left heading 320, climb and maintain 3,000 feet Runway 35L, cleared for take-off" | | | | | | | | | | |
| 5 | | | | | | | | | | "CAASD 86, Roger, Cleared for take-off 35L, turn left heading 320 and maintain 3,000 feet" | | Starts takeoff |
| 6 | Right after the previous communication | | | | | | | | | | "CAASD 11 pushed off gate B17. ready for taxi" | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 (11) | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | | CAASD 11, Louisville Tower, Roger, Taxi to runway 35L via Juliette and Bravo, altimeter 2-9-9-2" | | | | | | | | | | |
| 8 | | | | | | | | | | | "CAASD 11, Roger, via Juliette, Bravo for Runway 35L, altimeter 2-9-9-2" | |
| 9 | | | | | | | | | | | Tower, Airport Five wishes to proceed from FBO to Echo for Runway inspection on 35R" | |
| 10 | | "Airport Five, roger, hold short of 35R at Echo 4, and stand by" | | | | | | | | | | |
| 11 | | | | | | | | | | | "Airport Five roger, holding short of 35R at Echo" | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 (11) | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | As participant (AC2 / CAASD 49) on Twy E, reaches E3 | "CAASD 49, Runway 29, taxi in position and hold" Note: make sure CAASD 49 gets departure clearance before stopping on 29 to get the correct trigger mechanism | | | | | | | | | | |
| 13 | | | | | | | | | "CAASD 49, Roger, taxi in position and hold, Runway 29" | | | |
| 14 | Immediately following previous communication | "CAASD 45, Runway 35L taxi into position and hold" | | | | | | | | | | |
| 15 | | | | | | | | "CAASD 45, Position and hold, Runway 35L" | | | | |
| 16 | As participant (AC2 / CAASD 49) enters Rwy29 | "CAASD 49, fly runway heading, climb, maintain 3000 ft, Runway 29, cleared for takeoff, no delay, wind calm" | | | | | | | | | | |
| 17 | | | | | | | | | "CAASD 49 cleared for take off | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 (11) | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Runway 29”” | | | |
| 18 | **<u>Immediately</u> after AC1 / CAASD 45 replies (to simulate end of stepped on transmission)** | | | | | | | “……rolling” | | | | Error induction: communication error from AC1 who falsely initiates takeoff |
| 19 | Immediate follow with additional transmission | | | | | | | | | | “Louisville Tower, CAASD 55 turning visual final Runway 29 at 4 miles” | |
| 20 | | CAASD 55, Louisville Tower, one departure prior to your arrival, Runway 29 cleared to land, wind calm” | | | | | | | | | | |
| 21 | | | | | | | | | | | “Roger Runway 29 cleared to land, CAASD 55” | |
| 22 | | | | | | | | | | | Louisville Tower, CAASD 67, pushed off A15 for taxi, inform | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 (11) | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | ation alpha" | |
| 23 | | "CAASD 67, Louisville Tower, taxi to Runway 35L via Juliet and Charlie, altimeter 2-9-9-2" | | | | | | | | | | |
| 24 | | | | | | | | | | | "CAASD 67, roger, Juliet and Charlie for Runway 35L, 2-9-9-2" | |
| 25 | After participant, AC2 / CAASD 49 initiates takeoff-roll | | | alert | alert | | CAASD 49, runway unsafe | AC11 / CAASD 45 is created | | | | |
| 26 | *7 seconds after AMASS alert* | | | | "AC2 / CAASD 49 abort take-off, traffic ahead on crossing runway" | | | | | | | |
| *27* | *End of scenario* | | | | | | | | | | | |

Scenario Script 9: **Departure** – Arrival

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Pilot (AC1 / CAASD 49) is ready for pushback and departure on rwy 11* | | | | | | | "Louisville Tower, this is CAASD 49, pushed off gate B17 ready for taxi" | | | | |
| *2* | | "CAASD 49, taxi to Runway 11 via Juliet and Golf, hold-short of runway 17R. altimeter 2-9-9-2" | | | | | | | | | | |
| 3 | | | | | | | | "CAASD 49, Roger, Juliet and Golf, Runway 11, altimeter 2-9-9-2, hold short of 17R" | | | | |
| 4 | Immediately after previous communication | | | | | | | | "Louisville tower, CAASD 45 is 5 miles out for 17 left" | | | |
| 5 | | "CAASD 45, Louisville Tower, Runway 17L cleared to land, wind calm" | | | | | | | | | | |
| 6 | | | | | | | | | "CAASD 45, Roger cleared to land Runway 17L" | | | |
| 7 | Right after the previous communication | | | | | | | | | "Louisville tower, CAASD 25 is 3 miles out for 17 | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | right” | | |
| 8 | | “CAASD 25 Louisville Tower, Runway 17R cleared to land, wind calm” | | | | | | | | | | |
| 9 | | | | | | | | | | “CAASD 25 cleared to land 17R” | | |
| 10 | After AC3 / CAASD 25 landing | “CAASD 25 turn left at “B4, taxi to the ramp. | | | | | | | | Lands | | |
| 11 | | | | | | | | | | “CAASD 25 left on B4” | | |
| 12 | After AC3 / CAASD 25 has exited the runway: ATC to AC1 / CAASD 49 | “CAASD 49, Cross Runway 17R at Golf, taxi into position and hold runway 11” | | | | | | | | | | |
| 13 | | | | | | | | “CAASD 49, Crossing 17R and Position and hold on Runway 11” | | | | |
| 14 | Pilot AC1 / CAASD 49 pulls onto runway 11 | “CAASD 49, turn left 080, climb and maintain 3000 feet, Runway 11 cleared for take-off, no delay, please | | | | | | | | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | | | | | | | | "CAASD 49, Roger cleared for immediate take-off, heading 080, 3,000 feet" | | | | |
| 16 | Pilot (AC1 / CAASD 49) initiates take-off | | | illuminate | alert | | " CAASD 49, runway unsafe" | (Initiates take-off) | AC2 / CAASD 45 is created in simulator | | | |
| 17 | Seven seconds after AMASS | | | | "CAASD 49, cancel take-off clearance traffic on crossing runway" | | | | | | | |
| 18 | After AC2 / CAASD 45 landing | "CAASD 45, turn left at D2, taxi to the ramp" | | | | | | | Lands | | | |
| 19 | | | | | | | | | "CAASD 45, we'll turn right on D2" | | | |
| *20* | *End of scenario* | | | | | | | | | | | |

Scenario Script 10: Arrival - **Arrival**

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Participant (AC2 / CAASD 49) is lined up for arrival on 35R .Approach control contacts participant* | CAASD 49, contact Louisville tower at 124 point 2 | | | | | | | | | | |
| *2* | | | | | | | | | “Roger, contacting Tower 124 point 2, CAASD 49” | | | |
| *3* | *Participant (AC / CAASD 49) contacts ATC* | | | | | | | | Participant: “Louisville tower, CAASD 49 is 5 miles out for 35R right” | | | |
| 4 | ATC responds to call from participant (AC2 / CAASD 49) | “CAASD 49, runway 35R cleared to land , wind is calm | | | | | | | | | | |
| 5 | | | | | | | | | “ Roger, CAASD 49 is cleared to land runway 35R” | | | |
| 6 | Soon after previous communication | | | | | | | “Louisville Tower, CAASD 59, 5.5 miles for Runway 29” | | | | |
| 7 | | “CAASD 59, Louisville Tower, Roger reduce to minimum approach speed, Runway 29, cleared to land, wind calm” | | | | | | | | | | Error induction: the 2 aircraft would be in conflict as they approach the intersecting runways (this communication should alert AC2 of the potential conflict |
| 8 | | | | | | | | “CAASD | | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 59, Roger , reducing speed to 135 knots, cleared to land on runway 29" | | | | |
| 9 | A few seconds after the previous communication: Callup from AC3 / CAASD 42 | | | | | | | | | "Louisville Tower, CAASD 42, ready for taxi abeam gate A12, requesting runway 35R" | | |
| 10 | ATC responds to call from AC3 / CAASD 42 | " CAASD 42, taxi to Runway 35R via Hotel, November, Foxtrot, and Delta, hold short of Runway 29" | | | | | | | | | | Secondary error induction: AC3 provides an incorrect readback, but this readback is unrelated to this scenario but intended to attract the pilot's attention |
| 11 | | | | | | | | | | "CAASD 42, roger, taxi to runway 35R via Hotel, November, Foxtrot and Delta | | |
| 12 | | | | | | | | | | | Louisville Tower, CAASD 22 Heavy, 12 out for Runway 35R" | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | | "CAASD 22 Heavy, Louisville Tower roger, 7 miles behind a 757, Runway 35R, cleared to land, wind calm" | | | | | | | | | | |
| 14 | | | | | | | | | | | "CAASD 22 Heavy is cleared to land Runway 35R, copied the traffic" | |
| 15 | | | | | | | | | | | Tower, UPS Tug 5, request towing a 767 from UPS Ramp 4 to UPS Ramp 9" | |
| 16 | | "UPS Tug 5 roger, tow via taxiways Delta, Foxtrot and Charlie to Ramp 9" | | | | | | | | | | |
| 17 | | | | | | | | | | | "Delta, Foxtrot and Charlie to Ramp 9, UPS Tug 5" | |
| 18 | Participant (AC2 / CAASD 49) approaches runway | | | | alert | alert | "AC2 / CAASD 49, runway unsafe" | | | | | |
| 19 | 7 seconds after AMASS | | | | "AC2 / CAASD 49, traffic ahead on runway 29" | | | | | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *20* | AC1 / CAASD 59 lands | CAASD 59, exit runway at M and taxi to the ramp | | | | | | | | | | |
| 21 | | | | | | | | “CAASD 59, Roger, via M to the ramp” | | | | |
| 22 | AC2 / CAASD 49 lands | CAASD 49, exit runway at D4 and taxi to the ramp | | | | | | | | | | |
| *23* | | | | | | | | | “CAASD 49, via D4, cleared to the ramp” | | | |
| *24* | *End of scenario* | | | | | | | | | | | |

Scenario Script 11: Taxi **– Departure**
Departure on **WRONG** runway

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Experimenter instructs pilot that he is lined up twy B toward 17R and calls ATC to issue clearance* | "CAASD 49, fly runway heading, maintain 3000, runway 17R, cleared for take-off" (pilot is actually on 35R. If the error is caught acknowledge the mistake and clear on 35R) | | | | | | | | | | |
| *2* | *There is no other communication with the controller* | | | | | | | | "CAASD 49 cleared for takeoff on 17R" | | | |

Scenario Script 12: Taxi - **Arrival**

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Experimenter instructs pilot that he is lined up on rwy 35 R and requires to fly visual approach* | "CAASD 49, Louisville tower, cleared to land 35R, wind calm" | | | | | | | | | | |
| *2* | | | | | | | | | "CAASD 49, cleared for visual to 35R" | | | |
| *3* | | "CAASD 49, clear to land runway 35R" | | | | | | | | | | |
| *4* | *There is no other communication with the controller* | | | | | | | | "CAASD 49, cleared to land 35R" | | | |

Scenario Script 13: Non-conflict scenario, warm-up scenario for condition 1; Repositioning

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Participant (AC1 / CAASD 49) calls up ATC that he/she is ready for taxiing* | | | | | | | "CAASD 49, ready for taxi clearance, at UPS ramp 3, need to reposition to gate A 14" | | | | |
| *2* | | "CAASD 49, taxi to gate A 14 via Charley and Juliet" | | | | | | | | | | |
| *3* | | | | | | | | "Roger, CAASD 49, taxi via Charley, Juliet" | | | | |
| 4 | | | | | | | | | "Louisville tower, CAASD 59, 5 miles out for Runway 17R" | | | |
| 5 | | "CAASD 59, Louisville Tower, Roger, cleared to land Runway 17R, wind calm" | | | | | | | | | | |
| 6 | | | | | | | | | Roger, cleared to land on 17R, CAASD 59" | | | |
| 7 | | | | | | | | | | "UPS 214, pushed off UPS ramp 2, ready for taxi, request departure on | | UPS 214 is never created in the simulation. |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | runway 17L” | | |
| 8 | NOTE: UPS 214 is not created on the ground display, but proceed as if the aircraft is ready per instruction 12. | “UPS 214, Louisville Tower, roger, taxi to runway 17L via taxiway Delta, foxtrot, altimeter 2-9-9-2” | | | | | | | | | | |
| 9 | | | | | | | | | | “UPS214, Roger, via Delta to Runway 17L, altimeter, 2-9-9-2” | | |
| 10 | After CAASD 59 has landed | “CAASD 59, turn left at B4, taxi to the ramp” | | | | | | | | | | |
| 11 | | | | | | | | | “Roger, “CAASD 59, exit at B4 to the ramp” | | | |
| 12 | After participant crossed rwy 29 | “UPS 214, rwy 29, cleared for take-off” | | | | | | | | | | |
| 13 | | | | | | | | | | “Roger, cleared for take-off, UPS 214” | | |
| 14 | UPS 214 takes off | | | | | | | | | | | |
| 15 | *Scenario ends as participant reaches the ramp* | | | | | | | | | | | |

Scenario Script 14: Non-conflict scenario, warm-up scenario for condition 2, shows REL's and THL's; Departure on 35L

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Participant (AC1 / CAASD 49) calls up ATC that he/she is ready for taxiing* | | | | | | | "CAASD 49, ready for taxi clearance, at UPS ramp 5" | | | | |
| *2* | *ATC responds to participant* | "CAASD 49 Louisville Tower, taxi to rwy 35L via Bravo" | | | | | | | | | | |
| *3* | | | | | | | | "Roger, CAASD 49, taxi via Bravo" | | | | |
| 4 | After participant starts taxiing | | | | | | | | "Louisville tower, CAASD 34, 6 miles out for Runway 35L" | | | |
| 5 | | "CAASD 34, Louisville Tower, Roger, cleared to land Runway 35L, wind calm" | | | | | | | | | | |
| 6 | | | | | | | | | Roger, cleared to land on 35L, CAASD 34" | | | |
| 7 | | | | | | | | | | | "CAASD 23, pushed off gate UPS 4, ready for taxi | |
| 8 | | "CAASD 23, Louisville Tower, | | | | | | | | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | taxi to runway 35R via Delta" | | | | | | | | | | |
| 9 | | | | | | | | | | | "CAASD 23, Roger, via Delta to Runway 35R, altimeter, 2-9-9-2" | |
| 10 | | | | | | | | | | | | Participant holds short at 35L while AC2 / CAASD 34 lands |
| 11 | AC 2 / CAASD 34 has landed | "CAASD 49, rwy 35L, taxi into position and hold" | | | | | | "Roger, 35L, position and hold, CAASD 49" | | | | |
| 12 | As AC2 / CAASD 34 has rolls out | | | | | | | | "Louisville Tower, CAASD 34, request to exit runway at intersection rwy 11" | | | |
| 13 | | "CAASD 34, that's approved, turn right on runway 11, taxi to the ramp via Charlie" | | | | | | | | | | |
| 14 | | | | | | | | | "Roger, turning right onto runway 11, via Charlie to the ramp, CAASD 34" | | | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | As CAASD 34 has exited the runway | "CAASD 49, fly runway heading, climb, maintain 3000, runway 35L, cleared for take-off" | | | | | | | | | | |
| 16 | *After participant has initiated the take-off, scenario ends* | | | | | | | | | | | |

**Scenario Script 15**: Non-conflict scenario, warm-up scenario for condition 3, shows no technologies; Arrival on 35L

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Participant (AC1 / CAASD 49) flies an approach to rwy 35L, is about 5 miles out* | | | | | | | "Louisville Tower, this is CAASD 49, lined up for 35L, about 8 miles out. Will need to go to hangar 1" | | | | |
| *2* | | "CAASD 49, Louisville Tower , cleared to land 35L, wind calm, foxtrot approved" | | | | | | | | | | |
| *3* | | | | | | | | Roger, cleared to land on 35L, CAASD 49" | | | | |
| 4 | | | | | | | | | "Louisville Tower, this is CAASD 13, ready to taxi at gate E2" | | | |
| 5 | | "CAASD 13, Louisville Tower, taxi to runway 35L via Juliet and Bravo" | | | | | | | | | | |
| 6 | | | | | | | | | "Roger, 35L, taxi via Juliet and Bravo" | | | |
| 7 | | | | | | | | | | | "Louisville, UPS34, 5 miles out for runway 35R" | |

| No. | Trigger | ATC | REL | THL | AMASS | AOL | AMASS Direct | AC 1 | AC 2 | AC3 | Other AC | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | | "UPS 34, Louisville Tower, rwy 35R cleared to land, wind calm" | | | | | | | | | | |
| 9 | | | | | | | | | | | "Roger, cleared to land on 35R" | |
| 10 | | | | | | | | | | | " Louisville Tower, CAASD 13, number 1 for take-off, 35L" | |
| 11 | After AC1 / CAASD 49 (participant) lands | "CAASD 13, 35L, position and hold" | | | | | | | | | | |
| 12 | | | | | | | | | | | "Roger, position and hold, CAASD13" | |
| 13 | Immediately after | "CAASD 49, turn left at F, taxi to maintenance ramp" | | | | | | | | | | |
| 14 | After pilot exits runway, scenario ends | | | | | | | | | | | |

**Appendix B**

# Scenario Run Order

| Run<br>Participant | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 14 - III | 4 - III | 1 - III | 5 - III | 6 - III | 13 - I | 11 - I | 8 - I | 9 - I | 2 - I | 15 - II | 10 - II | 12 - II | 7 - II | 3 - II |
| 2 | 14 - II | 5 - II | 2 - II | 6 - II | 7 - II | 13 - I | 12 - I | 9 - I | 10 - I | 3 - I | 15 - III | 11 - III | 1 - III | 8 - III | 4 - III |
| 3 | 14 - II | 6 - II | 3 - II | 7 - II | 8 - II | 13 - I | 1 - I | 10 - I | 11 - I | 4 - I | 15 - III | 12 - III | 2 - III | 9 - III | 5 - III |
| 4 | 14 - III | 7 - III | 4 - III | 8 - III | 9 - III | 13 - I | 2 - I | 11 - I | 12 - I | 5 - I | 15 - II | 1 - II | 3 - II | 10 - II | 6 - II |
| 5 | 14 - III | 8 - III | 5 - III | 9 - III | 10 - III | 15 - II | 3 - II | 12 - II | 1 - II | 6 - II | 13 - I | 2 - I | 4 - I | 11 - I | 7 - I |
| 6 | 14 - II | 9 - II | 6 - II | 10 - II | 11 - II | 15 - III | 4 - III | 1 - III | 2 - III | 7 - III | 13 - I | 3 - I | 5 - I | 12 - I | 8 - I |
| 7 | 13 - I | 10 - I | 7 - I | 11 - I | 12 - I | 15 - III | 5 - III | 2 - III | 3 - III | 8 - III | 14 - II | 4 - II | 6 - II | 1 - II | 9 - II |
| 8 | 14 - II | 11 - II | 8 - II | 12 - II | 1 - II | 13 - I | 6 - I | 3 - I | 4 - I | 9 - I | 15 - III | 5 - III | 7 - III | 2 - III | 10 - III |
| 9 | 13 - I | 12 - I | 9 - I | 1 - I | 2 - I | 14 - II | 7 - II | 4 - II | 5 - II | 10 - II | 15 - III | 6 - III | 8 - III | 3 - III | 11 - III |
| 10 | 13 - I | 1 - I | 10 - I | 2 - I | 3 - I | 14 - II | 8 - II | 5 - II | 6 - II | 11 - II | 15 - III | 7 - III | 9 - III | 4 - III | 12 - III |
| 11 | 13 - I | 2 - I | 11 - I | 3 - I | 4 - I | 14 - II | 9 - II | 6 - II | 7 - II | 12 - II | 15 - III | 8 - III | 10 - III | 5 - III | 1 - III |
| 12 | 14 - II | 3 - II | 12 - II | 4 - II | 5 - II | 15 - III | 10 - III | 7 - III | 8 - III | 1 - III | 13 - I | 9 - I | 11 - I | 6 - I | 2 - I |
| 13 | 13 - I | 8 - I | 7 - I | 11 - I | 6 - I | 15 - III | 9 - III | 2 - III | 10 - III | 3 - III | 14 - II | 5 - II | 12 - II | 1 - II | 4 - II |
| 14 | 13 - I | 9 - I | 8 - I | 12 - I | 7 - I | 14 - II | 10 - II | 3 - II | 11 - II | 4 - II | 15 - III | 6 - III | 1 - III | 2 - III | 5 - III |
| 15 | 13 - I | 10 - I | 9 - I | 1 - I | 8 - I | 14 - II | 11 - II | 4 - II | 12 - II | 5 - II | 15 - III | 7 - III | 2 - III | 3 - III | 6 - III |
| 16 | 14 - III | 11 - III | 10 - III | 2 - III | 9 - III | 15 - II | 12 - II | 5 - II | 1 - II | 6 - II | 13 - I | 8 - I | 3 - I | 4 - I | 7 - I |
| 17 | 14 - III | 12 - III | 11 - III | 3 - III | 10 - III | 13 - I | 1 - I | 6 - I | 2 - I | 7 - I | 15 - II | 9 - II | 4 - II | 5 - II | 8 - II |
| 18 | 13 - I | 1 - I | 12 - I | 4 - I | 11 - I | 15 - III | 2 - III | 7 - III | 3 - III | 8 - III | 14 - II | 10 - II | 5 - II | 6 - II | 9 - II |
| 19 | 14 - III | 2 - III | 1 - III | 5 - III | 12 - III | 13 - I | 3 - I | 8 - I | 4 - I | 9 - I | 15 - II | 11 - II | 6 - II | 7 - II | 10 - II |
| 20 | 14 - III | 3 - III | 2 - III | 6 - III | 1 - III | 13 - I | 4 - I | 9 - I | 5 - I | 10 - I | 15 - II | 12 - II | 7 - II | 8 - II | 11 - II |
| 21 | 14 - III | 4 - III | 3 - III | 7 - III | 2 - III | 13 - I | 5 - I | 10 - I | 6 - I | 11 - I | 15 - II | 1 - II | 8 - II | 9 - II | 12 - II |
| 22 | 14 - II | 5 - II | 4 - II | 8 - II | 3 - II | 13 - I | 6 - I | 11 - I | 7 - I | 12 - I | 15 - III | 2 - III | 9 - III | 10 - III | 1 - III |
| 23 | 13 - I | 6 - I | 5 - I | 9 - I | 4 - I | 14 - II | 7 - II | 12 - II | 8 - II | 1 - II | 15 - III | 3 - III | 10 - III | 11 - III | 2 - III |
| 24 | 13 - I | 7 - I | 6 - I | 10 - I | 5 - I | 15 - III | 8 - III | 1 - III | 9 - III | 2 - III | 14 - II | 4 - II | 11 - II | 12 - II | 3 - II |
| 25 | 13 - I | 11 - I | 7 - I | 2 - I | 12 - I | 15 - III | 5 - III | 4 - III | 9 - III | 3 - III | 14 - II | 10 - II | 6 - II | 1 - II | 8 - II |

| Run<br>Participant | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 14 - III | 12 - III | 8 - III | 3 - III | 1 - III | 15 - II | 6 - II | 5 - II | 10 - II | 4 - II | 13 - I | 11 - I | 7 - I | 2 - I | 9 - I |
| 27 | 14 - III | 1 - III | 9 - III | 4 - III | 2 - III | 15 - II | 7 - II | 6 - II | 11 - II | 5 - II | 13 - I | 12 - I | 8 - I | 3 - I | 10 - I |
| 28 | 14 - II | 2 - II | 10 - II | 5 - II | 3 - II | 15 - III | 8 - III | 7 - III | 12 - III | 6 - III | 13 - I | 1 - I | 9 - I | 4 - I | 11 - I |
| 29 | 14 - III | 3 - III | 11 - III | 6 - III | 4 - III | 15 - II | 9 - II | 8 - II | 1 - II | 7 - II | 13 - I | 2 - I | 10 - I | 5 - I | 12 - I |
| 30 | 13 - I | 4 - I | 12 - I | 7 - I | 5 - I | 15 - III | 10 - III | 9 - III | 2 - III | 8 - III | 14 - II | 3 - II | 11 - II | 6 - II | 1 - II |
| 31 | 14 - II | 5 - II | 1 - II | 8 - II | 6 - II | 13 - I | 11 - I | 10 - I | 3 - I | 9 - I | 15 - III | 4 - III | 12 - III | 7 - III | 2 - III |
| 32 | 14 - III | 6 - III | 2 - III | 9 - III | 7 - III | 15 - II | 12 - II | 11 - II | 4 - II | 10 - II | 13 - I | 5 - I | 1 - I | 8 - I | 3 - I |
| 33 | 14 - II | 7 - II | 3 - II | 10 - II | 8 - II | 15 - III | 1 - III | 12 - III | 5 - III | 11 - III | 13 - I | 6 - I | 2 - I | 9 - I | 4 - I |
| 34 | 14 - II | 8 - II | 4 - II | 11 - II | 9 - II | 13 - I | 2 - I | 1 - I | 6 - I | 12 - I | 15 - III | 7 - III | 3 - III | 10 - III | 5 - III |
| 35 | 14 - III | 9 - III | 5 - III | 12 - III | 10 - III | 15 - I | 3 - I | 2 - I | 7 - I | 1 - I | 14 - II | 8 - II | 4 - II | 11 - II | 6 - II |
| 36 | 14 - II | 10 - II | 6 - II | 1 - II | 11 - II | 15 - III | 4 - III | 3 - III | 8 - III | 2 - III | 13 - I | 9 - I | 5 - I | 12 - I | 7 - I |

**Note:** Arab numerals indicate scenario numbers; Roman numerals indicate the simulation conditions.

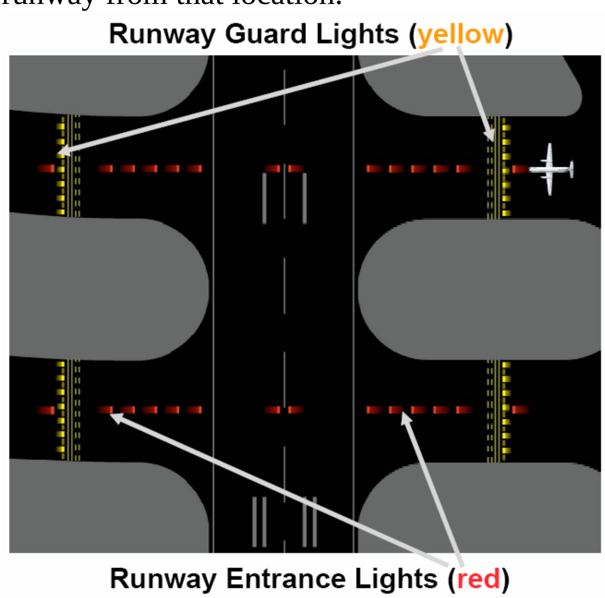
Appendix C

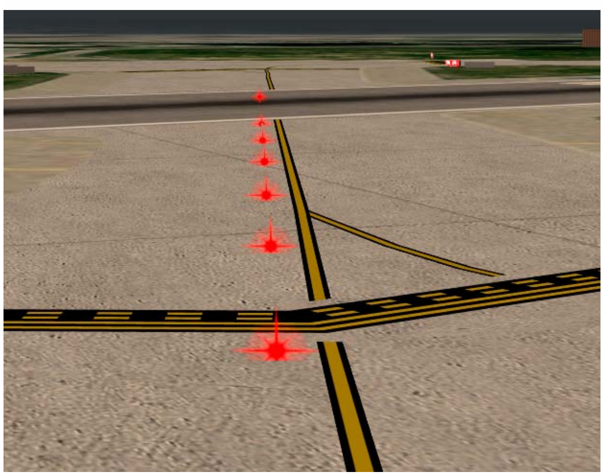
# Training

This section contains the training material for the pilot warning technologies that participants received during the briefing session.

**Runway Entrance Lights (RELs)**

RELs are a series of in-pavement red lights spaced evenly along the taxiway centerline from the taxiway hold line to the runway edge. The first REL is located just prior to the hold-short line in line with in-pavement runway guard lights. The last REL is near the runway centerline (see figure 1). RELs are directed toward the taxiway hold line and are oriented to be visible only to pilots and vehicle operators who cross / enter the runway from that location.



**Runway Entrance Lights from Cockpit**

The REL system is designed to provide a direct status indicator to pilots that a runway is unsafe to cross / enter. The system is fully automatic, surveillance-driven, and is not actuated by the air traffic control tower (ATCT). However, ATCT sets the brightness levels and activates and deactivates the system.

**Arrivals**

All RELs are simultaneously illuminated when an aircraft is on final approach. RELs progressively turn off at the lighted taxiways just prior to the landing aircraft passing the taxiway. All RELs turn off as the landing aircraft reaches taxi speed.

**Departures**

All RELs illuminate when a departing aircraft accelerates beyond 20 kts. All RELs are turned off when the departing aircraft transitions to airborne status.

**CAUTION**

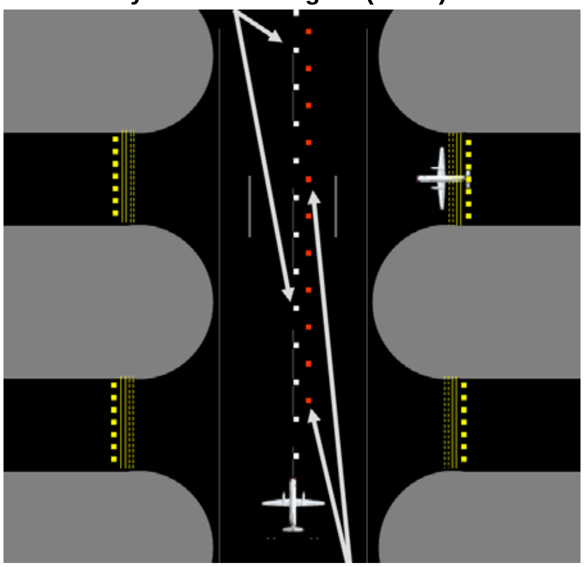
The turning off or absence of an illuminated REL does not constitute a clearance to cross / enter the runway. RELs indicate runway status only.

- When the RELs illuminate, the pilot should remain clear of the runway.
- When cleared to either "takeoff, cross the runway, position and hold, or immediate takeoff", and RELs are illuminated:
  stop the aircraft and indicate to Air Traffic that the pilot has stopped with red lights and then wait for further clearance.
- If the aircraft crosses the hold line and the pilot subsequently observes illuminated RELs, then if practical the pilot should stop the airplane and notify Air Traffic that they are stopped across the hold line because of red lights.
- If 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 RELs indicates the runway is unsafe to cross or enter) and contact ATC at the earliest opportunity

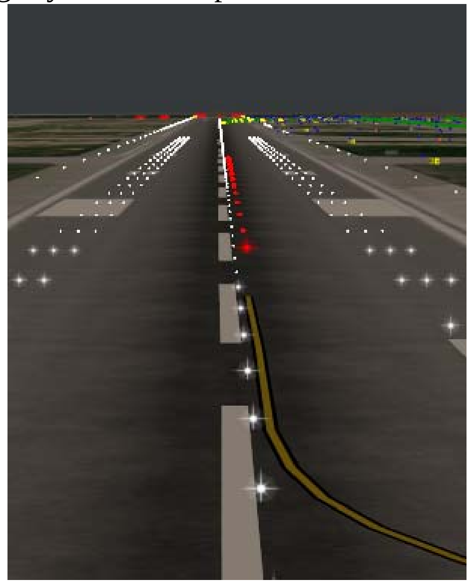
**Take-off Hold Lights (THLs)**

THLs are a series of 11 in-pavement red lights spaced evenly along the runway centerline for about 1000 feet. The first THL is about 875 feet from the runway threshold. THLs are directed toward the departure threshold and are visible only to pilots on the runway in departure position or during an initial take-off roll.

**Runway Centerline Lights (white)**



**Take-off Hold Lights (red)**



**Take-off Hold Lights from Cockpit**

The THL system is designed to provide a direct alert to pilots who are in position for takeoff or starting its takeoff at this location that the runway is not safe for takeoff at this location. The illuminated red lights indicate that another aircraft or vehicle could come in conflict if the pilot continues the departure.

The system is fully automatic, surveillance-driven, and is not actuated by the air traffic control tower (ATCT). However, ATCT sets the brightness levels and activates and deactivates the system.

**CAUTION**

The turning off or absence of illuminated THLs does not constitute a clearance to depart on the runway. THLs indicate runway status only.

When the THLs illuminate, the pilot is advised not to initiate a takeoff maneuver

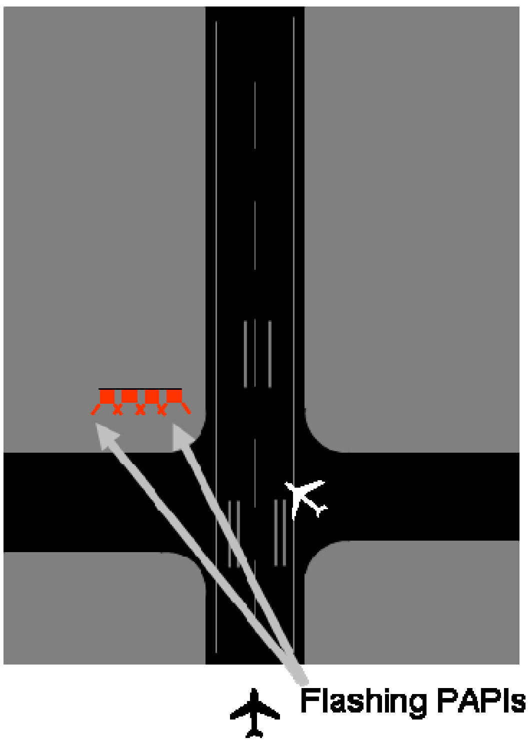
When cleared for takeoff and the THLs are illuminated, stop the aircraft and indicate to

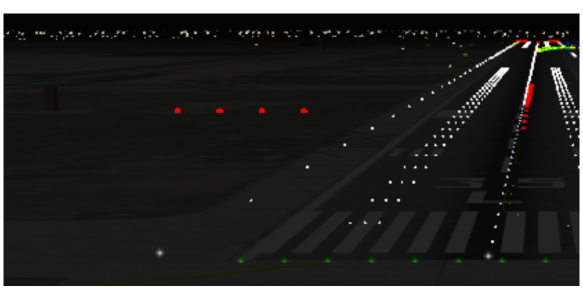
Air Traffic that the pilot is stopped with red lights on the runway and wait for further clearance.

If the THLs illuminate after the pilot has initiated a takeoff maneuver, the pilot should immediately decide if the take-off can be aborted safely. The pilot should subsequently inform Air Traffic that the take-off was stopped because of the red lights on the runway.

**Arrival Occupancy Lights (AOL)**

For purposes of this study, AOLs consist of flashing Precision Approach Path Indicator Lights (PAPI). PAPIs will indicate to arrivals their vertical glide slope angle; Flashing PAPIs will also indicate an arriving aircraft that an aircraft or vehicle is on the runway and that it is unsafe to land. The pilot should initiate a go-around and contact air traffic control that he/she is initiating a going around because of the flashing PAPI's.



**Arrival Occupancy Lights from the Cockpit**

The AOL system is designed to provide a direct alert to pilots who are intending to land on a runway that it is not safe to land on this runway. The flashing lights indicate that another aircraft or vehicle could come in conflict if the pilot continues the landing.

The flashing is fully automatic, surveillance-driven, and is not actuated by the air traffic control tower (ATCT). However, ATCT sets the brightness levels and activates and deactivates the AOL system.

**CAUTION**

When the PAPIs are flashing, the pilot should not land on the runway and should initiate a go-around. Pilots should immediately contact air traffic control that a go-around is initiated because the PAPI's are flashing.

Non-flashing PAPIs do not indicate a landing clearance.

## Surface Collision Warning System (SCWS)

The surface collision warning system (SCWS) presents an auditory warning directly to the cockpit about a potential collision risk. In addition, air traffic control receives a warning about the situation as well.

Pilots are alerted by a message that consists of two parts. First, the callsign of the aircraft is given. Second, a warning about the unsafe runway is given. The message is played three times.

**Example:**

> "CAASD 49, Warning: Runway Unsafe"

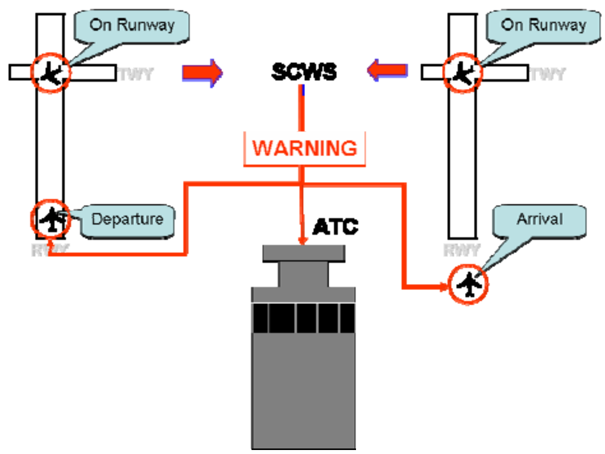
**Important:**

When pilots receive the incursion warning message, pilots should immediately initiate appropriate action and inform Air Traffic Control about their action. The message content is independent of the situation and needs to be interpreted by the pilot.

Air Traffic Control will have received the alerting information at the same time as the pilot.

**How it works**

Potential collision risks are determined by the Airport Movement Area Safety System (AMASS) a ground based surface surveillance system with alerting logic. Alerts are communicated to the cockpit via sideband frequency of the ground marker beacon. The auditory alert is played on the Enhanced Ground Proximity Warning System (EGPWS). Only the alerted aircraft and ATC receives the warning.




**Controller Alert**

**Pilot Alert: "CAASD49, Warning, Runway Unsafe"**

**Enhanced Airport Surface Markings**

The enhanced airport surface markings are intended to increase the visibility of the hold-short environment and therefore assist pilots in better detection of the markings location. In addition the enhanced markings are aimed at providing a degree of expectation to the pilots that they are approaching a runway holding position marking.

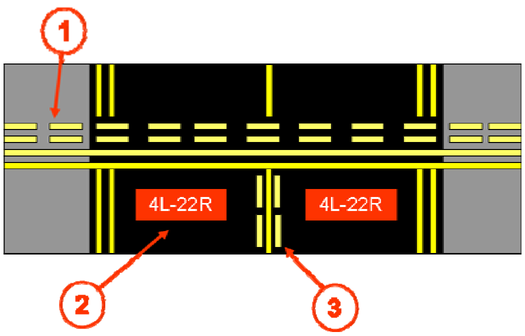



**Figure 2. Enhanced Surface Markings**

**1) RUNWAY HOLDING POSITION MARKINGS ON TAXIWAYS:** Markings extended onto the shoulder beyond the taxiway edge lines. This should help pilots to better position themselves with respect to the holding position marking (i.e., they can continue to see the position markings out the cockpit sides).

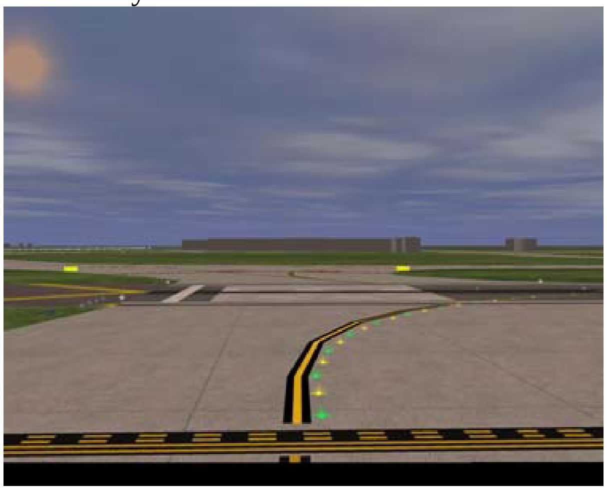
**2) SURFACE PAINTED HOLDING POSITION SIGNS:** Placed on both sides of the taxiway centerline (if sufficient space is available). This should help to increase the conspicuity of the runway holding position marking and provide visible cues to surface operators who, due to eye height, may have difficulty seeing the surface painted sign to the left of the centerline.

**3) MODIFIED TAXIWAY CENTERLINE:** Dashed yellow lines are placed on both sides of taxiway centerline. The modified taxiway centerline will be implemented approximately 150 ft. prior to the runway holding position marking (if sufficient space is available). This should help provide increased awareness that pilots are approaching a runway holding position marking.


**Enhanced Surface Markings seen from the cockpit**

## Yellow-Green Lead-on Lights

Yellow green lead-on lights are intended to increase the visibility of the hold-short environment and support the perception of the runway environment.

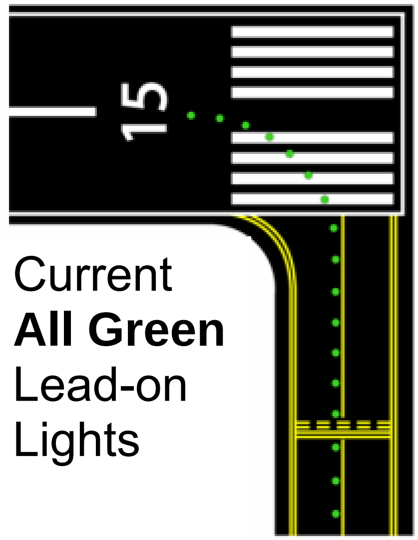


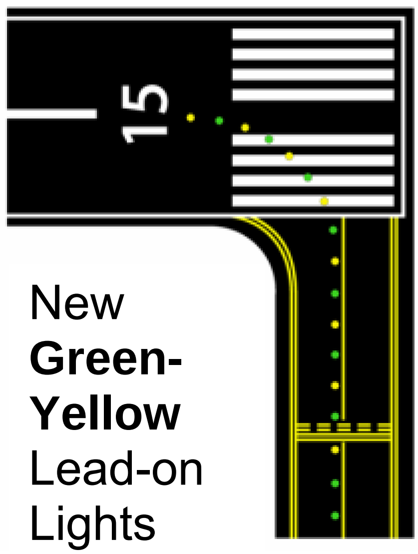
**Yellow-Green Lead-on Lights**

Whereas under the current lighting standard, the color pattern of taxiway centerline lead-on lights is all green, the pattern for lead-off lights is alternating green and yellow. Under the proposed modification, the color pattern for both lead-on and lead-off lights would be alternating green and yellow. Thus, alternating green and yellow centerline lights always indicate the runway environment.

**CAUTION**

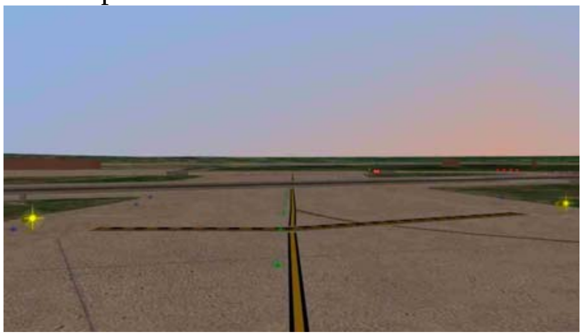
Lead-on lights are either on or off, independent of other traffic and do indicate any kind of clearance or runway occupation. They are intended only to provide guidance on to the runway in an area beyond the holding position marking.



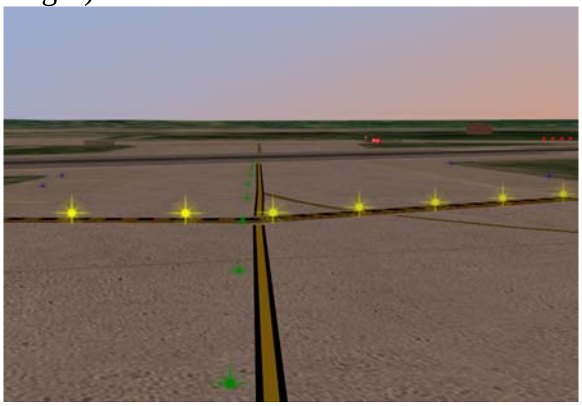



**Runway Guard Lights**

Runway guard-lights are intended to increase the visibility of the hold-short environment and support the perception of the runway environment.
Runway guard-lights consist either of elevated or in-pavement lights that are flashing at a rate of approximately 30 flashes per minute.



Elevated runway guard-lights ("wig-wags")



In pavement Runway Guard-lights

**CAUTION**
Runway guard-lights are either on or off, independent of other traffic and do indicate any kind of clearance or runway occupation.

They are intended only to identify the holding position.

**Appendix D**

# Experimental Material

This section contains the experimental data collection material that participants completed during the briefing, simulation, and after the simulation session. This section consists of the following materials: Background questionnaire, post-run survey, experimenter survey, controller survey, post simulation survey, and the training assessment survey.

# Pilot Background Questionnaire

Please complete the following background questionnaire. Your identity will be kept completely confidential and will not be included in any of the reports or documents that will be produced as a result of this study.

Employer: ______________________________________________________
Participant Code:___________ Date:_________________

1. Age:__________ Years Sex: ____ Male ____ Female

2. Approximately how long have you been a pilot?

___________ Years __________ Months

3. Estimated total flight hours logged: ____________
Estimated hours logged the past 90 days: __________

4. Type of flying you do most often: (check all that apply)
______Local area, pleasure only ______ Personal & business, cross country
______ Mostly business flying ______ Professional pilot or full-time CFI

5. FAA Pilot Certificate Held:
______Recreational ______Private ______Commercial ______ATP
_____CFI

6. Ratings Held: (check all that apply)
_____Instrument _____Multiengine _____Glider _____Rotorcraft
Other:_________

7. Type of Aircraft Usually Currently Flown:
_____Light Single _____Complex Single _____Light Twin
_____Turboprop _____Jet

8. How many hours have you logged in multi-engine aircraft?_______________

9. What type of airports are you comfortable operating at? (check all that apply)
_____Very small, non-towered airports _____Small Towered Airports (Class D)
_____Medium-size airports (Class C) _____Large Airports (Class B)

10. Approximately what percentage of your current operations are at towered airports: ____________ %

11. Do you have a current medical certificate? _______ Yes _______ No

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

# Post-Run Survey

Please indicate your agreement to following statements on a scale from strongly agree to strongly disagree by placing a checkmark into the appropriate box. If you find you cannot answer a question or a question does not apply, please mark the last column. After completing the first page, **please go on to the following pages**.

## A. Scenario Safety Survey

### A.1. About your experience in each scenario:

| **Indicate your agreement to the statements below.** | | Strongly disagree | Some-what disagree | Neither disagree nor agree | Some-what agree | Strongly agree | Not applicable/ Did not use |
|---|---|---|---|---|---|---|---|
| 1. | I had sufficient awareness about other aircraft on the airport. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2. | As approaching the runway environment I was appropriately aware of the runway. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3. | I had all the information I needed to prevent a runway conflict. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4. | Runway safety was sufficient in this scenario. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 5. | Another pilot with less experience than myself could have easily had a runway conflict. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 6. | If there was a conflict in this scenario, it was easy to avoid. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 7. | Nobody would have had a runway conflict in this scenario. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

___________________________________________
___________________________________________
___________________________________________
___________________________________________
___________________________________________
___________________________________________
___________________________________________
___________________________________________
___________________________________________

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

**Participant Code:__________ Date ___/___/___ Scenario ________**

**A.2. About the Simulation Scenario:**

| | **Indicate your agreement to the statements below.** | Strongly disagree | Some-what disagree | Neither disagree nor agree | Some-what agree | Strongly agree | Not applicable/ Did not use |
|---|---|---|---|---|---|---|---|
| 1. | The traffic situation that this scenario approximated was realistic. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2. | The radio communication was realistic. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3. | The weather and visibility conditions were realistic. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

## B. Additional Scenario Safety Survey

| **Indicate your agreement to the statements below.** | | Strongly disagree | Some-what disagree | Neither disagree nor agree | Some-what agree | Strongly agree | Not applicable/ Did not use |
|---|---|---|---|---|---|---|---|
| 1. | The **enhanced markings** increased my awareness about the runway. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2. | The **runway guard-lights** increased my awareness about the runway. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3. | The **yellow-green lead-on lights** increased my awareness about the runway. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4. | The **combination** of yellow-green **taxiway lead-on lights** and **runway guard-lights** was useful. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 5. | (If applicable): The **runway entrance lights** (**REL**) increased my awareness about other traffic. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 6. | The **RELs** increased runway safety. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 7. | (If applicable): The combination of yellow-green taxiway lead-on lights and **RELs** was appropriate. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 8. | (If applicable): The take-off hold-lights (**THLs**) increased my awareness of other traffic. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 9. | (If applicable): The **THL**s increased runway safety. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 10. | (If applicable): The **auditory warning** about a potential conflict helped to avoid the conflict. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 11. | (If applicable): The timing of the **auditory warning** about the potential conflict was optimal. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 12. | (If applicable): The Arrival | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Participant Code:__________** **Date ___/___/___** **Scenario ___ ____**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Occupancy Lights (**AOLs** or flashing PAPIs) increased my awareness of other traffic. | | | | | | |
| 13. | (If applicable): The **AOLs** increased runway safety. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

**Participant Code:__________** **Date ___/___/___** **Scenario ___ ____**

# C.1. Participant Workload Rating Instructions

After each scenario, please indicate your workload using the response alternatives on the next page. You will be asked to indicate your workload after each scenario. Please read the definitions for workload below before proceeding to the next page.

**Workload SCALE DEFINITIONS**

MENTAL DEMAND (*Low/High*
How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

PHYSICAL DEMAND (*Low/High)*
How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

TEMPORAL DEMAND (*Low/High)*
How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

EFFORT (*Low/High)*
How hard did you have to work (mentally and physically) to accomplish your level of performance?

PERFORMANCE (*good/poor)*
How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

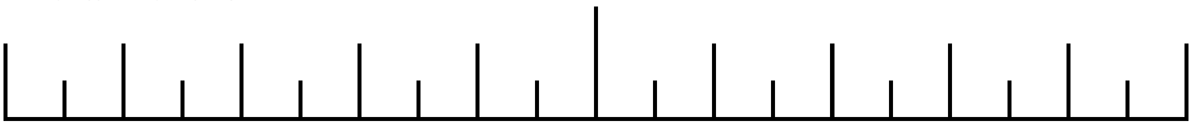
FRUSTRATION LEVEL (*Low/High)*
How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

**Participant Code:__________ Date ___/___/___ Scenario ________**

## C.2. Participant Workload Rating Form

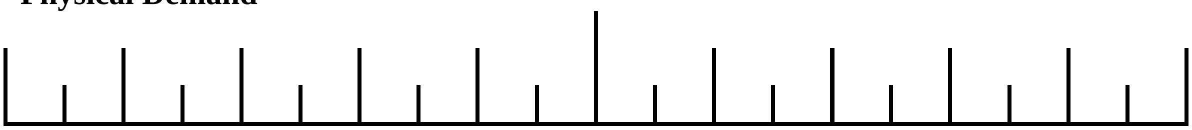
Please rate the workload that you experienced during this scenario on each of these 6 scales by marking the appropriate position with an X.

**Mental Demand**



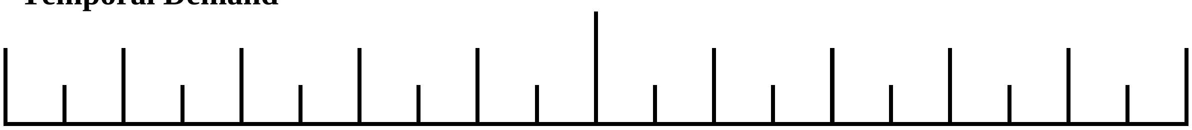
Low Demand High Demand

**Physical Demand**



Low Demand High Demand

**Temporal Demand**



Low Demand High Demand

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

**Effort**

Low Effort High Effort

**Performance**

Low Performance High Performance

**Frustration**

Low Frustration High Frustration

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

## D.1. Situation Awareness Rating Instructions

After each scenario, you will be asked to answer questions about the scenario. These questions are of subjective nature and ask for your individual perceptions during the scenario. There is no right or wrong answer to give, only your best estimate of your personal experience from your point of view. Do not spend too much time on any one item. Your initial 'gut feeling' is likely to be the most accurate estimation.

The following are the definitions of each of the 6 rating items. Please read through these until you are sure you understand their meanings. Refer to these descriptions as you do the ratings on the next page.

**1. Complexity of the Scenario**
How complicated was this scenario and the instructions? Was it complex (high), or simple and straight forward (low)?

**2. Demand on Cognitive Resources**
How demanding was the taxiing concerning your cognitive resources? Were there difficult decisions required and did the situation demand constant attention and maximum efforts (high) or was it easy and minimally demanding (low)?

**3. Supply of Cognitive Resources**
How great a supply of cognitive and attentional resources did you have during the scenario? Could you bring a very large capacity to bear on the task (high), or did you have limited resources (low)?

**4. Understanding of the Situation**
How well did you feel you understood the visual and acoustic environment, the instructions, the potential conflicts? In retrospect, did you usually have a good understanding for most of the time (high), or did you have many unknowns and was uncertainty a major part of the time (low)?

**5. Information Quality**
How good was the information you obtained from various sources (controller, radio, signs, out-of-the window) during this scenario? Was the knowledge communicated via all sources very accurate and precise (high), or was it noisy with high levels of uncertainty (low)?

**6. Situation Awareness**
Rate your overall situation awareness. The term overall situation awareness refers to what is commonly known as the pilot's "staying ahead of the aircraft " where the pilot has a thorough understanding of the current situation and can take appropriate action as necessary and can anticipate future events and decisions well in advance (high), or has very limited ability to anticipate future events and has an incomplete understanding of the situation (low)?

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

**Participant Code:__________** **Date ___/___/___** **Scenario ___ _____**

## D.2. Post-Run Situation Awareness Assessment

Where applicable, please circle the most accurate response.

**1. Complexity of the Scenario**

1 2 3 4 5 6 7
Low Complexity High Complexity

**2. Demand on Cognitive Resources**

1 2 3 4 5 6 7
Low Demand High Demand

**3. Supply of Cognitive Resources**

1 2 3 4 5 6 7
Low Supply High Supply

**4. Understanding of the Situation**

1 2 3 4 5 6 7
Low Understanding High Understanding

**5. Information Quality**

1 2 3 4 5 6 7
Low Quality High Quality

**6. Situation Awareness**

1 2 3 4 5 6 7
Low Awareness High Awareness

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

# Experimenter Post Run Form

The term ***overall situation awareness*** refers here to what is commonly known as the pilot's "staying ahead of the aircraft " where the pilot has a thorough understanding of the current situation and can take appropriate action as necessary.

1. From your position as observer, please indicate your best estimate about the subject pilot's level of OVERALL SITUATIONAL AWARENESS, while operating his/her aircraft, during this run.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very Low Awareness | | | Average Awareness | | | Very High Awareness |

2. From your position as observer, rate your subjective estimate about the pilot's OVERALL WORKLOAD during the run. When rating the workload, consider the pilots activity level, speed of implementing actions, amount and quality of radio communication.

| 7 | 6 | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|
| Very High | | | Average | | | Very Low |

Did the subject pilot commit an error during the run?

YES NO

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

Was this error set up in the scenario?

YES NO

**Description:**

3. Comment on **any other issues** that were observed during this run that could help understand the events as they occurred.

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

# Controller Post-Run Form

The term ***overall situation awareness*** refers here to what is commonly known as the pilot's "staying ahead of the aircraft" where the pilot has a thorough understanding of the current situation and can take appropriate action as necessary.

1. From your position as controller, please indicate your best estimate about the subject pilot's level of OVERALL SITUATIONAL AWARENESS, while operating his/her aircraft, during this run.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very Low Awareness | | | Average Awareness | | | Very High Awareness |

2. From your position as controller, rate your subjective estimate about the pilot's OVERALL WORKLOAD during the run. When rating the workload, consider the pilots activity level, speed of implementing actions, amount and quality of radio communication.

| 7 | 6 | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|
| Very High | | | Average | | | Very Low |

Did the subject pilot commit an error during the run?

YES NO

**Participant Code:__________ Date ___/___/___ Scenario ________**

Was this error based on the scenario script?

YES NO

**Description:**

3. Comment on **any other issues** that were observed during this run that could help understand the events as they occurred.

# Post-Simulation Survey

## A. Technology Evaluation

**A. 1. Based on your experience in this simulator, please evaluate the airport technologies by how well they support runway safety.**

**Participant Code:__________** **Date ___/___/___** **Scenario ___ _____**

| **Indicate your agreement to the statements below.** | | Strongly disagree | Some-what disagree | Neither disagree nor agree | Some-what agree | Strongly agree | Not applicable/ Did not use |
|---|---|---|---|---|---|---|---|
| 1. | The **enhanced markings** increased my awareness about the runway. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2. | The **runway guard-lights** increased my awareness about the runway. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3. | The **yellow-green taxiway lead-on lights** increased my awareness about the runway. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4. | The **combination** of yellow-green **taxiway lead-on lights** and **runway guard-lights** was useful. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 5. | The **runway entrance lights** (**REL**) increased my awareness about other traffic. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 6. | The **RELs** increased runway safety. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 7. | The combination of yellow-green taxiway lead-on lights and **RELs** was appropriate. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 8. | The take-off hold-lights (**THLs**) increased my awareness of other traffic. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 9. | The **THL**s increased runway safety<br>. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 10. | The **controllers warning** about a potential conflict helped to avoid conflicts. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 11. | The timing of the **controllers warning** about potential conflicts was optimal. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 12. | The **auditory warning** about | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Participant Code:__________ Date ___/___/___ Scenario ________**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | potential conflicts helped to avoid the conflict. | | | | | | |
| 13. | The timing of the **auditory warnings** about potential conflicts were optimal. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 14. | The Arrival Occupancy Lights (**AOLs** or flashing PAPIs) increased my awareness of other traffic. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 15. | (If applicable): The **AOLs** increased runway safety. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Please provide your comments on the following pages:**

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

**A.2. Enhanced Markings, comments:**

**A.2. Runway Guardlights, comments:**

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

**A. 2. Green-Yellow Lead-on Lights, comments:**

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

**A. 2. Runway Entrance Lights, comments:**

**Participant Code:__________**　　　　**Date ___/___/___**　　　　**Scenario ________**

**A. 2. Take-off Hold Lights, comments:**

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

**A. 2. Arrival Occupancy Lights (flashing PAPIs), comments:**

**Participant Code:__________ Date ___/___/___ Scenario ___ ____**

**A. 2. Direct Auditory Alerting, comments:**

**Participant Code:__________ Date ___/___/___ Scenario ___ _____**

**A. 3. Based on your experience in this simulator, please rank each airport technologies by how well it supports runway safety. Rank the technology that you perceive as providing the largest safety improvement as 1 and the technology with the least safety improvement with 8. Write the number beside each technology.**

____ Enhanced surface markings

____ Taxiway centerline Lead-on lighting

____ Runway guardlights

____ Runway Entrance Lights

____ Take-off Hold Lights

{ ____ Arrival Occupancy Lights }

____ Auditory Alert through the Controller

____ Automated Auditory Alert

**Comments:**

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**Participant Code:__________**  **Date ___/___/___**  **Scenario ________**

**A.4. Previous Experience with Technologies**

Have you seen any of these technologies on airports (circle one):

YES NO

If yes, please indicate which technology you have seen and where:

**Comments:**

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

## B. Simulation Evaluation

| **Indicate your agreement to the statements below** | | Strongly disagree | Some-what disagree | Neither disagree nor agree | Some-what agree | Strongly agree | Not applicable/ Did not use |
|---|---|---|---|---|---|---|---|
| 1. | The flight characteristics of the simulator did not interfere with my ability to operate the aircraft. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2. | The simulation scenarios were realistic for the assessment of airport safety technologies. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3. | The visual depiction of the lighting was accurate for the assessment of airport safety technologies. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4. | The visual depiction of the traffic was realistic for the assessment of airport safety technologies. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 5. | The content of the radio communication was realistic for the assessment of airport safety technologies. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 6. | Overall, the simulation was realistic. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Comments:**

______________________________________________________________

______________________________________________________________

Participant Code:__________ Date ___/___/___ Scenario ________

# C. Evaluation of the Training Procedure

## C.1. Evaluation of Training Effectiveness of the Printed Training Material

Evaluate the effectiveness of the printed information material as training material for the simulation (training phase 1). You received that training material during the initial briefing.

| **Indicate your agreement to the statements below** | | Strongly disagree | Somewhat disagree | Neither disagree nor agree | Some-what agree | Strongly agree | Not applicable/ Did not use |
|---|---|---|---|---|---|---|---|
| 1. | The printed technology information prepared me well for using the technologies. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2. | After reading the printed technology information I had questions that were not answered by that information. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3. | The printed technology material is similar to what I use as pilot. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4. | The experimenter answered my questions about the technology sufficiently. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Comments:**

______________________________________________________________

______________________________________________________________

______________________________________________________________

Participant Code:__________ Date ___/___/___ Scenario ___ _____

## C.2. Evaluation of Training Effectiveness of the Demonstration Scenario

Evaluate the effectiveness of the demonstration scenario as training material for the simulation (training phase 2). You have seen the training video during the simulation briefing.

| | **Indicate your agreement to the statements below** | Strongly disagree | Some-what disagree | Neither disagree nor agree | Some-what agree | Strongly agree | Not applicable/ Did not use |
|---|---|---|---|---|---|---|---|
| 1. | The viewed scenario provided sufficient information for me to use the technologies. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2. | After viewing the scenario I had questions that were not answered. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3. | The viewed scenario was similar to how I would experience the technologies as pilot. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4. | The experimenter answered my questions about the technology sufficiently. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Comments:**

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**Participant Code:__________ Date ___/___/___ Scenario ___ _____**

## C.3. Evaluation of Training Effectiveness of NOTAM text

Evaluate the effectiveness of the NOTAM in preparation of the simulation (training phase 2). You have read the NOTAM prior to the block of simulation trials with the warning technologies.

| | **Indicate your agreement to the statements below** | Strongly disagree | Some-what disagree | Neither disagree nor agree | Some-what agree | Strongly agree | Not applicable/ Did not use |
|---|---|---|---|---|---|---|---|
| 1. | The NOTAM information prepared me well for using the technologies. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2. | After reading the NOTAM I had specific questions that were not answered by that information. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3. | The NOTAM is similar to what I use as pilot. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4. | The experimenter answered my questions about the technology sufficiently. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Comments:**

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

**Participant Code:__________** **Date ___/___/___** **Scenario ___ _____**

## C.4. Overall training

Evaluate the effectiveness of the overall training

| **Indicate your agreement to the statements below** | | Strongly disagree | Some-what disagree | Neither disagree nor agree | Some-what agree | Strongly agree | Not applicable/ Did not use |
|---|---|---|---|---|---|---|---|
| 1. | Overall the training was sufficient for a pilot to use the technologies. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2. | More or better training is needed to familiarize pilots with the technologies so that they can use them to increase runway safety. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Beyond this simulation, how should pilots we optimally prepared for new surface technologies?

**Comments:**

_______________________________________________
_______________________________________________
_______________________________________________
_______________________________________________
_______________________________________________
_______________________________________________
_______________________________________________

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

## Post-Simulation Interview Form

1. Please comment on your experiences while operating the aircraft. Specifically, in what concerns was the simulation realistic and where was it not realistic?

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

2. Please comment on your experiences communicating with the controller. Specifically, in what concerns it realistic and where was it not realistic?

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

3. Please comment on your experiences with radio communication. Specifically, in what concerns was it realistic and where was it not realistic?

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

4. Please comment on your experience with the **modified lead-on lights**: Specifically, please consider any effects on your perception/detection of the runway environment.

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

5. Please comment on your experience with the **runway guard lights**: Specifically, please consider any effects on your perception/detection of the runway environment.

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

6. Please comment on your experience with the **enhanced markings**: Specifically, please report any effect on your awareness of the runway environment.

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

7. Please comment on your experience with the **runway entrance lights**: Specifically, please consider effects on your awareness of the departure situation.

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

8. Please comment on your perceived effectiveness of the integration of the various lighting systems in the hold-short environment, i.e. runway guardlights, taxiway centerline lighting, runway entrance lights.

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

9. Please comment on your experience with the **take-off hold lights**: Specifically, please report any effects on your awareness of the takeoff situation.

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

10. Please comment on your experience with the **arrival runway status lights**: Specifically, please report any effects on your awareness of the arrival situation.

**Participant Code:__________** **Date ___/___/___** **Scenario ___ _____**

11. Please comment on your experience with the **direct conflict alerts**: Specifically, please report any effects on your awareness of the situation.

**Participant Code:__________** **Date ___/___/___** **Scenario ___ _____**

12. Please comment on your experience with the **conflict alerts from the controller**: Specifically, please report any effects on your awareness of the situation.

**Participant Code:__________** **Date ___/___/___** **Scenario ________**

13. Please comment on your experience with the **direct conflict alerts**: Specifically, please report any effects on your awareness of the situation.

Appendix E

# Participant Comments

All comments are literally transcribed.

**Runway Entrance Lights**
Participants provided 40 comments about runway entrance lights.
**POSITIVE-32**
The runway entrance lights were valuable aids that prevented me from following the other aircraft across an active runway.
They illuminated in a timely manner and were clearly visible
RELs increased runway safety
RELs increased awareness about traffic
Marked improvement in awareness.
I have always thought that the existing WIG-WAG lights were too small (not visual enough). These RELs are very visible.
Very helpful in adding awareness of a potentially unsafe runway (due to departures or arrival of other aircraft)
Adds to situational awareness
These red lights worked very well. Implement this system soonest!
Liked. Very good automated tool that can make me aware when a controller cannot (or I'm busy).
Another good visual aid to display a fouled runway.
Helps by clearing up whether aircraft are approaching rwy. (for arrivals)
These RELs are very visible.
These lights are good and should be correlated with the light-gun signal in terms of steady or flashing illumination.
These, I think, will be very important, especially in low visibility condition..
Very useful & can't miss
Very noticeable and anytime I see red, I stop and figure out why before continuing. (red)
Very useful. Easy to see and respond to.
Very useful for warning.
They serve as a backup to ATC controller instructions or at night or IMC conditions.
Good concept! Having red lights "pop up" leaves no doubt that the plane should not continue.
Best feature-like a traffic signal.
There was plenty of advanced warning by the REL's to stop and question the clearance.
This is a MAJOR step toward runway safety.
They clearly let the pilot know that it is unsafe to enter the runway.
Should be installed at all airports operating commercial traffic.
Effective and simple. Red means stop.
Very effective
The similarity in display as well as function of the REL, to the THL made it easy and intuitive to comply with their signal. So much so that I did not actively recognize one type of light system vs. the other, but was still able to quickly and accurately interpret the signal.
Absolutely great. It would be hard to have an incursion if installed.

This is a useful concept, "it saved the day".
These add a clear safety factor.

**NEGATIVE-5**

The combination of REL and modified lead-on lighting (yellow/green) provides too many lights. Green / yellow does not mean "runway"
The combination between green-yellow lights and red REL's is not optimal, too many lights on twy line.
Ok-more lights to go bumpy over.
They were coming on too late as warning about runway occupancy in the scenario.
Don't understand why they start so far down the runway.

**SUGGESTIONS-3**

I would rename them something like runway stop lights, not 'entrance lights'
When these came on when I was on an approach I first thought it was flashing PAPI for myself. Possibly try to shield these lights from airborne traffic.
They need to be bright enough and very obvious to the pilot in full sunlight (and with the sun directly in the windscreen).

**Take-Off Hold Lights**

Participants provided 37 comments about take-off hold lights.

**POSITIVE-22**

Easy to see runway THL lights-may be something more pilots need to get used too, especially on low visibility structures.
This is another MAJOR step in the right direction.
Similarly very effective.
It was very clear when the runway was not safe for take-off.
THL's increased safety
Extended taxi/hold line was easy to see
THL were easy to interpret and comply with.
Very easy to notice due to the fact at this point on the runway your are looking straight down the runway, as opposed to making a turn while crossing hold short line. Again, red = stop and figure out what is going on.
Nice for very long and/or crowding runways. Also for intersections runways, i.e. ORD
Seemed useful as long as they displayed at the appropriate time. If too late into the takeoff roll, this would distract pilot decision making ability.
Clearly a positive improvement. Agree that these can save lives
Effective and simple. Red means stop.
Easily seen and highly useful.
These are also very useful in an environment in which a lot is going on.
They give an easily identifiable warning.
Great backup for tower during low visibility

Very useful-hard to miss-red always gets attention & it's where you are looking.
Excellent feature that serves as another source of information to aide the pilot.
Good visual effect; identified potential incursion prior to pilot's awareness of potential conflict.
Provided crucial information as to continue or abort T.O.
Amazing bonus to situation awareness in low visibility or runways with a crown or slope that obscures far end of runway.
Probably most effective in low visibility situations!

**NEGATIVE-8**

Experience is required with THL's, don't understand why they start so far down the runway.
I'd rather see the white runway centerline lights extinguish and be replaced by the red takeoff hold lights. This would be along the same line of thought when a conventional runway centerline light is illuminated red for the last 1000' feet of a runway, ie. danger, stop now!
I blew through these in high intensity low visibility scenario. Maybe deep down I confused them with ILS Cat 2 runway lights (approach lights) which are the same as on the last 1000' of runway. Either way, I should have noted red looking at me. Point is it didn't register.
If they are just red, they don't stand out as much, at least flashing is required.
The THLs were hard to detect at times, especially in daylight scenarios. There is a significant risk factor associated with this technology, if a false alarm trigger a high-energy abort.
Good feature-marked improvement-but will slow down operations at busy airports.
Pilot action after hold lights extinguish (red to white) is difficult to under stand.
May result in too many aborted take offs when used at complex airports.
You need to know the aircraft characteristics to alert effectively; e.g. in a Cessna 172 you should not abort for a given scenario, because of the quick acceleration and low VR; also the a/c weight has to be known.

**SUGGESTIONS-7**

Consider a combination of red lights along the runway centerline and "crossing the T" by placing red lights across the end of the touch down zone lighting.
Worked great-would like to see more lights. If the THL's were longer, I would not know for how long I can abort. Any airport with crossing runway operations should have THL's.
Airport such as LGA & DCA would benefit from THL's.
Consider when these come on during a Take off. (T/O) If they come on late in T/O row and the pilot decides to abort after V1 speed, a safe abort may not be accomplished. I guess it depends on your prediction system.
Correlate the signal with light-gun signal as well.
Need to be very bright and obvious during daylight observation.
Need the string to be longer! Easy to miss if you are near VR

**Arrival Occupancy Lights**
Participants gave 49 comments about arrival occupancy lights.

**POSITIVE-21**
These are useful and I have seen them before.
This is a piece of confirming information.
Flashing PAPIs very effective improvements.
Good for intersections runways and/or low vis
Somewhat useful, less noticeable during daytime.
Good idea--particularly at tower airports and with low vis!
Excellent.
Great idea-Pilots always include PAPI in Scan-
Excellent simulation.
Agree that these could save lives in low visability situations.
In my opinion the most useful of the signals. A distant landing runway can be very difficult to determine the status of visually without this new AOL signal.
Again, very important, especially at night.
Like the system, with same reservations as before…although I'm more comfortable with it than before..meaning, not as concerned with the "not trusting" it.
Good idea.
Added info on visual approaches. I usually don't use the PAPI, but when the pilot learns to include it into the scan pattern, this is very useful.
Excellent.
A definite benefit and easy to see.
The flashing PAPI was also useful in aiding the decision making process. As long as the pilot is aware of this function, there should be no trouble in understanding the signal. (I am thinking from a GA perspective where some pilots who may have not had recent flying experience, misinterpreting these signals)
Very helpful during night operations.
Very effective in notifying pilot of impending conflict.
Often hard to see ACFT on RWY.
**NEGATIVE-18**
I missed them once (day VFR) and they caught something I didn't see once (dusk lo vis) so I'm mixed on these. PAPIS drop out of my scan as I cross the fence, so if they go off then, I might miss them.
Sometimes PAPIs are hard to notice during the day and when on short final.
Difficult to immediately recognize the flashing
Not sure if my students would notice or pay attention.
The PAPI's in the simulator seemed to frequently flicker between white to red.

The current flash rate was not high enough

Never saw 'em (sorry!) [The pilots was somewhat not used to using PAPI's because of his recent experience @ a local airport: experimenter comment].
Might miss the lights due to focus inside the cockpit
Using a single pilot scenario I frequently missed this because my focus was on cockpit instruments
The least useful and required some time to recognize and actualize go around info.
I found that by the time these began alerting I had already identified the threat and moved my attention to the runway and not the PAPI's. At the time of alerting, the pilot did not look on rwy anymore.
I had a hard time seeing these. Easier at night. I think the reason for this is that I only glance at the PAPI's and then look back to the runway and instruments. With one quick look, you can obtain the glideslope information a PAPI gives you.
Were of no help whatsoever. I suspect simulator fidelity along with the flash rate made them less conspicuous then they should have been.
GA: does not use glide-slope -3%...not use w/ PAPIs.
Were helpful but not as noticeable as other marking.
Honestly, I don't think these were very effective. Perhaps it was the simulations visibility but I did not pick up on them.
Perhaps in a lower visibility scenario they would be more effective. Conversely in high visibility scenarios they would probably be harder to pick out.
A bit distracting.

**SUGGESTIONS-10**
Perhaps a flashing of the approach lighting system in sequence would help.
Suggestion to also have the runway-end-identifier lights flash in addition to the PAPI's
At smaller fields you can usually see the entire field on approach. [faster flash might be more noticeable]
However, you may think about flashing THL's as well at the same time.
If they flashed more frequently it might be more visible
This is a good idea too but it needs some work. The timing of their use is critical. If turned on too soon it confuses the approaching A/C. If turned on too late, they are of little benefit.
PAPI's need to flash at a rapid rate to quickly alert the crew members.
These would be better at the beginning of the runway because that is where the pilots focuses when landing. If you break out at close to mins focus in on runway not PAPI lights.
Consider strobing these lights all red, instead of flashing the lights on & off at current glide slope indication. Pilot usually does a scan that includes the inside and outside of the cockpit.
Possible not to notice if on instrument-maybe flash all red below 200'? Instead of just flash whatever is showing.
Training is required for FPAPI's to be useful.

**Direct AMASS alerts**

Participants provided 59 comments about AMASS alerts that are provided directly into the cockpit.

**POSITIVE-34**

Great!

Should use whenever possible

These work the most effective.

Again, audio warning great!  But in this case red lights also a great alert.

All doubt is removed when you hear the warning.

The aural warnings work by far the most effective [than lights] in notifying of a conflict. There is no interrelation at all to be done.

Very useful if sounded early enough to execute a safe go-around.

Good.

Hard to miss in simulation with sterile cockpit should be heard in real line ops.

Very good as a backup (responded to other inputs before auditory warning came on)

I like the aural indication because the PAPI s are not always in the scan. Particularly in low visibility situations.

Auditory alert was loud enough.

Oral warning is great!  Can concentrate on flying the APCH & not worry about sensory overload.

The voice is pleasant compared to other warnings in cockpit.  Eg: GPWS, wind shear.

Voice warning very helpful at lower visibility (minimums, e.g.)

Auditory alert would come at same time as visual alert…if not looking at visual you get auditory warning. Also, an additional display should be added inside the cockpit to display alert.

Very helpful-men are accustomed to taking orders from females (especially if they're married!)

Very helpful.

Liked the female voice in that it stood out from the other communications.

Good system to backup the flight crew if communications with tower are lost.  They also serve to validate a pilot's actions to go around.

A good backup to visual indicators

Super-especially liked the use of my call sign;

The timing was sufficiently early.

Good, should be based on speed of the aircraft when triggers the alert.

Good addition and really helpful.  Visual cues always came first and were acted upon

The best of all since the audio input clashes against all visual cues.

Once use to the tones and identifying it, I believe it is effective.

Very good technology.

Helpful as back up to visual reference.

This was nice and I believe will give more time to react. In some situations it is difficult to make out a small plane or vehicle on the runway.
Most direct, least ambiguous of all signals, but does not make the decision for the pilot, the pilot must have received this signal with sufficient time to react appropriately. I felt in these scenarios that there was adequate time to make the correct decision.
This worked great during the experiment. Will it work great in real life too?
Was the best technology by far. Pilots in higher performance aircraft are more attuned to audio alerts from such devices as EGPWS & TCAS.

**NEGATIVE-18**

Technology observations: female voice not loud enough or strident enough for awareness.
Worked but felt it had potential to be less effective in high communication environments (was heard-but almost seemed like background chatter). The warning needs to be louder and distinguished from other traffic.
Auditory warning seemed to delay a few seconds after visual warning
Synthetic voice.
This was sporadic
The auditory alert did not come on early enough (once go around was initiated)
Perhaps one problem may be if warning is simulcast ACFT on other arrivals may be distracted, even perhaps go-around unnecessarily..might try this as a future scenario. Example: ACFT landing 35L & ACFT 35R gets auditory warning. Would ACFT 35L have enough SA to continue his approach or would he accidentally go around too!
Moderately Effective-prefer red lights and flashing PAPI-least important of proposed features.
Hard to hear in sim. Not obvious possibly due to not having heard it before it occurred during sim.
Because the warning was not loud enough, I had to think about what to do.
The warning did not come on early enough.
Only criticism I have is that the auditory alerts seem to be a little slow-perhaps if these warnings triggered a few seconds earlier, they would provided more useful information.
Helpful, but a little late. If it was sooner it would be more effective.
I don't fly in an environment with auditory alerting (at least not yet), so I did not find this particularly helpful. I imagine this might be helpful in a high workload, more distracting environment, as long as this does not result in sensory overload.
In my scenarios it was late. The threat had already been identified. Alerts come too late, if they came earlier, then they would be more beneficial, however, false alerts might be an issue.
In the scenarios I often saw what was happening prior to the actual alerting.
This system is just add to the chaos of a conflict situation. Unless a pilot has a specific, immediate response to an aural warning that has been incorporated into training and procedures-this system is useless.

I also thought that the timing was late.

**SUGGESTIONS-4**

Don't play the call sign, but only the message; Since I am the only one being alerted, I know that I am addressed.
Did not get much experience on this element. I only heard the warning once, after my-go around was underway.
The female's voice needs to be deafening & urgent.
The predictive algorithm (sic) used to start the auditory alert needs to take into account a 3 second delay for human psychological denial in a threatening situation. This warning must be accomplished sooner. While it may not be optimal, accounting for a 3 second psychological delay and an additional 3 seconds to change performance of the aircraft should be considered a part of the warning envelope.

**QUESTIONS-3**
Good in theory/on paper. Practical application??
Does the system have integrity? Logically if the AOL has integrity then this should as well.
However-how many "talking" devices do we need in planes? Seems like it could be just another thing to ignore.

**Runway Guardlights**
Participants provided 39 comments about runway guardlights.

**POSITIVE-33**
Yes, especially [useful] in low visibility.
These [lights] say that you are coming up on a runway crossing or hold line.
When arriving at these lights, pilot can stop and question
Best visual improvements was RHLs
Very effective.
Provided outstanding situational awareness (particularly since we had no TCAS or SMG's).
If we can only afford one technology at this time, this is the one!
Extremely useful visual indicator.
Definite Improvement
*Great* I like them
Very useful & noticeable!
Great idea-easy to understand
I like how these draw added focus to the runway entry points. It becomes very clear where the markings are.
Excellent! Much more vis. than hold short line.

These lights are particularly useful at night, in low visibility situations or in instances where pilots/flt crew are not familiar with the rwy environment.
Effective to taxing aircraft.
Very good
Very helpful in identifying runway environment & where to hold-short.
These were extremely useful especially in low visibility light conditions.
They serve as a useful additional warning sign not to cross the hold-short line.
They are useful under low visibility conditions
Like the rwy guard lights. They even (especially) help to identify the rwy environment at night & in low vis-that's great
Enhanced and re-enforced position on taxiways. More effective than current "wig-wag" lights by covering entire width of taxiway.
Good
Increased safety during low vis.
Effective in alerting pilot to approaching runway.
These are also very effective in identifying the runway environment.
They get your attention day or night.
Easily recognized the hold-line did not add anything to the lights;
I use these regularly and find them especially helpful in low visibility taxi situations.
Same as enhanced markings except harder to miss. They make you become alert if you were relaxed or not expecting them. (yellow)
These lights make the hold-short line readily identifiable.
Like these a lot since you can tell you are approaching an active runway much earlier than without them. Especially good in low visibility. (yellow)

**NEGATIVE-5**
These lights can be distracting from the air. For example KCLE.
A fatigued pilot could think he is cleared on the runway.
I find them distractive.
During the simulation, runway guard lights were not placed at every taxiway/runway intersection, so there is some doubt as to my current location on the taxiway (especially during low visibility) when I am expecting to see perhaps, one or two intersections pass by as I taxi to a specific intersection. Basically I was not sure if every taxiway/runway intersection was supposed to be identified by those lights or not.
They were visible on approach and were somewhat distracting given the number of taxiway/runway intersections.
**QUESTIONS-1**
Are RGL's visible under snow conditions?

**Enhanced Markings**
Pilots provided 47 comments about Enhanced Markings

**POSITIVE-30**

I have used these markings at Providence (PVD) and find they are a vast improvement over the current standard markings.

These help reduce the potential confusion associated w/dense taxiway environments.

I would believe that these will also reduce ground controller workload and increase pilot "self-navigating" capacity.

These features enhance the operational safety around runways & taxiways.

It was different there the real world but adapting was easy.

They are low cost and can be easily incorporated into existing airport facilities.

The red on-pavement markings are very useful.

The red rwy markings are especially useful.

The extended runway hold position markings onto the shoulder are effective.

Overall they were extremely helpful.

Definite improvement-striping & sinage.

All EASM are good.

These additions would enhance safety at both small & large airports.

Enhance markings helpful

Made hold short easier to recognize.

Love the new runway centerline stripe and runway indicators.

The enhanced markings provide a good daytime reference when matched with runway identification signs.

Generally, I am in favor of the enhanced markings, as they do increase my situational awareness.

I really like the enhanced markings as there is no question on what they mean and they are cost effective.

Added to safe operation in all aspects of the airport environment.

Extended holding position markings are a good idea as are the painted holding position signs.

The visual change (example dashed lines outside of taxi lines) is a good cue of change to come being the runway.

Mandatory instruction signage, (holding signs) painted on the surface of the taxiway allowed me to identify the correct runway, where I had been cleared onto a different runway during the simulation.

These are great.  Most importantly the surface painted holding position signs.

The modified centerline is useful, as attention is focused on the centerline.

[Effective] As are the hold position signs and modified taxi-centerline.

Love the new runway centerline stripe and runway indicators.

My favorite was the "modified taxiway centerline".

Where space is an issue, you may be able to get away with the runway entrance signs on both sides and not have the surface painted holding position signs.

Added to the situational awareness on the approach end.

Increased centerline markings were more visible in low-visibility conditions.

**NEGATIVE-10**

I am not smart, so if I'm overloaded, enhanced markings won't work.  Red lights, flashing lights-always gets my attention.

The extended hold-short markings seem less important.

Enhanced markings will help but they're not as effective as the warning lights.

It will take some time to get used to these markings.

The enhanced markings were nice, but I didn't think they contributed all that much to increased runway/ground ops safety.

During night hours these may be harder to see, especially with any surface contamination such as snow or even the glare from a wet runway.

The modified taxiway centerline may prove confusing.  I associate dashed lines with the runway side of a holding position.  This may also be significant when clearning or taxing across a runway.

Modified taxiway centerline was not noticeable.

The dashed lines on the taxiway center line were not very noticeable & did not really contribute to my awareness.

The red runway (surface painted holding position signs) number boxes painted on the ground were the most useful as opposed to the wider (modified taxiway centerline) taxiway center lines.

**SUGGESTIONS-5**

More lights on the runway causes passengers (on commercial flights) some stress from the bumps down the runway.  Some pilots will off-set the center-line as to not go bouncing down all the light bumps.  Not sure how many more lights would affect this.

16. Arrival scenario: Interesting scenario would be one where there is a conflict and the AOLs fail to alert => consequence of conditional/expectation/Also, partial deployment could be detrimental.

There is a question in my mind about the technology used to support this feature and the warning can be reliably directed at the intended recipient.  Also, the timing may be such that a longer call sign (e.g. a six digit n-number) would preclude a timely response.

These markings take it "to the next level", however, over time, pilots may adjust and block out the change.  The change becomes normal.

The runway holding position marking on T-way extended onto shoulder beyond the T-way edge lines helps the most of the three.

**QUESTIONS-2**

For departing A/C, what determines "airborne status" as shown in the handout?

Would this interfere with the issuance of an TIPH clearance after the preceding A/C has started its takeoff roll?

**Modified Lead-on Lights**
Participants provided 43 comments about modified lead-on lights.

**POSITIVE-18**
Yellow-green slightly more effective than current system.
Again very effective in providing close proximity to the runway. Very similar to SMGs low vis. System in use today.
A great low cost (I assume) alternative for smaller airports.

Adds to situational awareness.
Marginal Improvement-certainly need the enhanced markings with or without the lead-on lighting.
This is a good idea but not as important as the REL's & THL's
Really useful in low vis-
Lights did increase situational awareness
Like the added clarity as to where the proper ARC to the runway centerline will be.
This takes all the guess work out of positioning the aircraft.
These lights are valuable at night, low visibility scenarios, or where the flt crew is not familiar with the airport environment.
Extremely helpful in identifying runway environment.
Helps and prepares crew for entrance onto active runway-good transition from solid green/taxiway.
Increased both safety & situational awareness during low vis.
Very easy to follow
They increase alertness
Helpful, but not as good as some of the other systems.4
Easy and simple to follow

**NEGATIVE-24**
I'm negative about the coloring. I'm just using them to stay on centerline at night when raining.
I would think they are mostly useful to indicate specific lead off Taxiways. Come to think of it, the same is probably true for lead on taxiways-I found them moderately helpful only.
Color doesn't stand out as caution or danger (or "ask yourself: are you cleared here?) Sorry.
Yellow lights at the hold short lines aren't adding anything to my SA.
Probably the least noticeable and a less useful indicator of runway entry.
Green-yellow hard to distinguish over solid green lighting.
No-good. Hard to see different colors.
Tended not to notice these. Already lots of alternating/changing colors on an airport. For this test I really didn't notice them unless remembering to look

Not sure how effective these lights are. Logically they are understandable, but they don't stand out.
If the lighting is not at every taxiway, this could add confusion.
They are useful under low visibility conditions; green means "go", so I like the current lead-on lights more.
Didn't really do much for me.
If a rwy has all the proposed markings, & runway guard lights, then I don't think this is warranted (especially if equipped with REL's). That said, if this system was added to an airport surface that didn't have any of the other safety features, it would increase awareness/safety. But the rwy guard lights do almost as much, if not more good, by themselves.
Not needed or desired.
Adding more confusion past hold short line.
Although an effective means of providing taxi directions, I'm not convinced that the alternating yellow-green sequence enhances situational awareness.
I find these to have very little effect on safety.
It did not add anything.
These do not seem to be very useful. I think the combination of green lead on lights with runway guard lights is sufficient.
These were not a big improvement over "all green taxi" lights. With further experience and training they could be useful, but they did not impress me immediately.
I did not care for the yellow & green lead-on lights. I like the big, bold red blocks at the runway threshold. It has helped me at other airports.
I did not see any great advantage on the addition of yellow lights to the taxiway centerline. I understand that they indicate a portion of the centerline that crosses a hold short line, but when in combination w/the rwy guard lights it seems an unnecessary redundancy.
Only seemed useful in low-vis situations.
I believe they are not as beneficial as runway guard lights.
If a particular intersection lacks runway guard lights, then I can see the benefit of added yellow lights to the taxiway centerline.

**SUGGESTIONS-1**

Proper training will increase their effectiveness.

# Glossary

| | |
|---|---|
| **AMASS** | Airport Movement Area Safety System |
| **ANOVA** | Analysis of Variance |
| **AOL** | Arrival Occupancy Light |
| **ARTS** | Automated Radar Tracking System |
| **ASDE-3** | Airport Surface Detection Equipment-3 |
| **ATC** | Air Traffic Control |
| **ATCT** | Air Traffic Control Tower |
| **ATM** | Air Traffic Management |
| **ATO** | Air Traffic Organization |
| **ATP** | Air Line Transport |
| **EGPWS** | Enhanced Ground Proximity Warning System |
| **FAA** | Federal Aviation Administration |
| **FY** | Fiscal Year |
| **GA** | General Aviation |
| **MIT** | Massachusetts Institute of Technology |
| **NAS** | National Airspace System |
| **NASA** | National Aeronautics and Space Administration |
| **ND** | Navigation Display |
| **NOTAM** | Notice to Airmen |
| **NTSB** | National Transportation Safety Board |
| **OTW** | Out-The-Window |
| **PAPI** | Precision Approach Path Indicator |
| **PFD** | Primary Flight Display |
| **PRAS** | Passive Runway Awareness System |
| **REL** | Runway Entrance Light |
| **RGL** | Runway Guard Light |
| **RI** | Runway Incursion |
| **RVR** | Runway Visual Range |
| **RWSL** | Runway Status Light System |
| **SART** | Situation Awareness Rating Technique |
| **SCIP** | Surveillance Communications Interface Processor |
| **SDF** | Louisville Standiford Field |
| **TAIU** | Terminal Automation Interface Unit |
| **THL** | Take-off Hold Lights |
| **TIPH** | Taxi in Position and Hold |
| **TLX** | Task Load Index |

| | |
|---|---|
| **VASI** | Visual Approach Slope Indicator |
| **WAK** | Workload Assessment Keypad |