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Testing and Evaluation Methods of the Runway Status Lights System

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This paper presents the test phases and methodology utilized to assess the suitability of the Runway Status Lights concept to operate in the National Airspace System. Testing was performed in three different phases to ensure that the system's basic metrics were met. These metrics measured system usability along with proper Runway Entrance Light activation and deactivation. This paper will present the different test methods utilized in each of the phases along with the corresponding data analysis performed.

I. Introduction

The National Transportation Safety Board has listed runway incursions as an important aviation safety concern with the need of providing a direct warning capability of runway status to the flight crew. The current definition of a runway incursion is any occurrence in the airport runway environment involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in a loss of required separation with an aircraft taking off, intending to take off, landing or intending to land. The Federal Aviation Administration (FAA) is evaluating the Runway Status Lights (RWSL) concept that provides a direct warning capability to flight crews on runway status. This in turn may reduce the severity of runway incursions and prevent runway accidents. The FAA William J. Hughes Technical Center has been a leading member of a team consisting of many FAA experts tasked to test and evaluate the operational suitability of this new concept.

The RWSL concept is designed to operate in all-weather conditions automatically to provide a direct indication of runway status to pilots and airfield vehicle operators, increasing their situational awareness. Any change to air traffic control operations has the potential to cause a negative effect on flight safety, thus the RWSL concept was designed to operate in a non-interfering manner with air traffic control's operations.

The RWSL concept consists of several elements that include Runway Entrance Lights (RELs), Takeoff Hold Lights (THLs), and Runway Intersection Lights (RILs). The RWSL system processor sends activation and deactivation commands to a Field Lighting System (FLS) that illuminates and extinguishes the appropriate light fixtures that make up the RELs, THLs, and RILs. RELs are in-pavement lighting fixtures that are situated at selected runway-taxiway intersections and face the taxiways that intersect runways. Illuminated RELs provide an indication to pilots and airfield vehicle operators that the runway is unsafe for entry or crossing. Takeoff Hold Lights (THLs) work in conjunction with the RELs and are situated at selected full-length and intersection takeoff-hold positions. THLs are also in-pavement fixtures, installed alongside the runway centerline, facing aircraft in the takeoff hold position. Illuminated THLs provide an indication to pilots and airfield vehicle operators that the runway is unsafe for departure. RILs work in the same way as RELs and are in-pavement light fixtures that are located at selected runway-runway intersections. RILs are illuminated when the runway is unsafe for entry or crossing from another runway that may include high-speed traffic. A pilot or vehicle operator who sees an REL, THL, or RIL turn off must still obtain verbal clearance from air traffic control before proceeding. The RWSL concept does not convey clearance, as do some lighting systems currently installed at select airports. The RWSL processor uses the airports' surveillance radars to assess the runway status and then automatically sends appropriate light commands to the FLS. The FLS computer then illuminates the RELs, THLs, and RILs.

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REL, THL and RIL deactivation is timed uniquely in order to operate in a non-interfering manner with air traffic's operations, specifically the use of anticipated separation between aircraft. This is done, for the case of RELs, by deactivating RELs prior to a high-speed aircraft crossing through an intersection but when it is safe for an aircraft or vehicle to start motion toward the runway. The THLs are deactivated just before the blocking or crossing traffic clears the runway, when it is safe for the departure to commence. RILs are currently set to activate and deactivate the same way as RELs.

Figure 1 illustrates an aircraft landing on runway 9 along with REL response. RELs are not activated at the first intersection showing the use of anticipated separation. RELs are activated at the second taxiway-runway intersection indicating to the awaiting aircraft that the runway is unsafe to enter.

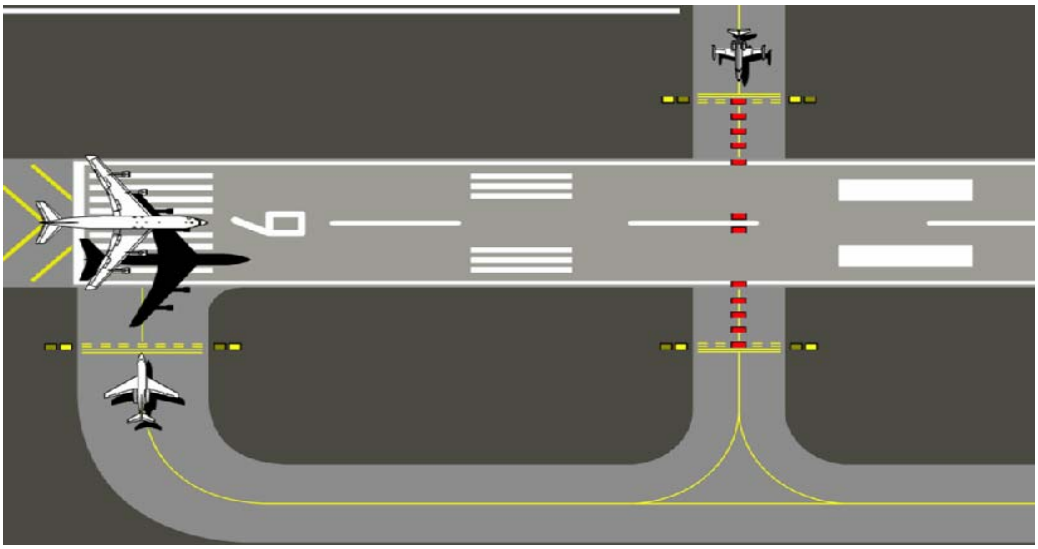

Figure 1. Runway Entrance Lights (RELs)

A sample THL configuration is shown in Fig. 2. THLs are activated in front of the departure that is stopped on the runway in the takeoff hold position because the runway is currently occupied by crossing traffic downfield. The current THL configuration being evaluating has been modified to use two rows of lights as opposed to the single row as displayed in Fig. 2.

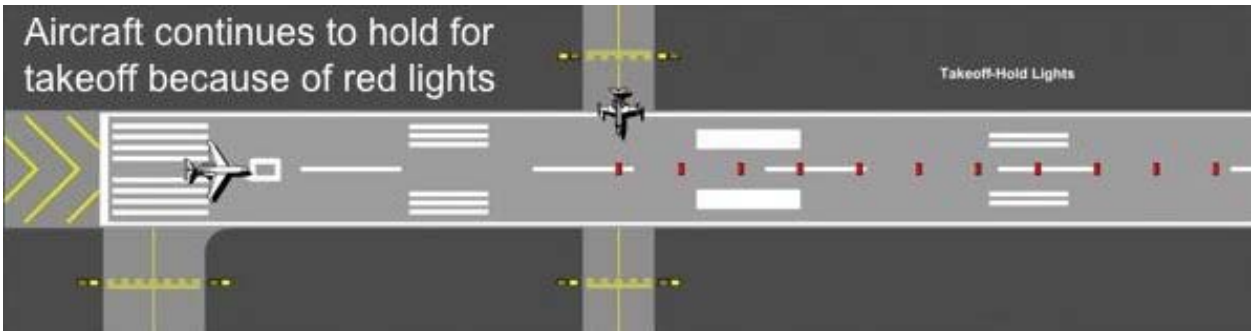

Figure 2. Takeoff Hold Lights (THLs)

II. Test Phases

To facilitate the testing of a complex project, the system under test can be broken down into smaller components and tested individually. Each component can be tested in series or in parallel. Series testing has each component being tested separately and at different times. Parallel testing has each component being tested separately but in parallel with all other components. Each test phase has defined system implementations, test procedures, technical goals, and entrance and exit criteria for each system component. The common goal between the different test operations is to prepare each part of the system for an operational evaluation. Engineering development, shadow operations and an operational evaluation are test phases which can be applied to most research and design projects. The objectives for each test phase are described in this section.

A. Parallel Testing

Test efforts can be divided between different test groups. Each group is responsible for testing specific components of the system that fall under each groups' distinct expertise. This testing can then be done in parallel to minimize the amount of time required to test the complete system. The tests conducted can consist of both qualitative and quantitative tests. The focus of a qualitative test is to assess the system based on usability and quality of operation. The disadvantage of a qualitative test is that results may not be repeatable and care must be taken to select representative test subjects. A quantitative test on the other hand focuses on measurable data quantities. This type of test has the ability to provide consistent results when performed multiple times by different test groups. The outcome from the parallel testing is a system component that is ready to enter the operational evaluation phase.

B. Engineering Development Test

The purpose of an engineering development test is to assess the core functionality of the initial system design under repeatable laboratory conditions. This is strictly a quantitative test because it focuses on providing consistent measurable results which can be repeated as changes are made to the core functionality. No interaction is made with the systems user groups during the conduct of the engineering development test. The outcome desired from the engineering development test is a system that is capable to enter the shadow operations test.

C. Shadow Operations Test

The shadow operations test phase verifies that the system has the ability to perform in an operational environment without interfering with other systems or does not alter the systems users' behavior in a negative way. User groups are then introduced to the system in a simulated operational environment to elicit their feedback. Feedback and a qualitative assessment from the users allows for optimization of the system in preparation for the operational evaluation phase.

D. Operational Evaluation

The operational evaluation test phase verifies the operational suitability of the system. It includes test and analysis of an end state system in an operational environment. This is done in order to determine if quantity production is warranted considering its effectiveness as compared to currently available systems.

III. Test Methodology and Data Analysis

The RWSL concept development and test effort was split among different FAA groups but was overseen by a single FAA RWSL program office. The RWSL system components were tested using both series and parallel testing. The testing of the RWSL concept was broken into three serial tests, first testing the REL concept followed by testing of the THL concept and finally the testing of the RIL concept. The FAA Technical Center's role in the testing and evaluation of the RWSL REL concept consisted of three phases: engineering development tests of the RWSL processor, shadow operations tests of the RWSL timing and an operational evaluation of a complete RWSL REL system. The testing to determine if an off the shelf lighting system could be used for the RWSL REL concept was conducted in parallel with the RWSL processor tests as was the determination and testing of the actual configuration of the RELs. The tested components, the RWSL system processor, along with the FLS and the configuration of the RELs were brought together as a complete RWSL system in the operational evaluation. Each of the test phases, as applied to the REL portion of the RWSL system, are described below.

A. Parallel Testing

The effort to develop an REL configuration that was differentiable from other lighting configurations and that was intuitive to pilots was led by the FAA's Flight Standards group. This effort involved researching the different REL light configurations and selecting the configurations that would best suit the needs of the pilots. Part of the research involved exposing pilots to the various REL configurations in flight simulators. The various lighting configurations were used to determine which REL configuration would ultimately prevent a pilot from crossing onto an active runway. The pilots' feedback along with the research performed on different REL light configurations led to a most likely configuration. This configuration was demonstrated to pilots and airfield lighting experts at the FAA Technical Center using a temporary static light configuration set up on a taxiway. This was the final evaluation of the FLS before an in-pavement installation was made.

The effort to select and test a field lighting system (FLS) was conducted in parallel with the REL configuration development and test. The primary goal for the RWSL FLS was to select a commercial off the shelf lighting system and verify that it would meet requirements for the operation of RWSL. Testing of the FLS was performed first at the vendor's facility and again on site following the system installation. Testing included tests of the interface, system control, and potential timing delays due to cable lengths.

B. Engineering Development Test

The essential goal of the RWSL engineering development test of the RWSL processor was to determine if the surveillance information available was of sufficient quality to activate and deactivate RELs in accordance to runway status. A key element of the engineering development test was to test the capability of the RWSL system to identify all types of airport movement activity. To accomplish this task, recorded surveillance data was collected at two key site airports, San Diego International Airport (SAN) and Dallas/Fort Worth International Airport (DFW). This data was used to develop scenarios which included taxiing, departing, and landing aircraft along with their transition states.

The following scenarios listed in Table 1 were selected to test the RWSL system's ability to provide a light activation and deactivation response for different traffic scenarios.

Table 1. Scenarios Extracted from Various Airport Movement Activity

Arriving Aircraft	**Taxiing**
Normal Arrival	Aircraft taxiing into position and hold
Go Around	Aircraft taxiing on runway
Dog Leg Approach	Vehicles
Surveillance Coverage Gap	
Landing Aircraft	**Departing Aircraft**
Normal Landing	Normal Departure
No track handoff between terminal and surface radars	Unusual Acceleration Drops in Poor Weather
Touch and Go	Departure Aborts
Long Landing Rollout	Intersection Takeoffs
Slows Down then Speeds Up	
High Speed Exit	
Airborne Departures	
Normal Aircraft	
General Aviation (GA) Aircraft	
High Performance GA Aircraft	
Aircraft With Long Departure Roll	
Turbo Prop Aircraft	
Heavy Aircraft	

The scenarios that contained the surveillance track information were played back on the RWSL processor where the activation and deactivation of the RELs were visually monitored and logged. Normally the light commands would be sent to the field lighting system, however during the engineering development test they were only sent to the laboratory display.

Another element of the engineering development test was to determine if the RWSL processor could positively identify when an aircraft becomes airborne during its departure roll strictly from its surveillance track's movement behavior. In order to verify that the system could meet this condition, truth data needed to be collected. The truth data was collected manually by having a test engineer enter into a software program the aircraft's type and position on the runway when it was approximately 50 ft off the runway with a positive rate of climb. The software program added a time synch and formatted the data. The main concern with this type of data collection is the potential for manual errors. Errors in the truth data could lead to the mis-identification of problems with the RWSL processor's airborne departure declarations. To validate the truth data the manually collected data from Dallas/Fort Worth Airport was compared against simultaneously collected surveillance data containing time synched transponder altitude information. The data collected manually at San Diego could not be validated in this manner so any issues discovered with the RWSL processor's airborne declaration were manually analyzed.

Engineering development success criterion was based on two objective measures of REL performance: missed detections and false activations. A missed detection is defined as a failure of an REL to be activated when it should be. A false activation is defined as an REL being activated when it should not be. The exit criterion defined by the RWSL Research Project Management Team for successful completion of the engineering development test is listed in Table 2. This success criterion was to be achieved prior to entering the shadow operations test.

Table 2. RWSL Development Test Performance Goals

	Missed Detections	**False Activations**
Engineering Development Test	1/320 operations	1/800 operations

C. Shadow Operations Test

The shadow operations test verified that the RWSL concept could be optimized to perform in a live air traffic environment without requiring any changes to air traffic's operations. Shadow Operations introduced a third objective measure of REL performance, instances of interference. An instance of interference is defined as an REL illumination that causes an interruption to a safe operation. Shadow operations consisted of system interaction with the air traffic controller user group, data analysis, and system optimization. The RWSL system was supplied with live surveillance data and the REL activation and deactivation along with corresponding airport traffic was presented to air traffic controller test participants via a RWSL display. RELs were not active during the shadow operations test and no interaction with operational controllers, pilots, or airfield vehicle operators occurred.

Prior to the start of the formal shadow operations test an optimization effort was conducted using subject air traffic controllers. The subject controllers observed traffic out the tower windows and told the FAA test engineer when they felt it was safe to issue a clearance to an aircraft to cross at each intersection. This time was recorded by a software program which was time synched to the RWSL processor and used to optimize the timing of the RELs.

During the formal shadow operations test each air traffic controller test participant was given an overview of the RWSL concept and briefed on their test participation. Air traffic test controllers were given an active role in the RWSL Shadow Operations testing whenever possible. The air traffic controller test participants observed live traffic from the tower cab while listening to live air traffic controller communications and identified when the RELs should be on and off for each traffic operation while the FAA test engineer watched the corresponding RWSL display. The FAA test engineer logged any discrepancies between the air traffic controller's identification of when the RELs should be turned on and off and when the RWSL system turned the RELs on and off. Any time differences of 4 seconds or greater were recorded as either a false activation or a missed detection. It was previously determined that time differences of less than 4 seconds had a small likelihood of causing interference. If an active air traffic controller issued a clearance while the RELs were still on at the corresponding taxiway and the air traffic controller test participant felt there was potential for interference, these cases were recorded as instances of interference.

The success criterion for the shadow operations test is listed in Table 3. This success criterion was to be achieved prior to entering the operational evaluation.

Table 3. RWSL Shadow Operations Performance Goals

	Missed Detections	False Activations	Interference
Shadow Operations Test	1/360 operations	1/900 operations	1/900 operations

D. Operational Evaluation

The operational evaluation test phase verified the operational suitability of the RWSL REL concept for use in the National Airspace System. RELs were installed on the SAN and DFW airport surfaces at selected runway-taxiway intersections. Fig. 3 and 4 depict the REL locations at SAN and DFW airports respectively.

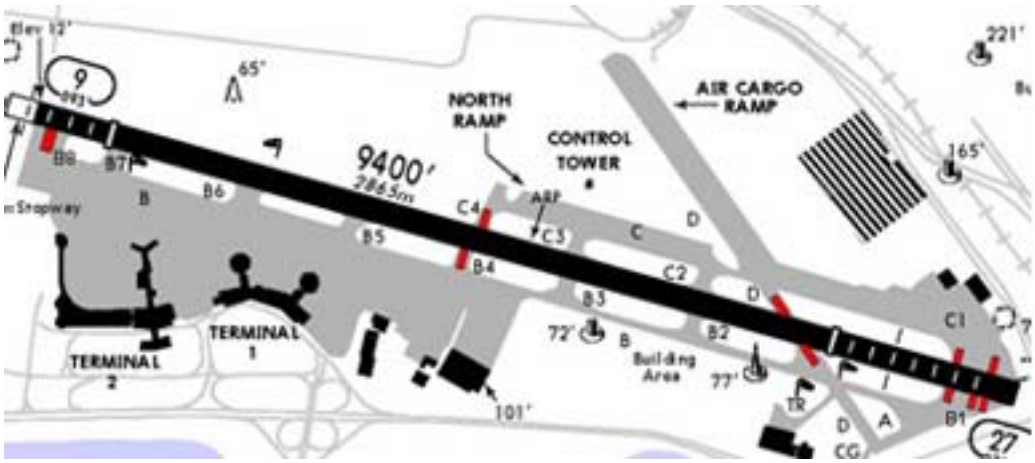

Figure 3. SAN REL Locations

*Note: There are currently no THLs at SAN airport. Testing of THLs will begin later this year.

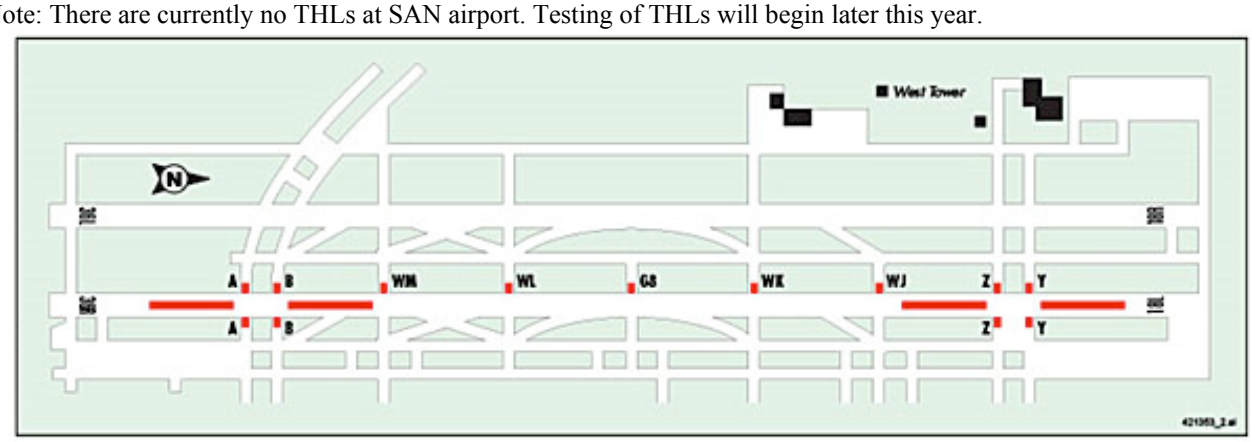

Figure 4. DFW West Side REL Locations

Before the operational evaluation began, the FLS system was connected to the RWSL system to verify the system's interfaces were properly configured. In preparation for the operational evaluation, a full system operational demonstration was conducted to provide an opportunity to revalidate the operation of all the RWSL system

components and to reassess the visual presentation of the RELs from various vehicles and aircraft under both day and night conditions.

After successful completion of the RWSL system demonstration, all air traffic controllers were trained about the RWSL system. This training included an overview of the RWSL concept, how to change the REL intensity using the RWSL display, how to input comments using the comment field on the RWSL display and what to do if the system is not working correctly.

To train pilots and airfield vehicle operators on the operation and protocol of the RWSL system, briefing slides and recorded data movies were published on the RWSL website and delivered on compact disks to all airlines chief pilots, Fixed Based Operators, and pilot organizations. To make sure that as many pilots as possible would receive training, many publications had to be made which included a pilot guide to RWSL published as two new Jeppesen inserts, a Class II NOTAM published on the FAA website and hundreds of RWSL posters and thousands of laminated, color instruction cards delivered to all airlines that fly in and out of the SAN and DFW airports. The posters and cards were displayed and distributed, respectively, to crews flying into and out of the SAN and DFW airports. The Automatic Terminal Information Service was updated as well to notify pilots when the RWSL system was in operation.

During the operational evaluation, pilots and airfield vehicle operators were able to view the RELs as they were activated by the RWSL system in response to live traffic. It was requested that pilots and airfield vehicle operators fill out a survey following coming into contact with the RWSL system. The completed surveys were sent to a separate group with expertise in human factors for analysis. This feedback was collected used to support the determination of the operational suitability of the RWSL system. Air traffic controllers input was sent to the FAA Technical Center where it was analyzed to determine if the RWSL system was invisible to controllers.

To collect data for analysis without having to commit an FAA Test Engineer to stay at the airport for the entire test period, a dedicated data connection line was available to download log data directly from the RWSL system. A RWSL Test Tool program was used to analyze the log data quickly. The test tool program looks for system abnormalities that can be played back using the RWSL playback tool.

Any issues discovered during the operational evaluation testing were discussed between the FAA test engineers, air traffic controllers, and the FAA RWSL program office and were classified by severity. If the issue was deemed critical, appropriate modifications were made to the RWSL software. To verify the modifications resolved the critical issue and did not introduce any new issues, previous data recordings were processed through the new build in an off-line mode using test data from the previous engineering test effort. After verification was made, the new build was released and installed.

The success criterion for operational evaluation is listed in Table 4.

Table 4. RWSL Operational Evaluation Performance Goals

	Missed Detections	**False Activations**	**Interference**
Operational Evaluation	1/400 operations	1/2000 operations	1/1000 operations

If the RWSL concept meets the success criterion for the operational evaluation, a cost benefit analysis is performed. A positive cost benefit analysis demonstrates the system can move forward to implementation into the National Airspace System.