# EFFECTS OF A FINAL APPROACH RUNWAY OCCUPANCY SIGNAL (FAROS) ON PILOTS' FLIGHT PATH TRACKING, TRAFFIC DETECTION, AND AIR TRAFFIC CONTROL COMMUNICATIONS

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Eighteen pilot participants with varying experience levels flew 36 approaches in a medium fidelity cockpit simulator. Eighteen baseline trials were flown with a standard Precision Approach Path Indicator (PAPI) and 18 trials were flown with the proposed Flashing PAPI (FPAPI). The results showed a significant increase in lateral tracking error with the FPAPI as compared to the PAPI trials, but no increase in vertical tracking errors. There was also a trend toward an increase in the number of radio communications with the FPAPI. Pilots were able to determine runway occupancy status and land or go-around as required in both the baseline and FPAPI trials.

## Introduction

On February 1, 1991 at Los Angeles International Airport (LAX), USAir flight 1493 (USA1493), a Boeing 737, was landing on runway 24L when it collided with Skywest flight 5569 (SKW5569), a Fairchild Metroliner, which was positioned at an intersection awaiting clearance for takeoff on runway 24L. As a result of the collision, both airplanes were destroyed. All 10 passengers and 2 crewmembers aboard SKW5569 were killed, as were 20 passengers and 2 crewmembers aboard USA1493 NTSB (1991). As this and other recent accidents have shown runway incursions pose a significant safety risk.

At present, there is no automated capability in the National Airspace System (NAS) to directly warn airborne flight crews of runway occupancy status at either controlled or uncontrolled airports. The Final Approach Runway Occupancy Signal (FAROS) concept was designed to address the need to reduce the potentially serious consequences of runway incursions, specifically those involving an aircraft on approach while another aircraft or vehicle is on the same runway. The FAROS provides a visual indication of runway occupancy status directly to landing pilots through the Flashing Precision Approach Path Indicator (FPAPI) FAA (2004). The MITRE Center for Advanced Aviation System Development (CAASD) conducted a simulation to examine Human Factors issues related to the proposed FPAPI implementation of FAROS.

## Method

### Experimental Task

Pilots were required to fly several approaches using both a standard PAPI and the new FPAPI system. They used the two PAPI systems to maintain the proper glide path and used the visual depiction of the runway to align themselves laterally. To minimize training time, pilots flew with the autothrottle engaged and set to the proper final approach speed. Their task involved tracking inbound to the airport, completing a short checklist, flying a stable approach, communicating with ATC, and determining runway occupancy status. All approaches were flown to runway 18 Center (18C) at Memphis International Airport (MEM). There was a continuous wind field beginning at 3000 feet from 220 degrees at 20 knots and decreasing to 10 knots from 210 degrees at the airport surface. This wind field was used for all trials. The time of day simulated a dusk environment that was clear of clouds with some light haze.

### Experimental Design

Each pilot flew two trial types, baseline and experimental. The baseline trials were similar to today's environment with a steady PAPI and pilots were required to visually scan the runway to determine its occupancy status. The experimental trials included a FPAPI system, which provided pilots with a visual indication of the occupancy status of the runway. There were 18 baseline and 18 experimental trials for a total of 36 trials per pilot. The trials were blocked and pilots flew one block of 18 trials, took a short break, and then flew the other block of 18 trials.

Within each block of 18 trials, there were 16 trials with intruding traffic on the runway and two trials that did not include traffic. The no-traffic trials were included to provide pilots an opportunity to land without any traffic. These no-traffic trials were randomly presented within the block of 18 trials.

During each approach, the intruding aircraft entered runway 18C from one of two different locations. Half of the intruders entered the runway near the approach end at taxiway "Charlie 8" (C8) and the other half entered the runway midfield at intersection "Delta" (D). Half of the intruders entered the runway, positioned themselves for takeoff, and then remained in position until the end of the trial requiring the cockpit to execute a go-around in order to avoid a runway incursion. The other half of the intruders entered the runway, positioned for takeoff, remained in position for a few seconds, and then began the takeoff roll, thus clearing the runway in time for the cockpit to land. The intruders crossed the hold short line at two different points while the cockpit was approaching the runway. Half of the intruders crossed the hold short line when the cockpit was about 5 nautical miles (nm) from the threshold and the other half crossed the hold short line when the cockpit was about 2.5 nm from the threshold. Each of these three factors was completely balanced across the participants and randomly presented (without replacement) throughout the 16 approaches, which contained traffic, yielding a 2 (intruder type) x 2 (intruder location) x 2 (incursion timing) factorial within-subjects design of intruder type. Each of these eight intruder types was replicated, generating a total of 16 legs with intruders along with two non-traffic legs for each participant. Furthermore, the 18 trials were presented twice to each pilot, once as a baseline trial (no FPAPI system) and once as an experimental trial (with the FPAPI system). The order of presentation for the two trial types (baseline and experimental) was counterbalanced.

A single failure trial (miss) was presented to each pilot on the last trial within both the baseline and the experimental conditions. The miss trial was always presented as the last trial during each block in order to maximize the opportunity for pilots to develop trust in the system. This trial simulated a "lost" intruder that wandered onto the runway environment without being cleared by ATC. Thus there was no ATC communication with the "lost" intruder. Furthermore, the FPAPI system did not detect the intruder entering the runway, due to a surveillance failure accordingly, neither the FPAPI system nor ATC detected the intruder and a missed detection resulted. This yielded two trials per participant for a total of 36 failure trials.

Simulation Environment

The cockpit was an enclosed, fixed based, mid-fidelity transport aircraft simulator (see Figure 1). It was configured as a generic twin-engine, large weight category, jet aircraft. It had an autothrottle system, which was used throughout the evaluation to control speed. The simulation included audio capabilities supporting aircraft environmental sounds (e.g., slipstream noise) and ATC communication. A side-stick controller was used for aircraft control. The center pedestal housed 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 displayed the Primary Flight Display (PFD) instruments and navigation information. A nineteen-inch display occupied the center instrument panel and displayed engine and flap status information. These comprised the Electronic Flight Instrumentation System (EFIS) displays. Pilots used the Precision Approach Path Indicator (PAPI) and out-the-window (OTW) depiction of the runway in order to fly the approaches and navigate to the runway. The OTW visual scene driver gave pilots a 130-degree virtual representation of the outside world. For more detail on the MITRE CAASD Air Traffic Management (ATM) simulation facility see Oswald and Bone (2002).

Figure 1 MITRE Air Traffic Management Lab Cockpit Simulator

Participants

Eighteen pilots were recruited for the simulation. Nine were classified as General Aviation (GA) pilots and nine were classified as Airline Transport Pilots (ATP) based on their experience. The GA pilots all indicated that they primarily flew piston aircraft (total flight hours M = 2097, SD = 2729, and range 109-8900). The ATP pilots all indicated that they primarily flew turbine aircraft (total flight hours M = 8798, SD = 6954, and range 2300-23000). All pilots were current within the previous three months.

Procedure

Upon arrival, pilots read and signed the informed consent form, filled out a short demographics questionnaire, and were given the experimental instructions orally. They were told that the experiment involved runway status automation and that the first trials were for training and familiarization with the simulator. Following this brief description, pilots were given some oral instruction about flying the simulator then four practice approaches were flown. A fifth trial was then flown in which the FPAPI system was activated when the intruder entered the runway environment. This was the pilots' first exposure to the FPAPI system and was intended to capture a naïve response to the system and elicit discussion following the practice trials. Due to space constraints, the naïve trial and subjective questionnaire data will not be discussed here see Helleberg (2004) for details. Pilots were then given a brief written description of the FPAPI system relating to the function, system design, and pilot procedures. After the pilot read the FPAPI system description, the experimental and baseline trials followed in a counterbalanced order (i.e., half of the pilots flew the baseline trials first, the other half flew the experimental trials first) with a short break between blocks of trials.

Each trial began with the cockpit simulator aligned with the runway and on the glide slope with the autothrottle engaged and set to the final approach speed. The pilot was told to assume control of the aircraft and fly the approach using the simulator's side stick to track vertically and horizontally to the runway. Along the approach the pilot was required to complete a short checklist (gear down and extend final flaps) as well as determine the occupancy status of the runway prior to landing. A confederate ATC provided normal take off and landing clearances on the tower frequency and responded to any spontaneous requests from the participant pilot. The pilot was responsible for making all radio calls.

## Results

### Pilot Experience

Across the dependent variables, there were no significant performance differences or interactions with the independent variables between the GA pilots and airline pilot experience groups. Therefore, the data from the two groups were pooled for the following analyses.

### Decision Making Land/Go-Around

Each of the eighteen pilots flew 36 experimental trials, in which they were required to determine the occupancy status of the runway and make a decision as to whether it was safe to land or they should execute a go-around. This yielded a total of 648 trials available for analysis (see Figure 2). Each pilot was presented with four trials in which there was no intruding traffic and a clear runway. Across these 72 trials all pilots completed the approach and landed.

The remaining 576 trials included intruding traffic. On half of these trials the intruders remained on the runway thus requiring the pilot to execute a go-around to avoid a runway incursion. These trials will be referred to as "go-around" trials. On the other half of the trials the intruders departed the runway in time for the pilot to land without causing a runway incursion. These trials will be referred to as "landable" trials. During the landable trials the intruder would lift off of the runway when the pilot's aircraft was between three-quarter and one nm from the threshold. The number of go-arounds and landings, as well as the distance from threshold when the go-around call was made, were recorded and served as the dependent variables.

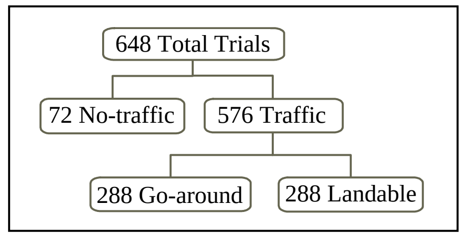


Figure 2 Experimental Trials Across All Pilots

*Go-Around Trials* Pilots initiated go-arounds on all 288 of the go-around trials. Therefore, regardless of whether the PAPI lights were flashing or not, none of the pilots landed on an occupied runway.

The distance from threshold when the go-around call was made was available on 269 of these trials (due to data collection errors, 19 of the trials did not have distance from threshold data). Across the 269 go-around trials, the FPAPI had no statistically significant effect on the distance from threshold when the go-around call was made ($t$ (267) = 1.54, $p$ ns). When the PAPI lights were steady ($n$ = 135), the pilots made the go-around radio call at a mean distance from the threshold of 0.75 nm. When the PAPI lights were flashing ($n$ = 134), the pilots made the go-around radio call at a mean distance from the threshold of 0.67 nm.

*Landable Trials* Pilots initiated go-arounds on 16 (6%) of the landable trials. Across these 16 trials, the FPAPI had no statistically significant effect on the number of go-around trials that occurred ($\chi^2$ (1, N = 15) =0.25, $p$ ns). Furthermore, the FPAPI had no statistically significant effect on the distance from threshold when the go-around call was made ($t$ (13) = -0.33, $p$ ns).

Across the 16 landable trials in which pilots elected to go-around, nine of those occurred when the PAPI lights were steady and seven occurred when the PAPI lights were flashing. Due to a data collection error, one of the FPAPI trials did not have distance from threshold data. Across the remaining 15 landable trials in which pilots elected to go-around, the mean distance from threshold when the pilots made the go-around radio call was 1.22 nm (n = 9) when the PAPI lights were steady and 1.39 nm (n = 6) when the PAPI lights were flashing.

Attention Allocation

During each approach, the pilots' were required to fly the aircraft and track their way to the runway surface using the PAPI for vertical guidance and the visual depiction of the runway for horizontal guidance. The pilots' ability to maintain the proper flight path was used as a measure of attention allocation.

*Flight path Tracking* The flight path tracking error calculation was conducted only on the portion of each trial that contained traffic. This was done to reduce any dilution of the errors during the portion at the beginning of each trial in which the lights were not flashing or, in the case of the steady PAPI trials, would not have been flashing. Root Mean Square (RMS) errors were calculated for both the lateral and vertical dimensions across the 576 traffic trials.

The FPAPI resulted in a statistically significant increase in lateral tracking errors ($F(1, 16) = 5.82$, $p < .03$). The lateral tracking errors increased from a mean of 60.0 feet during the steady PAPI trials to a mean of 66.8 feet during the FPAPI trials.

The FPAPI had no statistically significant effect on the pilots' vertical tracking performance ($F(1, 16) = 0.00$, p ns). The vertical tracking errors were similar between the steady PAPI trials (mean of 76.3 feet) and the FPAPI trials (mean of 76.1 feet). Figure 3 depicts the relationship between the state of the PAPI and flight path tracking performance.

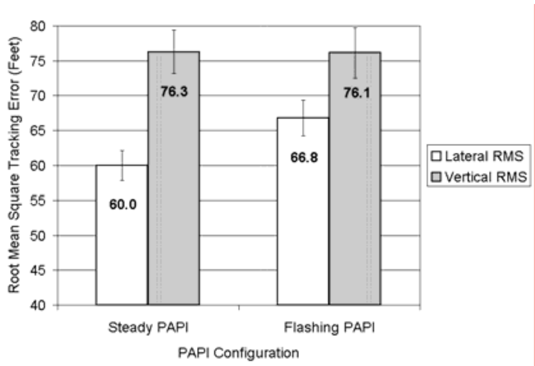


Figure 3 Pilot Flight Path Tracking Performance Across Flashing Conditions

ATC Communications

A confederate "air traffic controller" (ATC) was available to respond to pilot requests during the approaches. Whenever the pilot contacted ATC, the experimenter marked the data stream in order to derive the total number of calls as well as the distance from threshold when the call was made. The number of communications and distance from threshold results are described below. Eighteen pilots flew 36 trials each for a total of 648 trials available for analysis (see Figure 2). Each pilot was presented with four trials in which there was no intruding traffic and a clear runway. None of the pilots contacted ATC during the 72 trials that did not include intruding traffic.

The remaining 576 trials included intruding traffic. On the go-around trials pilots were required to make one radio call to report initiation of the go-around maneuver. On the landable trials, the pilot could complete the trial without contacting ATC. The number of trials in which pilots contacted ATC, as well as the distance from threshold when calls were made, were recorded as the dependent variables.

*Go-Around Trials* Pilots contacted ATC on all 288 of the go-around trials as well as the 16 additional landable trials in which pilots elected to go-around. This resulted in a total of 304 trials, which **required** one communication (i.e., notifying ATC of the go-around) for the following analysis.

Pilots completed 223 (73%) of the 304 go-around trials without making additional calls to ATC beyond the one required communication to ATC indicating that the pilot intended to execute a go-around. However, pilots made two or more communications on 81 (27%) of the 304 go-around trials. On eight (10%) of the 81 there were three communications. Across the 81 go-around trials with two or more communications, the FPAPI had no statistically significant effect on the number of trials in which pilots contacted ATC ($\chi^2(1, N = 80) = 0.01$, p ns).

The distance from threshold when the **initial** communication was made was available on 80 of these trials (due to data collection errors, one of the trials did not have distance from threshold data). Across the 80 go-around trials, the FPAPI had no statistically significant effect on the distance from threshold when the initial communication was made ($t(78) = -0.83$, p ns). When the PAPI lights were steady (n = 39), the pilots initially contacted ATC at a mean distance from the threshold of 1.56 nm. When the PAPI lights were flashing (n = 41), the pilots initially contacted ATC at a mean distance from the threshold of 1.46 nm.

*Landable Trials* There were a total of 288 landable trials and, on 272 (94%) of those trials, pilots completed the approach and landed. This resulted in 272 trials for the following analysis.

Pilots completed 223 (82%) of the 272 trials, in which pilots landed, without contacting ATC. However, pilots contacted ATC and made at least one communication on 49 (18%) of the 272 trials in which pilots landed. On three (6%) of the 49 trials there were two communications. Across the 49 trials, with at least one communication, the FPAPI had a marginally significant effect on the number of trials in which pilots contacted ATC ($\chi^2$ (1, N = 48) = 3.45, p = .06). With the FPAPI there were 31 trials in which pilots contacted ATC and with the steady PAPI there were only 18 trials.

The distance from threshold when the **initial** communication was made was available on 42 of these trials (due to data collection errors, seven of the trials did not have distance from threshold data). Across the 42 landable trials, the FPAPI had no statistically significant effect on the distance from threshold when the initial communication was made (t (40) = -0.78, p ns). When the PAPI lights were steady (n = 13), the pilots initially contacted ATC at a mean distance from the threshold of 1.68 nm. When the PAPI lights were flashing (n = 29), the pilots initially contacted ATC at a mean distance from the threshold of 1.87 nm.

Complacency

Each pilot was presented with two “miss” trials, in which an unannounced intruder entered the runway environment requiring the pilot to execute a go-around in order to avoid a runway incursion. This intruder was always presented on the final trial of each block in order to maximize the opportunity for pilots to develop trust in the system. During both the steady and FPAPI trials, ATC would not clear the “miss” intruder to depart ahead of the pilot’s aircraft (as had occurred during the previous 15 traffic trials). In addition during the FPAPI trials, the FPAPI system did **not** detect the intruder and the lights remained steady even though an intruder was located on the runway. The goal was to build the pilots’ **expectation** that the FPAPI system would provide accurate information (across the preceding 17 trials) and then **surprise** the pilots with a system failure. However, this yielded a limited number of trials for analysis and accordingly the following results should be considered preliminary.

*Go-Around Decision and Communications* All 18 pilots detected both of the unannounced intruders regardless of whether the preceding 17 trials had been with the steady or FPAPI. The distance from threshold when the go-around call was made was available on 34 of these trials (due to data collection errors, two of the trials did not have distance from threshold data). Across the 34 miss trials, the FPAPI **expectation** had no statistically significant effect on the distance from threshold when the go-around call was made (t (32) = 1.20, p ns). When the pilots **expected** the PAPI lights to remain steady (n = 17), they made the go-around radio call at a mean distance from the threshold of 0.73 nm. When the pilots **expected** the PAPI lights to flash (n = 17), they made the go-around radio call at a mean distance from the threshold of 0.52 nm.

*Additional Communications* If the pilot contacted the confederate ATC during the miss trial and inquired about the runway status, the controller indicated that he could not see anyone on the runway, thus requiring the pilot to make his or her own determination of whether or not the runway was occupied. This frequently resulted in multiple calls to ATC. On 13 (36%) of the 36 miss trials, pilots made a single call to advise ATC that they were initiating a go-around. However, pilots contacted ATC two or more times on the remaining 23 (64%) miss trials. On four (17%) of the 23, there were three communications. Across the 23 trials with two or more communications, the flashing PAPI **expectation** had no statistically significant effect on the number of trials in which pilots contacted ATC ($\chi^2$ (1, N = 22) = 0.39, p ns).

Furthermore, across the miss trials, which had multiple calls to ATC, the flashing PAPI **expectation** had no statistically significant effect on the distance from threshold when the **initial** call was made (t (21) = 0.81, p ns). When the pilots **expected** the PAPI lights to remain steady (n = 10), they made the initial call at a mean distance from the threshold of 1.56 nm. When the pilots **expected** the PAPI lights to flash (n = 13), they made the initial call at a mean distance from the threshold of 1.37 nm.

## Discussion

This simulation was designed to address a set of Human Factors issues related to the proposed FAROS using the FPAPI system. The primary purpose of the simulation was to examine the most critical issues that could not be safely tested during an Operational Evaluation (OpEval). A secondary purpose was to collect some preliminary data related to several operational issues. However, due to the nature of simulation, these operational issues cannot be completely resolved and the data reported here should be combined with operational testing data.

Pilot Experience
The pilots recruited for this simulation covered a wide range of experience levels. However, the results did not show any statistically significant differences in their performance during the simulation.

Land/Go-Around Decisions
None of the pilots landed on an occupied runway when the FPAPI was in use. However, none of the pilots landed on an occupied runway when the steady PAPI was in use either. This indicates that all 18 pilots visually verified the validity of the PAPI alert when it was flashing and also visually scanned the runway for traffic when the PAPI was steady.

There was no increase in go-arounds when pilots were flying with the FPAPI. Furthermore, there was no statistically significant difference in the distance from the threshold when pilots initiated their go-arounds due to the FPAPI. The data did not suggest that pilots were initiating go-arounds based on the FPAPI alone. Pilots tended to notice the lights flashing then shift their attention to scanning the runway for traffic as they neared the threshold. This suggests that pilots were using the status information provided by the FPAPI appropriately and FPAPI is unlikely to lead to an increase in unnecessary go-arounds.

Attention Allocation
The data revealed a statistically significant increase in lateral tracking errors associated with the FPAPI. However, there was not a corresponding increase in vertical tracking errors. One potential explanation for this result is that pilots may have focused their attention on the vertical tracking due to the attention capturing effect of the FPAPI. This may have led pilots to neglect their lateral tracking performance and concentrate on the vertical axis. However, the amount of lateral deviation was relatively small and may not be operationally significant, but should be considered when making the decision to move forward with an OpEval.

ATC Communications
The number of trials in which pilots contacted ATC and the distance from the threshold at the time of the call were used as objective measures of pilots' communications.

The data did not show any statistically significant increase in the number of trials, which contained communications due to the FPAPI. Also, the FPAPI had no statistically significant effect on the distance from the threshold when communications were initiated. However across the trials in which the intruder departed (landable), there was a trend suggesting that the FPAPI led to more trials with ATC communications. This suggests that a FPAPI could increase the number of ATC communications, however, it is possible that as pilots gain experience with FPAPI the number of ATC calls may decrease.

Complacency
All pilots detected both of the unannounced intruders regardless of whether the preceding trials had been with the steady or FPAPI. Furthermore, there was no statistically significant difference in the distance from threshold when the go-around call was made regardless of whether the preceding trials had the flashing or steady PAPI. Therefore, during the simulation the pilots did not show any evidence of complacency.

## Acknowledgements

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