COVER PAGE

Title of Design: Tactile Stimulation System

Design Challenge addressed: Runway Safety/Runway Incursions

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Executive Summary

Runway incursions (RI) are a serious threat to safe airport operations. Pilot loss of situational awareness (SA) is one of the key contributors to RIs. We propose the development and installation of surface modifications to create aviation grade rumble strips on taxiways near runway intersections. This new system would send a tactile signal to pilots to alert them that they are about to enter a potentially dangerous area. The effect would be to raise a distracted pilot's SA and thus reduce the likelihood of a RI.

Because it is unlikely that a surface modification would be usable for both small general aviation aircraft and large commercial aircraft, exploring the use of rumble strips may seem like an exercise in futility. This system, however, will not be a 'one size fits all' solution and will be tailored to meet specific challenges under specific conditions. Furthermore, it will not simply be a thoughtless deployment of motor-vehicle style rumble strips to an aviation setting. We believe that, with careful consideration, aviation grade rumble strips can be successfully deployed to target specific aircraft at certain intersections in order to prevent RIs of a particular nature. Due to the remarkably low cost of surface modifications, the high impact of tactile signals, and the large number of potential deployment spots, it is our contention that the deployment of our proposed design would have a significant positive effect on runway safety.

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I. Background and Problem Statement

A study of U.S. Air Force accidents indicates that approximately 52% of all U.S. Air Force accidents involve human error (Lewis, 1974). Each year, the Aircraft Owners and Pilots Association publishes the Joseph Nall report. The Nall report compiles and categorizes National Transportation Safety Board (NTSB) reports each year. The 2008 Nall report indicates that 76% of all fatal general aviation accidents are a result of human error (Krey, 2008).

Improving SA has been a consistent theme in preventing human error. A study analyzing general aviation pilots, flight school reports, and NTSB accident history identified several factors as contributing to the loss of situational awareness (SA), which can lead to human error (Endsley et al., 2000). Loss of SA resulting in human error were categorized as task management, basic procedures, and vigilance. Task management factors included managing high workloads, dealing with distractions, task prioritization, and division of attention. Basic procedure factors included completion of checklists, carrying out procedures, and radio communications. Vigilance factors included maintaining awareness of traffic and surroundings and ensuring proper procedures were followed.

Perhaps one of the most famous aviation accidents associated with poor SA occurred in 1977. Two Boeing 757s collided on the runway while trying to depart Tenerife. This accident was the result of a runway incursion (RI) and claimed 583 lives (Wynbrandt, 2009). SA amongst both pilots was a prominent causal factor for the accident. While the scale of this accident is unique, unfortunately the RI that led to it is not. In 2010, there were 966 total RIs (FAA, 2010e, 2010f). Each of these RIs had the potential to end in a deadly situation.

The FAA defines an RI as: "any unauthorized intrusion onto a runway, regardless of whether or not an aircraft presents a potential conflict" (FAA, 2009a). Seventy-one percent of all

RIs involved general aviation, and of those, approximately 63% were a result of pilot deviations (Duquette, Adams, & Jones, 2008). As a result of the plaguing problem of RI's, the FAA's Runway Safety Office has issued a call to action to industry on the problem (FAA, 2010f). The FAA believes that the solution is centered on a combination of cockpit procedures, airport signage and markings, air traffic procedures, and technology (Duquette et al., 2008). The call to action also cites airport surface analysis and reducing pilot deviations as key methods for managing RIs.

A taxiing pilot's environment is saturated with visual cues that require him/her to pay attention and correctly interpret their meaning in order to avoid RIs and taxi safely. At times, this cognitive workload can be overwhelming and result in the pilot losing SA. The conditions contributing to this phenomenon can vary. Positional knowledge and monitoring unforeseen hazards are just two examples of key information that may not be attended to if a pilot's head is down (Reynight, 2004). Something as simple as a distraction, poor division of attention, or confusion can result in a loss of SA. Our team proposes to meet this challenge by designing a system that introduces a direct and meaningful cue to an underutilized sense, thus raising pilot SA and lowering the likelihood of an RI.

According to the Maryland Department of Transportation (2005), "the audible and vibratory stimuli produced by the rumble strips increases drivers' awareness and attention while traveling through work zones, particularly inattentive, fatigued, or sleepy drivers". A review of research evaluating the effectiveness of rumble strips on highways concluded that the majority of studies indicated a large reduction of accidents after installing rumble strips (Carlson & Miles, 2003). Additionally, there was a 50% reduction in the pertinent crash rates due to rumble strips (Carlson & Miles, 2003).

Our team anticipated that benchmark improvements in attention management could be beneficial in the world of aviation. Our team set out to design a potential lifesaving attention management aid in the form of an airport surface modification in order to increase pilot SA and attention. Our design, called the Tactile Stimulation System (TSS), would consist of aviation grade surface modifications that would introduce audible and vibratory stimuli to gain a pilot's attention prior to entering the runway.

II. TSS Description

a. Concept of Operations

The TSS is intended to improve pilot SA by sending a direct tactile signal to the pilot when the aircraft is on a taxiway and approaching a dangerous area, i.e. a runway. It would be installed at a distance from the hold short line that would allow an aircraft or ground vehicle pass over, receive the tactile signal, and react before the hold short line. Red dots in Figure 1 depict potential deployment locations for the TSS, and the red line in Figure 2 depicts the location of the TSS on a taxiway.

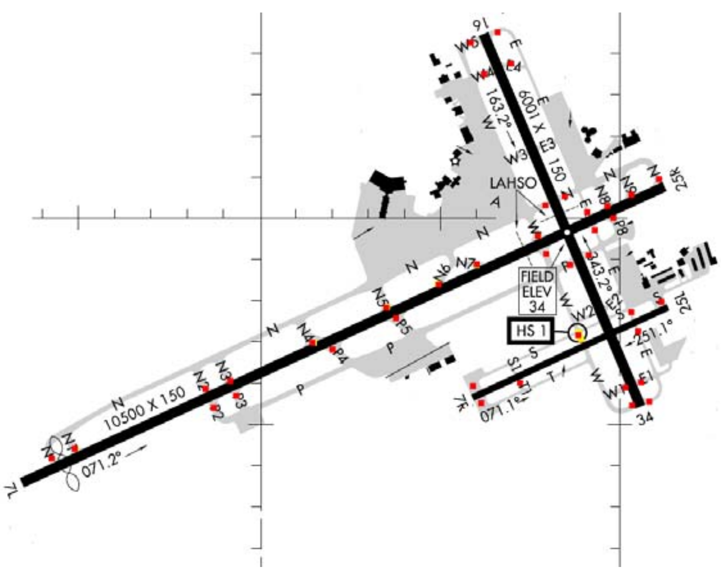


Figure 1. Daytona Beach International airport surface diagram

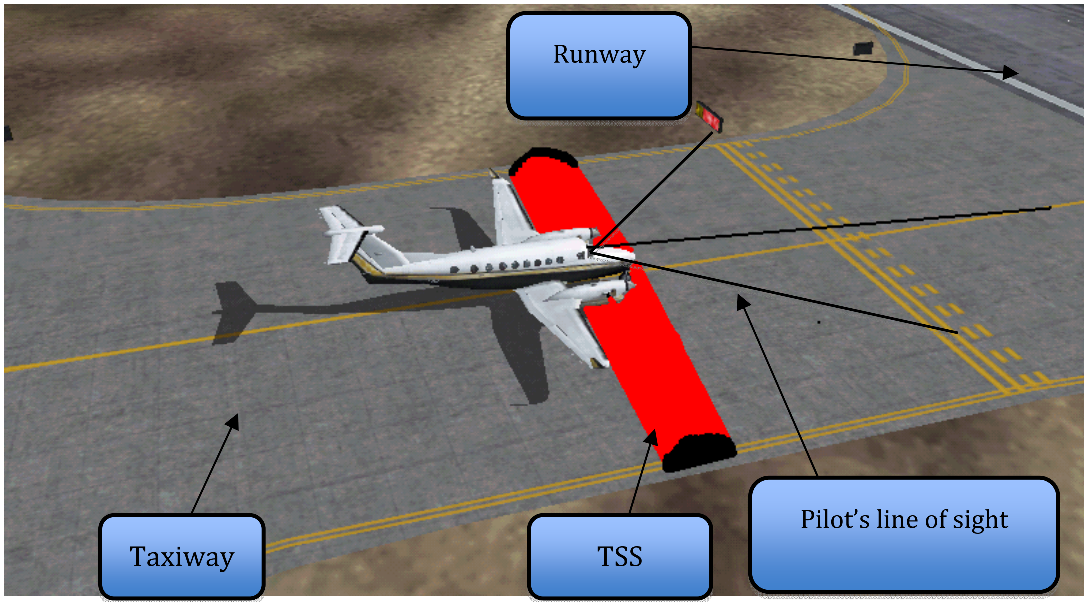


Figure 2. Operational View of TSS

b. Example Scenarios

Visually, pilots usually have at least three things in place to prevent them from unknowingly taxiing onto a runway. Flashing "wig-wag" lights, painted "hold-short" lines, and red runway identifier signs are currently in place and have been for many years in an attempt to reduce RI's. But what if the pilot is not looking outside? Or what if the airfield has confusing signs? How will they come to realize they are about to taxi onto a possibly active runway? We need a system that provides tactile feedback whose signal is unmistakable.

Whether it is because a pilot is unfamiliar with an airport or simply because they are unaware of where they are at an airport, pilots taxi onto active runways on an all-too frequent basis. Most of the time, they realize their mistake and turn around or keep going to clear the runway. At non-towered airports, these events aren't necessarily documented and can be quickly forgotten. But why should it ever come to this? What if a system was in place to alert pilots to their arrival at a runway that would make them stop and think, "Should I be here?" or even "Do I have clearance to taxi onto the runway?"

We are looking at a system that is resilient to the ‘heads-down’, the unfamiliar, or the lost pilot. What follows is a “what-if” scenario that could take place at any airport, at any time, taking the example of a pilot being unfamiliar with a field.

The pilot of the first aircraft contacts ground control and asks for clearance to taxi to the active runway for departure. Ground advises the pilot to expect an intersection takeoff instead of the normal full runway departure. Meanwhile, another aircraft is taxiing using an alternate route to the same runway for a full-length departure. Upon arrival at the intersection for its departure, the original aircraft taxis onto the runway without clearance as the second aircraft is on its takeoff roll. Air traffic control advises the first aircraft of the deviation and the pilot executes a 180 degree turn off the runway. The second aircraft, “already committed” to takeoff, rolls past the first aircraft missing it by a horizontal distance of 70 feet.

What was just described occurred at Daytona Beach International Airport on November 24, 2007. The pilot of the first aircraft, a Cessna 182, lost situational awareness and taxied onto the active runway (7L) as the second aircraft, a King Air, was on its departure roll. Refer to Figure 3 for a visual representation of the incident. What if the rumble strips had been in place? The pilot of the smaller C182 would have felt the vibrations and realized that he was approaching a runway. Hopefully, this would have caused him to stop the aircraft and re-evaluate whether or not he was doing what he was supposed to.

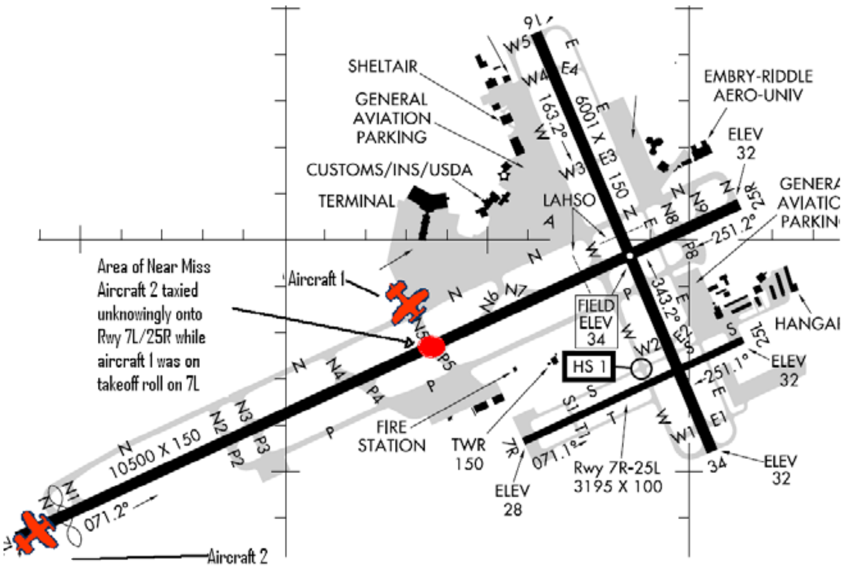


Figure 3. KDAB Runway Incursion

Figure 3 identified a hotspot (HS1) on the taxiway running adjacent to Runway 7K. What if a pilot is taxiing southwest along taxiway W, is instructed to turn on S, but loses situational awareness and misses or does not notice the intersection? Most of the time, the pilot will notice the signage, regain situational awareness, and take corrective action. But what if the pilot is looking back to see if that really was the turn they were supposed to make? What if they second-guess the signage? What if there is some other distraction that grabs their attention? They may end up crossing or turning on to Runway 7R.

Another case at Daytona Beach International Airport involved a solo student pilot taxiing with his head down in the cockpit as he was unknowingly coming up to an active runway. The pilot taxied onto the runway, still having no idea he was on a runway, causing a departing aircraft to abort the takeoff, narrowly missing the first aircraft. What would have happened if the rumble strips had been in place there? Would the student pilot have felt them and realized their error, bringing the aircraft to an abrupt stop on the taxiway?

Our goal with the TSS is to direct the pilot's attention back to the task of taxiing should it have strayed or become fixated on another task. We want them to challenge themselves when it comes to their own situational awareness. We want them to second-guess themselves. If pilots stop and think and come to the conclusion that they are not where they are supposed to be, and it took the vibration of their aircraft to alert them to that, then the TSS has served its purpose.

III. The Design Process: Research and Analysis

Our team of Human Factors students adopted a stakeholder-centric, design process. A great deal of effort went to gathering information from a variety of stakeholders in order to establish what shape our proposed system should take. We wanted to ensure that the design was practical and could be easily introduced into the existing infrastructure. To this end, we had three guiding principles that we considered every step of the way. The TSS shall: do no harm, be cost effective, and be adaptable.

We used our principles as we gathered and analyzed information. We lacked the expertise resources to conduct full-fledged prototype construction and testing, but we processed our information using analysis tools and logical thought processes in order to come up with several design variations that we recommend for further testing. We also developed a plan for implementing the TSS that could begin upon completion of this report.

a. Technology Review

There are many tools at the pilot's disposal to help raise SA and prevent a RI. In their most basic form, they are the pilot's map of the airfield, the compass, and, for some, the transparent windshield that allows the pilot to see the visual cues on the airfield. Slightly more sophisticated are the signs, lights, and runway markings are available to enhance and supplement the visual cues (FAA 2010a, 2010b, 2010c). More recent advances in technology have led to the development of GPS systems that superimpose aircraft location on an airport diagram.

Working in parallel with the visual cues are auditory cues that come over the radio. While visual cues primarily provide pilots with awareness of their position, auditory cues are coupled with procedure to raise awareness of aircraft position and movement with respect to other working parts of an airfield. Radio procedure helps the pilot understand where other aircraft are, where ground vehicles are, and what must happen for safe usage of the airfield.

Many of the aforementioned technologies have been available and used successfully for decades; however, they are not without their weaknesses. Visual cues can be confusing or misinterpreted and auditory cues can be time consuming or forgotten. Since 2003, the American aviation industry has been progressing towards the NextGen era. NextGen is a comprehensive upgrade of the American air transportation system. It comprises of a continuous deployment of several technologies that will, among other things, improve pilot SA on the ground and reduce RIs (FAA, 2010e).

Automatic Dependent Surveillance-Broadcast (ADS-B) provides airport traffic information to controllers and pilots of aircraft equipped with Cockpit Display of Traffic Information (CDTI). This enhances pilot SA of equipped aircraft by providing an accurate and information-rich visual cue in the cockpit. Full benefits of ADS-B are achieved when all aircraft are equipped, however non-compliant aircraft can still be incorporated into the CDTI with the deployment of the Traffic Information Services-Broadcast (TIS-B) (FAA, 2010d).

Controllers also benefit from Airport Surface Detection Equipment Model X (ASDE-X) and Airport Movement Area Safety System (AMASS). Both give controllers a picture of airport ground operations and have been tested with Runway Status Lights (RWSL). RWSL use ASDE-X or AMASS information and indicate to pilots when a runway is unsafe (FAA, 2009b).

Another aspect of NextGen is the introduction of Data Communications (Data Comm). This will permit information to be passed via digital links instead of the current method, which is analogue voice communications via radios. Analog voice communications are time intensive and restrict the capacity of airports. Data Comm will allow greater amounts of information to be transmitted with greater accuracy, which should help with pilot SA (FAA, 2009c).

b. Aviation Technology Challenges

NextGen upgrades are expected to dramatically improve the quality of visual and auditory cues, which help increase pilot SA during all ground operations. NextGen, however, does face some considerable challenges since it involves the development and deployment of several new systems on several timelines. Furthermore, it uses many aircraft–centric systems and is reliant on operators' willingness to equip (FAA, 2010d). Availability of existing technology is a challenge that affects operations at every airfield. Not all of the aforementioned SA aids are always available. The existing technology at each airfield and in each cockpit will vary greatly from airfield to airfield and cockpit to cockpit. Airfields may not have towers or sophisticated lighting systems, and pilots may not be able to afford the advanced technology in order to keep up with NextGen. There are several mutually reinforcing layers, such as runway markings and signs, for increased safety, but as implied by our problem statement, they can fail.

c. Literature Review

Our team conducted research to first understand the challenge of SA in aviation. We discovered that pilot SA is especially important because their environment is constantly changing. Mica Endsley (1995) describes three levels of SA where people perceive their environment, comprehend the task at hand and project what will or could happen. This applies especially to pilots when they are taxiing to a runway. Pilots must be aware of their surrounding environment to determine not only their location but also the location of other pilots in order to perform their job safely and effectively.

We investigated the effects of poor SA and found it to be a causal factor of pilot deviations. In reading NTSB accident reports, we were able to see that a large number of pilot deviations occur when pilots are not aware of their location on the runway/taxiway. A recent accident in Hilton Head Island, SC between two GA aircraft (NTSB, 2010) demonstrates the ease with which RI's can occur when a pilot has lost SA.

The team also conducted research into sensory modalities, and the possible benefit of tactile information presentation. For example Raj, Kass and Perry (2000) found that pilot performance in aircraft simulation was improved by vibro-tactile signals conveying aircraft position. The vibrating tactors used in their study provided an immediate signal that required little interpretation. In another study, Van Erp and Van Veen (2004) examined vibrotactile sensors in a vehicle navigation system. They found that vibrotactile displays decreased subjective workload and freed the visual system to benefit pilot performance, especially in high workload conditions.

We turned to the Federal Highway Administration (FHWA) to better understand existing surface modifications. 2010 FHWA document identified four different rumble strip designs: milled, rolled, formed and raised, each of which creates different sounds and tactile sensations, and each of which is engineered for different purposes and use in different locations. This FWHA documentation also provided us with insight into costs.

Next, we researched runway designs to determine how the Tactile Stimulation System (TSS) could integrate into airport hardware and operations. Apeagyhei et al. (2007) provided information on hot-mix asphalt (HMA) runways, the failure modes of saw-cut groove designs, and types of aircraft behavior that can accelerate wear. Information about, for example, different runway groove patterns and their individual functions, allowed us to better understand how the design of our rumble strips may impact aircraft. The report also gave us knowledge on the effect of weather on runways. This allowed us to think of possible design issues that would arise due to different weather conditions across the country.

d. Stakeholder Analysis

Stakeholders are identified as anyone that is involved in the daily airfield operations. Stakeholders that would be involved in the operation of the TSS include:

-Air-traffic controllers

-Airport managers

-Airport maintenance personnel

-Aircraft manufacturers

-Aircraft owners

-Construction companies

-Pilots

-Passengers

i. Stakeholder Requirements

Using research, surveys, and interviews, we were able to identify stakeholder requirements. Several safety concerns emerged during this process, which reinforced one of our guiding principles: above all else, the TSS shall do no harm.

The following are the Documented Stakeholder Requirements (see also columns in Table 1). The TSS shall:

-not produce FOD

-not impede movement

-not damage aircraft

-produce a tactile signal

-be weather resistant

-be low maintenance and durable

-be low cost

-be easily cleared of snow

-cause no more than minimal passenger discomfort

We were unable to find specific FAA regulations on surface modifications apart from those on saw-cut grooves (FAA AC150/5370-10E); therefore, a regulation-based requirement was not identified. However the TSS will require, and be subject to, new FAA regulations. These new regulations would be based on the results of TSS prototype testing and could feasibly be derived from the existing saw-cut groove regulations.

Table 1. TSS Requirements Mapped to Specific Stakeholders.

	TSS Requirements								
Stakeholders	Tactile Signal	No FOD	Not Impede	Weather Resistant	Easy to Maintain	Low Cost	Remove Snow	Pass. Comfort	**TOTAL**
Air Traffic Controllers	•	•		•	•	•	•		75%
Pilots	•	•	•	•			•	•	75%
Airport Managers	•	•		•	•	•	•		75%
Construction Co.	•	•		•	•	•	•		75%
Airport Maintenance	•	•	•	•	•	•	•		87.5%
Aircraft Owners		•						•	25%
Aircraft Manufacturer	•	•	•						37.5%
Passengers	•	•	•					•	50%
TOTAL	87.5%	100%	50%	62.5%	50%	50%	62.5%	37.5%	

ii. Interaction with Airport Operators & Industry Experts

We surveyed pilots and consulted airport managers, pilots (of both small and larger transport category aircraft), aircraft mechanics, the Florida Department of Transportation, a projects engineering coordinator, and air traffic controllers to help us understand the scope of undertaking the surface modification project. Our literature review along with these interactions with industry and aviation experts and our prior experience helped paint a complete portrait of the problem we are dealing with and how to best develop our design. Our interactions with members of the aviation community and industry were particularly integral to the process of evolving the TSS design and implementation plan. The interactions are summarized in the following paragraphs. Experts we contacted are listed in Table 2.

A survey was distributed to the Certified Flight Instructors (CFI) at Embry-Riddle Aeronautical University (ERAU) on September 22, 2010. Out of the 159 distributed, we received 85 back (53% return rate). The majority of the instructors indicated that they would be in favor of such a system if it helped prevent RIs. Over 95% of the CFIs indicated they would not avoid an airport if rumble strips were installed. The major concern was with the extent of the vibrations produced when aircraft tax over the strips and whether it would cause damage.

On September 27, 2010, Patrick O'Connell, a Hawker Beechcraft Corporation Demonstration Pilot was contacted by e-mail. Mr. O'Connell indicated that additional signage or markings on the taxiways would be "useless" as they have been encountered before and are "quite hard to read". He went on to say that small bumps would be "quite helpful in reminding the pilots that they are approaching a runway." A word of caution was included about potentially damaging the aircraft and passenger comfort.

We noticed a trend of pilots being concerned with potential damage to the aircraft as it taxied over the rumble strips. On October 20, 2010, Daytona Aircraft Services, Inc., an authorized Cessna repair shop was contacted by phone. A mechanic was asked if he thought rumble strips, much like those found on the side of a highway, would damage an aircraft. The mechanic indicated it should not be an issue for aircraft to be able to handle the vibrations or slight changes in elevation.

Martin Lauth, a retired air traffic controller, current instructor at ERAU, and one of our advisors was sent an e-mail on September 30, 2010. Mr. Lauth was asked about his thoughts on SA and why pilots seem to lose it. He attributes the loss of SA at airports to boredom; when there is not enough to do to keep a controller or pilot alert to their surroundings. When asked about the rumble strips, Professor Lauth answered "actually that would not be a bad idea; that would add another sense (besides sight and sounds) such as feel when the aircraft shakes a bit as it goes over the strips." Professor Lauth was interviewed in person on October 14, 2010 when we asked him to expand his viewpoints on our idea and pilot's loss of SA. He said that in order for the strips to be most effective, they should be focused on 'hot-spots', or known trouble spots where the aircraft has to cross a runway that they will not be using in order to get to their ground destination. They should be placed well before hold-short line so they can be easily seen. When asked to expand on loss of SA at an airport, Mr. Lauth attributed the loss to the following: unfamiliarity with the airport, distractions in the cockpit, lack of experience, and ATC not knowing where the aircraft is physically located.

With our subject matter experts (SMEs) providing positive feedback, we decided to find out what it takes to make rumble strips. The Florida Department of Transportation (DOT) was contacted on October 25, 2010 with a "to whom it may concern" e-mail. Cheryl Adams, an engineer at the Roadway Design Office responded with specification and design drawings for the rumble strips that they use on roadways along with a brief description of how they are made. Jason Pothen (e-mail exchange, November 18, 2010), a structures engineer at Boeing, warned that a one-size-fits-all rumble system would be difficult to design. Something felt by a large aircraft might create a challenging obstacle for smaller aircraft. Mr. Pothen went on to say that the shape of the strip would play a large role in the type of vibration that would be created. Armed with this information, our group decided to focus on smaller general aviation aircraft when the rumble system is designed. There might be potential for larger systems down the road.

With all of our information, we needed to talk to SMEs in the field who would be in charge of signing off on our design to have it implemented at an airport. Nick Landgraff, the DeLand Municipal Airport Manager, was contacted via phone on November 3, 2010. When asked if he thought loss of SA was an issue and his thoughts about a tactile feedback system, Mr. Landgraff responded by saying that he does not feel that loss of SA is a big issue at his airport but "every little bit helps". The money to provide such a system would be covered by Federal Aviation Administration (FAA) grants and could be part of a larger initiative. The strips would have to be contracted out as they are only able to make small repairs such as potholes. Wes Houser, a foreman at the DeLand airport (interviewed in person on October 29, 2010) expressed concern with propeller clearance, the creation of foreign object damage (FOD), and current FAA regulations. Steve Brocket, the airport manager at the Ormond Beach Municipal airport (interviewed via phone, November 17, 2010) concurred with the propeller clearance statement as well as indicating that different aircraft will react differently when travelling over the strips. Mr. Brocket recommended short but rapid rumbles to provide a unique vibration and indicated that he would gladly deploy the system if indeed it worked.

On November 6, 2010, Carl Schweizer, the Projects Engineering Coordinator at the Daytona Beach International Airport (DAB), was interviewed. He indicated that the strips are a good idea and wondered why they have not been implemented before.

Table 2. List of Industry Contacts

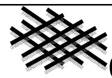
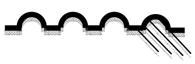
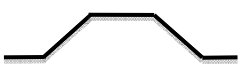
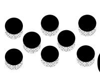
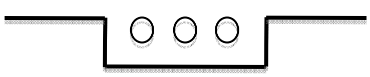
Name	Company	Title
Flight Instructors	Embry-Riddle Aero. Univ.	Certified Flight Instructors
Martin Lauth	Embry-Riddle Aero. Univ.	Retired FAA Air Traffic Controller, ATC Instructor
Patrick O'Connell	Hawker Beechcraft Corp.	Sales/Demonstration Pilot
Cheryl Adams	Florida DoT	Engineer, Roadway Design Office
Nick Landgraff	DeLand Municipal Airport	Airport Manager
Wes Houser	DeLand Municipal Airport	Airport Foreman
Carl Schweizer	Daytona Beach Int'l Airport	Projects Engineering Coordinator
Steve Brocket	Ormond Beach Municipal Airport	Airport Manager
Jason Pothen	The Boeing Company	Structures Engineer

e. Trade-Off Analysis

i. Ground Transportation Technologies

There are several existing forms of surface modifications used in ground transportation that can stimulate tactile senses. Table 3 lists the different surface modifications we evaluated for use in the airport ground environment.

Table 3. Existing Surface Modifications

Picture	Terminology	Description
(viewed from above)	Plaid Cuts	Cuts on the surface in a plaid pattern.
 or 	Transverse Indents	Either larger saw cut grooves or the pressed in rumble strips that are commonly found at the side of roads.
	Rumble Bumps	Above surface strips of material that are commonly found along centerlines or ahead of stop signs.
	Speed Bump	A large, above surface strip of material. Often found in parking lots.
	Elevated Pad	A long, above surface pad of material, commonly found at crosswalks in slow traffic areas.
(viewed from above)	Pedestrian Dots	A series of small, semi-spherical, above surface protrusions. Often found where sidewalks intersect roads.
	Metal Grate	Several metal bars laid into the surface. Used to prevent cattle from passing along a road.

A House of Quality is a decision-making and trade-off analysis tool that can be used for development and application of design strategy. It helps multidisciplinary design teams consider different perspectives and constraints to create a prioritization of engineering products (Lowe, n.d.). About two months into our project we found ourselves almost overwhelmed with the variety of potential surface modifications. With little field aviation research, we were unsure which design had the most potential. The House of Quality enabled us to assign quantitative relationships to previously qualitative problems.

The House of Quality allowed us to compare the potential surface modification solutions to the stakeholder needs, Figure 4. The columns each contain a different design solution while the rows represent stakeholder needs that we identified. Each cell is assessed a value based on the chance that the solution will satisfy the need. The values (++, +, 0, -, or - -) vary from a strong positive to strong negative chance of satisfying the need. The chance of success in each cell is then multiplied by the importance of the row (i.e.: the requirement) and the results of each cell in a column are added together to obtain a value score for the potential design solution. The value scores help assess the likelihood each solution may be successful developed. A high value score indicates a high potential solution and a low value score indicates a solution with less potential.

Solutions / Customer Needs	Importance (1-5)	Plaid Cut	Transverse Indents	Rumble-strips bumps	Speed bump	Elevated Pad	Metal Grate	Pedestrian Dot
Does not damage aircraft	5	0	0	0	_ _	+	_ _	+
Is not a FOD risk	5	_ _	+	0	+	+	++	_ _
Does not impede movement	5	++	+	+	_ _	_	+	++
Tactile Stimulation	4	_	+	++	++	+	++	+
Is durable and weather resistant	3	_ _	+	0	0	0	_	_
Maintainable	3	0	+	_	_	_	+	_
Snow Removal	3	+	+	_ _	_ _	+	_	_ _
Low Cost	2	0	+	+	+	_	_ _	_
Passenger Comfort	1	+	-	_ _	_ _	_	_ _	_
Value Score		-15	79	12	-58	18	11	-15
Potential (1-Best - 7- Worst)		5	1	3	7	2	4	5

++	=	Strong Positive (+5)
+	=	Positive (+3)
0	=	Neutral (0)
_	=	Negative (-3)
_ _	=	Strong Negative (-5)

Figure 4. TSS Design House of Quality

In keeping with our guiding principles, the customer needs related to safety were given the highest importance. The need for low cost was given low importance in the context of our analysis because all the potential design solutions are likely to be low cost. Any cost differences are likely to be insignificant when compared to other airport systems. Likewise, passenger comfort was given low importance since all of the potential systems would likely produce an effect that is much less dramatic than landing. We chose to include snow removal as a need in order to keep our analysis as broad as possible.

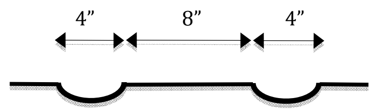
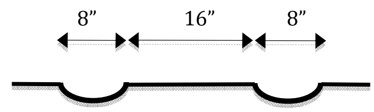
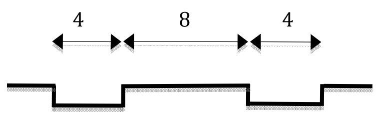
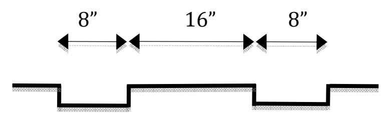
ii. Trade-Off Analysis Results

Based on the results of this House of Quality, we chose transverse indents for the TSS. We were able to determine that the speed bump, plaid cuts, and pedestrian bumps designs would likely achieve the fewest stakeholder requirements and, as a result, has the least amount of potential. Conversely, our analysis showed that the transverse indents design is the most promising potential design. Rumble strip bumps and elevated pad designs also show some promise as possible alternatives. This is especially true for rumble strips if snow removal were to be removed as a stakeholder requirement.

iii. Additional Testing Requirements

Determining the appropriate dimensions for the transverse indent style TSS will require engineering and testing. Given that smaller GA aircraft and road vehicles have comparable weights and wheel sizes, it stands to reason that dimensions for rumble strips used by FHWA would be a good starting point. Since aircraft landing gear is designed for fundamentally different tasks and aircraft taxi near runways at relatively slow speeds, several design dimensions should be examined. Using existing FWHA dimensions (Fitzpatrick, Brewer, & Parham, 2003), we recommend the four configurations in Table 4 be tested on a variety of GA aircraft at depths of 0.375”, 0.625”, and 1.000”. Note that the surface modifications would cross the entire taxiway.

Table 4. TSS Design Test Configurations

Length / Manufacture	Typical FWHA configuration	2 x Typical FWHA configuration
Pressed into surface		
Cut into surface		

IV. Safety and Risk Management

For this project we are using the FAA’s Safety Management System our safety risk assessments and to address the human-system integration (HSI) issues. We will be basing all our safety activities on the FAA’s Safety Risk Management Analysis Phases (see Figure 5). This section explains some of the hazards that may need to be addressed as part of the designing and testing of the TSS.

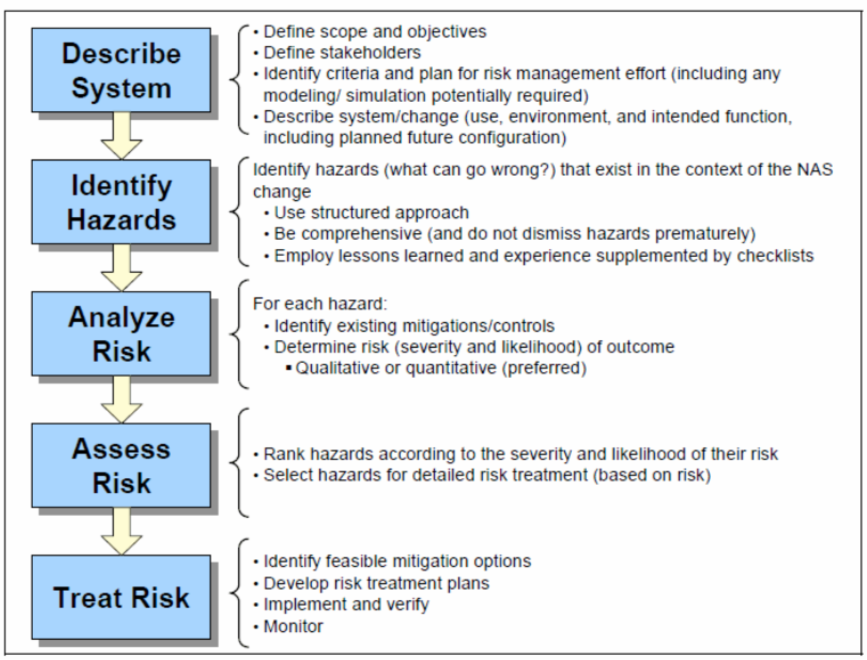


Figure 5. FAA’s Safety Risk Management Process (Adapted from FAA, 2004.)

a. Overview of the FAA Safety Process

Before we identify risks, let us briefly explain each phases of the FAA's SRM Analysis Phase:

i. Hazard Identification

Once the system is described, hazards are identified. During this phase, things that can go wrong and the possible causes are identified and documented. The level of detail required in the hazard identification process depends on the complexity of the change being considered and the stage at which the assessment is being performed. In implementing change there is always the potential for creating hazard and consequently increasing risk.

ii. Risk Analysis

In this phase, each hazard and the system state it potentially affects is evaluated to determine how to prevent or reduce the hazard's effects or occurrence. The analysis assessed a system performing its intended function in anticipated operational environments to identify those events or conditions that would reduce system operability or service.

iii. Risk Assessment

In this phase, each hazard's risk is compared and plotted on a risk acceptability matrix (see Figure 6). Higher priority hazards receive the greatest attention in the treatment of risk.

iv. Treating Risks

In this phase, options for dealing with risk are developed and managed.

b. TSS Safety & Risk Analysis and Management

The types of hazard associated with our system are believed to be fairly constant from airport to airport, with two main exceptions. The exceptions are differences in climate and airport users (i.e.: principally general or commercial aviation). The variability of climate and users will effect how the TSS is tailored for a particular airport and the potential impact and risks it may have. We believe that the lowest risk is associated with an initial deployment to warm climate general aviation airports. Our team identified potential hazards that could occur with the implementation, operation and maintenance of our system, and grouped them into three hazard categories: Human – System integration, System – System, and mechanical hazards. These categories of hazards are discussed in turn below.

c. Human-System Integration

Since one of our main proposed features is to increase safety it is essential to briefly discuss Human-Systems Integration (HSI). HSI promotes a "total system approach which includes humans, technology, the operational context and the necessary interfaces between and among the elements to make them all work in harmony" (Haskins, 2007, p. M-1). While there are many stakeholders for our system, our HSI is particularly concerned with the direct interactions between humans and the TSS.

Before our system is deployed it must be installed in a testing facility that will enable an assessment on how pilots (and aircraft) react to the TSS. This testing is important in order to understand the impact on pilots. It will also allow pavement specialists to develop and familiarize themselves with the specific procedures and materials that will be needed to deploy the system. During this testing phase, the maintenance crew can develop maintenance and repair training. HSI is an iterative process that will also be in place during deployment, operational life, and subsequent phases of the life-cycle of our system.

i. Human-System Integration Hazards

These hazards occur by incorrect interfacing of the human element with system technologies and procedures. Potential human-technology conflicts could result from failure of the system to produce the necessary vibration in order for pilots to feel it, and implementing system procedures that are incompatible with existing practices. Prototyping and operational testing and evaluation will help manage these risks. Prototyping will involve using sound engineering knowledge and practices to select, install, test, evaluate, and maintain the specific engineering and technical details of the TSS, This will facilitate a better understanding of the trade-offs and the risks involved in creating a stronger tactile signal. Operational testing and evaluation will give a better understanding of how the TSS integrates with existing practices. Prototyping and operational testing and evaluation will help manage these risks. Prototyping will involve using sound engineering knowledge and practices to select, install, test, evaluate and maintain the specific engineering and technical details of the TSS. This will facilitate a better understanding of the tradeoffs and risks involved in creating a stronger tactile signal. Operational testing and evaluation will give a better understanding of how the TSS integrates with existing practices.

Because these risks can be easily evaluated and removed during the design phase, they are assessed as extremely remote in likelihood. If they were to surface in airport operations, their safety impact would be low (See Figure 6). If the deployed system failed to provide enough vibration for every single aircraft type, it would be considered as not having a negative safety effect because of the current system of lights and labeling that should alert pilots that they are about to enter a runway. The TSS is a redundant system and is not intended to replace existing runway safety equipment, only to reinforce it.

ii. System-System Integration Hazards

These types of hazards occur when the design of our system conflicts with existing systems in the overall FAA system. Such hazards include conflicting functions flows in the new and pre-existing system, as well as the new system directly impeding the productivity or safety of the FAA system. We consider negative interactions between our TSS and current airfield technology to be extremely improbable and of no negative safety effect (see Figure 6). Our intention is to add another layer of sensory perception, which can operate synergistically with current systems. Nonetheless, issues with system-system integration hazards will need to be continually monitored throughout the evaluation and implementation stages.

In this category we can place the chance of an aircrafts movement being impeded by our system. Tactile stimulation is achieved through some sort of impedance, and if the impedance is too great, there is a chance that smaller aircraft will have to significantly increase power in order to pass over our system. This would introduce the risk that aircraft may ‘shoot’ onto the runway or pilots may lose some degree of control because they had increase thrust where they normally wouldn’t have. To prevent this situation our system must be specifically designed to accommodate safe usage by all aircraft and placed in a strategic position that would allow an aircraft to normalize its speed before entering a runway. Furthermore, it will be important to have an education campaign to ensure pilots are aware that they do not need to significantly increase power to a cross a TSS. Airports may consider setting aside certain non-TSS taxiways for at-risk aircraft. Nonetheless, it is our intention to implement the TSS where it is needed most.

At first, this would be taxiway hotspots that have a history of RIs. Eventually, we feel that the greatest safety impact can be achieved by deploying the TSS to the greatest number of intersections. It is important to consider all risks, and in so doing we have considered the potential risk to small aircraft. For these aircraft, this risk is assessed extremely remote and minor in terms of its potential impact on safety. The goal would be for an engineering team to determine the exact characteristics and parameters for system in order to achieve usability and safety for every aircraft type.

Another hazard that many stakeholders have identified is the possibility of damage to an aircraft. We hypothesize that other aircraft operations, such as landing, are much more violent than the envisioned interactions between an aircraft and our system. With this in mind, we consider that the potential damage to aircraft tires or fuselage would be extremely remote and of minor severity (as shown in Figure 6) because aircrafts are designed to withstand impacts at high speeds (i.e. landing). This was further reinforced when we spoke with an engineer at Boeing who felt it would be possible to design the TSS to specifications that do not damage aircrafts. Nonetheless, safety is our primary concern and thus testing during the design phase will be conducted to validate this anecdotal information.

iii. Mechanical Hazards

Faults, failures and malfunctions in the actual hardware of the TSS could result in unwanted actions and repercussions. The appropriate team of engineers must carefully select the materials for our system, so as to try to create a resilient and durable system that will withstand weather and the high traffic of aircraft operation. In all likelihood, materials will be the same as the existing taxiway. TSS must be resilient, robust and durable in order to reduce the possibilities of introducing the risk of generating foreign object debris (FOD) that could damage other systems (e.g.: aircraft). While it is difficult to quantify the FOD risk prior to testing, based on the performance of runway saw cut grooves (Apeagyhei et al. 2007), we believe the FOD risk can be minimized. The study found that there was far less groove failure on sections of runway where aircraft were traveling perpendicularly over the saw cut grooves. The TSS will be on sections of the taxiway where aircraft will be traveling slowly and where there will be minimal turning. This leads us to believe that there will be extremely remote potential for TSS FOD production, as shown in Figure 6.

Severity / Likelihood	No Safety Effect 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Frequent A					
Probable B					
Remote C		TSS hardware faults or failures			
Extremely Remote D	TSS fails to produce noticeable signal	Aircraft movement impeded - TSS causes over-shoot on inactive runway	Direct damage to aircraft		
Extremely Improbably E			FOD damage to aircraft	TSS causes over-shoot on active runway	

Figure 6. TSS Predictive Risk Matrix. (Adapted from FAA, 2004.)

V. TSS Implementation & Projected Impact

A stated FAA goal is to increase safety, which includes reducing the number of RIs (FAA, 2010). The TSS would contribute to the FAA's goal by enhancing pilot SA of aircraft location at runway crossings. In the gross majority of cases, the TSS would be a redundant system that does not greatly assist an already aware pilot. In the odd case where a pilot has lost SA, the TSS would send an invaluable, unmistakable signal to the pilot that he or she is about to enter a potentially dangerous area. There is no doubt that the events similar those described in earlier scenarios could happen again. The TSS would be another layer of defense in the fight to prevent those types of RIs. As an airport manager from a local airport said: "every little bit helps".

While it’s true that every little bit helps, finding ways to enhance pilot SA by adding even more visual and auditory cues can become an exercise of diminishing returns. New technology driven devices are often fighting for pilot attention in sensory modalities that are already saturated. Furthermore, there can be considerable financial costs associated with developing, producing, and maintaining these technical ‘little bits’ that will help. The advantage of the TSS is that it targets an untapped sense, which increases the likelihood of accurate perception (Wickens et al., 2004), and it does so at a relatively small cost, as we show in our benefits-cost section. The high impact and low cost are the TSS’s greatest strengths.

There are, however, potential limitations to the TSS’s impact. As mentioned earlier, a single TSS likely will not be able to send a signal to all aircraft types and sizes. Another potential limitation is snow removal. Any modification to the taxiway surface could impact snow removal operations and may prevent the successful deployment of the TSS in northern climates. Surface modifications on roadways are cleared of snow and so it stands to reason that the TSS could be designed to accommodate snow removal. However, roadways are not taxiways. Careful consideration of the tradeoffs must be given to the design of a northern climate TSS.

Lastly, the TSS may have a limited, or even negative impact if it is improperly designed and implemented. To simply use the FHWA design for roadway rumble strips on a taxiway would be ill advised. For one, the FHWA is concerned with a relatively small variety of wheel sizes that are relatively gently used, whereas the FAA must consider the tail wheel of a Piper Cub and the main landing gear of an A380 that are both designed for landing. The FHWA also has the luxury of not considering FOD, and many FHWA surface modifications are designed for high-speed traffic, whereas aircraft on taxiways are traveling at relatively slow speeds.

To have a positive impact on safety, the TSS must be designed for aviation and according to what our group used as our guiding principles. It must do no harm while stimulating the tactile sense and it must be tailored to each situation in a cost effective manner. We believe that the greatest impact can be achieved by focusing the deployment of the TSS to where it is needed most. This would likely be airfields with a high volume of training or transient traffic, non-towered airfields, airfields that host large fly-in events, and airfields with known hotspots. If properly designed and implemented, the TSS has the potential to have a significant positive impact on the FAA goal of increasing safety through the reduction of RIs.

a. TSS Implementation

We recommend a user and highest need driven implementation in order to maximize the impact of the TSS. We broke the TSS implementation plan into four phases: design, education, deployment, and evaluation, as shown in Figure 7. We have not explicitly outlined a pilot program for the TSS, though this may be a desirable course of action as a means of managing risk.

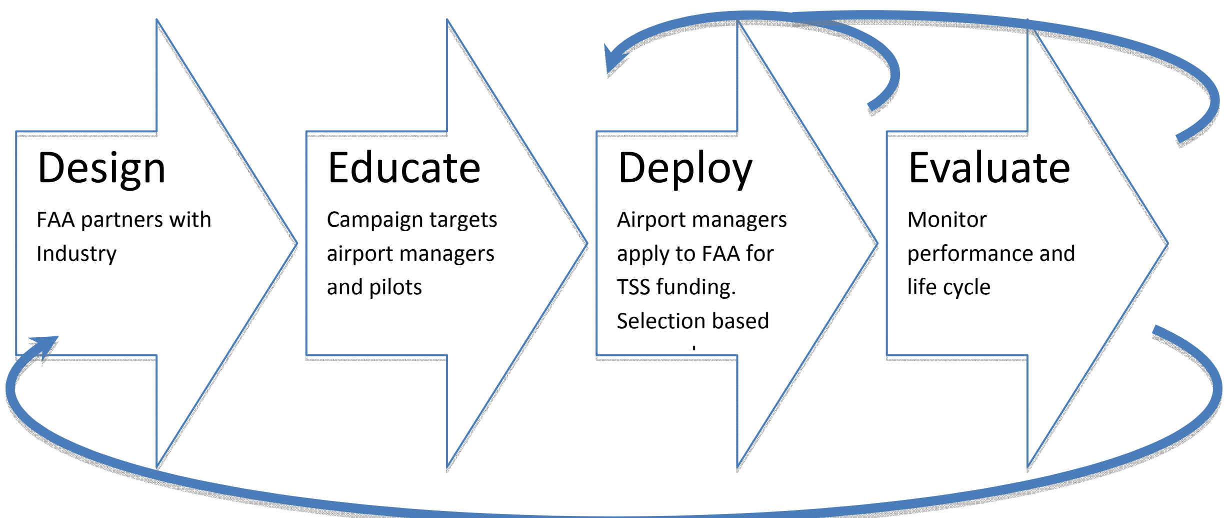


Figure 7. Phases of the TSS Design and Implementation Plan

i. Design

Our project team focused on using stakeholder input to assemble high-level requirements for the TSS. We also examined existing surface modifications to see which held the greatest potential for aviation. The next step would be for the FAA to partner with industry in order to further develop the requirements and produce an effective design. During the design phase, it will be important to maintain contact with the stakeholders we have identified.

The development of a design may involve developing several variations in order to accommodate different airfields. For instance, it may involve developing a northern climate TSS that sends a weaker signal, but can be cleared of snow, or it may involve developing TSSs that target different sizes of aircraft, though we recommend an initial focus on smaller GA aircraft.

ii. Educate

Once a design has been established, there would need to be an education campaign that targets several groups: airport managers, controllers, pilots, and passengers. Airport managers and controllers would need to know that the new system is available, what it can do, where it should be used, and what its limitations are. Knowing where it should be used and what the limitations are, airport managers would then be able to evaluate their own airfields and identify areas that may benefit from a TSS. They will also need to be taught about the TSS acquisition process. Controllers will need to know this information because they need to be aware of what systems are in use at their airfield. They will also need to be able to inform unfamiliar pilots.

Pilots will need to know that if they feel vibrations near the hold short lines, it is the normal operation of a new safety system. Likewise, pilots will need to know to educate their passengers. There was some concern from stakeholders that the vibrations would be unnerving to passengers. It is true that vibrations could be unnerving if the source is not known, but this can be overcome with an information brief. Pilots would explain to their passengers that the vibrations are normal and are from a system that is similar to the rumble strips nearly everyone has experienced on roadways. With this knowledge, the tactile stimulation from the TSS will pale in comparison to that of a landing and shouldn't alarm passengers.

iii. Deploy

To maximize the impact of the TSS, it should be deployed to locations on airfields that are at the highest risk of incidents such as those described in the scenarios described previously Nobody is in a better position to know these locations than the pilots, controllers, and airport managers themselves. Airport managers can evaluate and identify locations on their airfields that would benefit from a TSS based on their experience and feedback from controllers and pilots. The airport managers would then substantiate their need and apply to the FAA for funding to install a TSS. The FAA would then grant funding based on the substantiation provided. This way, it is the airport managers, with FAA encouragement and oversight, who will drive deployment of TSSs.

Initially, highest priority would be given to hotspots with a history of RIs that could have been prevented with the presence of a TSS. As system deployment progresses, other locations would be considered based on different criteria. Substantiation for other locations could include the lack of a tower and frequent use by junior or non-local pilots. The TSS program would not have to be a stand-alone process, but could be bundled together with other airfield improvement grants.

The strengths of this deployment technique are that it is user driven and focused on the areas of greatest need. It is the pilots and airport managers who will be encouraged to ask for the TSS, and not the FAA mandating that the TSS be used. This will likely increase user acceptance, since they are the ones requesting it, and has the potential to save the FAA considerable effort, since it will be the thousands of airport managers who are monitoring thousands of airports for appropriate deployment locations. That is not to say that the FAA's role is marginal. Ensuring that airport managers know about the system and what criteria are used to evaluate funding applications will be critical tasks.

As the highest priority needs are satisfied with TSS deployments, the FAA will then be able to consider lower priority locations that could also benefit from a TSS. Deployments are then iteratively rolled out to all airfields based on need.

iv. Evaluate

It will be nearly impossible to directly evaluate the performance of the TSS by tracking how many RIs it prevents. We suggest that it be noted whether a TSS was present in RIs as a means of evaluating performance. If a TSS was present for an RI, it will need to be established whether it was the nature of the RI or an actual failure of the TSS that allowed the RI to happen.

It would also be useful to gather TSS performance feedback from pilots and controllers. This could not only subjectively evaluate TSS performance, but would also give a feel for user acceptance. If the end users are not accepting of the new system, then it would be important to know why. This kind of information may lead to a redesign or to a halt to deployments. If, on the other hand, it is found that there is high user acceptance, then this will confirm that the system has a positive impact on safety and support further deployments of TSSs.

A second criterion that will need to be evaluated is durability. The design phase should produce a theoretical life cycle for the system, but the actual life cycle of TSSs should be monitored to confirm the theory. This will likely involve frequent inspections of the first several deployed TSSs. Instructions for more frequent inspections and feedback to the FAA should accompany the approval of the first several TSSs. Information on TSS durability will then feedback into the design process as necessary.

b. Commercial Potential

Based on stakeholder interviews and surveys, we concluded that there are many avenues in which TSS could be utilized by the aviation industry. Mr. Carl Schweizer (2010), a Project Engineering Coordinator at Daytona International Airport (DAB), stated that most runway designs are implemented by the FAA first on smaller scale. Therefore, our system design will initially be implemented at smaller airports that cater to general aviation and corporate aircraft, which also represents a large pool of potential customers. The FAA could support these smaller airports by providing funding as part of ongoing research to move the TSS design to larger scale airports. Mr. Carl Schweizer (2010) noted that although the FAA has a research facility for runway design testing, funding smaller airports would give them the ability to obtain real-world data. The TSS would be an affordable solution if the FAA combines funds with airports to make the system possible and achieve greater runway safety. After the design is evaluated in small settings, the design could be made to fit a larger scale airport.

The TSS is not a radical departure from existing paving technology and there would already be a pool of producers able to satisfy customer demand. For example, using the partnerships larger airports have with the FAA and contracted paving companies by assisting smaller airports with funds to hire contracted paving companies to implement the design in the initial phase.

VI. Financial Analysis

Intuitively, the TSS seems lower in cost than other existing technologies because it does not require expenditures such as electricity bills for lighting systems, money for configuring computer software or comprehensive training programs for operators. Existing surface modification technology in use on highways was described as “remarkably inexpensive” by Martin Markovich of Florida’s Department of Transportation (DoT) when contacted by the TSS team. To further substantiate this anecdotal evidence, we conducted a preliminary benefit cost analysis.

The team chose to examine the deployment of the TSS at runway hotspots. This was done to more accurately quantify our estimated costs and benefits because beginning here allows for a quick demonstration of the effectiveness of the TSSs. The FAA defines a hotspot as a “runway safety related problem area or intersection on an airport. Typically it is a complex or confusing taxiway/taxiway or taxiway/runway” (FAA, 2010b). Installing the TSS at these locations would have the greatest benefit per deployment and decrease the overall cost to FAA compared to implementing them at every airport and at every intersection.

For our analysis, we compared the benefit of preventing a RI to the cost of installing a TSS. The team focused on the cost of a Category A RI because other less severe RIs have smaller, less quantifiable costs. Due to incomplete data, the team made several conservative assumptions.

a. Benefit of TSS

To determine the benefit of the TSS we first looked at the cost of an accident involving this benefit as the prevention of an accident involving two general aviation aircraft. We assumed total loss of life and property. We also assumed that there would only be one pilot in each aircraft.

Cost = 2 (cost of a General Aircraft) x 2 (lives)

The FAA estimates the cost of a life at $5.8 million and the price of a general aircraft at $172,084 (FAA, 2008; GRA, Inc., 2007). This brings the cost of the accident in terms of aircraft and life to $12 million. This does not account for other costs such as clean up, delays, or investigations. For benefit cost analysis purposes, the cost of a Category A RI will be considered the same as a crash. We chose to do this is because a Category A RI is a “near” collision that was only avoided through chance or extreme action. This means that an accident was avoided only due to luck or extreme skill on the part of the pilot. Relying on luck or extreme skill for safety is unacceptable, which makes a Category A RI as unacceptable as an actual collision. Thus, for our benefit cost analysis, the benefit of preventing a Category A RI is the same as preventing a collision.

Deploying the TSS to runway hotspots is based on the assumption that if a RI already occurred in that location, another one will occur due to the challenging conditions of the hotspot. Our analysis is based on preventing the next RI at a hotspot.

We found that the occurrence of Category A RI’s due to pilot deviation between 2005-2008 was 30 out of a total of 2,166 incursions (FAA, 2009a, 2009b). The team then calculated probability that any one of the historical RIs was a Category A:

Cat. A (30)/RI (2166) = 0.01385

This gave us the likelihood that a pilot deviation RI would be Category A. These numbers of total RIs and Category A RIs due to pilot deviation include commercial air carriers and incursions that the implementation of TSS may not necessarily prevent, which represents data from areas that are beyond the scope of this analysis. To overcome this, the team assumed that a TSS preventable general aviation RI has the same likelihood of being a Category ‘A’ RI as all pilot deviation RIs do. Ascertaining the true probability would be a challenge due to underreporting at non-towered airfields, but our assumptions allow for a reasonable probability estimate and a sufficient level of confidence for the purpose of an initial benefit cost analysis.

To understand how much an RI costs, the team multiplied the cost of a Category 'A' RI by the probability a RI would be a Category A RI ($12 million x 0.01385). This equated to $166,200 per RI based on the cost and probability of Category 'A' RIs. In other words, the benefit of the TSS to preventing a single RI is $166,200.

b. Cost of TSS

The New York DOT quotes the cost of roadway rumble strips as price per foot: $0.30/ft. of 6 inches and $0.60/center line foot including equipment and labor. Carson and Miles at (2005) Texas A&M conducted research suggesting a uniform price of $1.50/linear foot across Texas. We researched further to find that the Maryland State Highway Administration (2005) quotes "a set of three, 20ft, fully transverse, above ground rumble strip at $6,200 along the Baltimore Beltway," which is roughly $2,000 each and which includes labor, equipment, and material some of the aforementioned prices are for transverse indent-style strips, while others are for above ground-style strips.

These figures represent installation figures for roadway rumble strips used by motor vehicles. As stated before, the TSS would be implemented on taxiways and would be subject to aviation standards. However, the team believes a comparison can be made for initial cost-benefit purposes using roadway rumble strips. The highest figure we were able to find was $2,000 per roadway strip system. Being an aviation system, TSS would likely be more expensive than roadway rumble strips. TO account for this, we multiplied $2,000 by a conservative factor of ten to estimate the cost of an aviation grade surface modification.

The cost of TSS maintenance will likely be negligible. The FHWA has found that surface modifications have little effect on the deterioration of asphalt or concrete surfaces (FHWA, 2011). In other words, they have the same lifecycle as surfaces that are not modified and will not require additional maintenance, though to be conservative, we have estimated $2,000 per TSS per year for maintenance and lifecycle tracking. Another cost will be awareness and education campaign, to which we have allocated $50,000 for the first year and $20,000 for subsequent years. We do not believe that a formal TSS training program will be required due to the simplicity of the system.

Table 5 is the projected benefit cost of a 100-system deployment over 5 years. We have assumed that 10% of the deployed TSSs will prevent a RI each year.

Table 5. Five Year Benefit Cost Analysis

Item	Estimated Cost	Estimated Benefit	Total Benefit
100 x Tactile Stimulation Systems	$2,000,000		
First Year Awareness Campaign	$50,000		
Maintenance and Lifecycle Tracking	$2,000/year		
Subsequent Awareness Campaigns	$10,000/year		
Total Initial Cost	$2,050,000		
Total Subsequent Annual Costs	$12,000		
Prevention of a Single RI		$166,200	
Annually, 10% of 100 x TSSs Preventing an RI		$1,662,000	
Year 1 (Benefit-Cost)			-388,000
Year 2 (B-C)			1,274,000
Year 3 (B-C)			2,936,000
Year 4 (B-C)			4,596,000
Year 5 (B-C)			6,260,000

Table 5 is based on a limited deployment, a likely over-estimation of cost, an estimation of benefit that does not take into account many ancillary benefits, and yet it still demonstrates the significant total benefit of the TSS. What the above analysis does not account for are costs associated with design and development, which are difficult to estimate at this time. Since the TSS is a simple design based on existing technology and does not involve software, costs will be relatively low and would likely be covered by our conservatively calculated total benefits.

Appendix A

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Appendix B-

Description of University

At Embry-Riddle Aeronautical University, what we do- and do best- is teach the science, practice, and business of the world of aviation. Since it was founded just 22 years after the Wright brothers' first flight, the university and its graduates have built an enviable record of achievement in every aspect of aviation and aerospace. The curriculum at Embry-Riddle covers the operation, engineering, research, manufacturing, marketing, and management of modern aircraft and the systems that support them. The university engages in extensive research and consulting that address the unique needs of aviation, aerospace, related industries.
Residential campuses in Daytona Beach, Florida, and Prescott, Arizona, provide education in a traditional setting, while Embry-Riddle Worldwide provides instruction through more than 130 campuses in the United States, Europe, Canada, and the Middle East, and through online learning.

ERAU prides itself for the diverse education its students receive. Academics at ERAU include aviation operations, meteorology, human factors psychology, systems engineering, software engineering, humanities, international relations, communication, mathematics, aerospace engineering, physics, business, and much more. The university community is additionally proud of the quality of the education obtained. Class size at both the Daytona Beach and Prescott, AZ campuses averages 24 students and the overall undergraduate student-faculty ratio at these campuses is 16 to 1. Low class sizes make possible the use of interactive and authentic approaches to learning, such as project-based learning approaches.
The university values community diversity and actively encourages diversity by means of programs aimed to support and provide education about minority groups, including ethnic

minorities, gender identity minorities, religious minorities, and students with handi-caps. Among its many efforts, the ERAU Office of Diversity Initiatives is involved in community outreach programs designed to foster interest in science, technology, engineering, and math among women and underrepresented groups in the K-12 educational system. During the summer months campus is home to GEMS (Girls Exploring Math and Science) and an aviation/aerospace program for all 6th graders at a local middle school.

Appendix C-

Description of Non-University Partners

Not applicable.

Appendix E

Faculty Advisor Dr. Kelly Neville

Any one of the TSS team members would have qualified as an effective team lead, but the group opted for a non-hierarchical structure in which responsibility was shared. And responsibility was shared very nicely. This flat organizational structure, also adopted by our RIPLS team, is atypical in engineering, as noted in team member Marshall Lloyd's reflections, but generally is effective for innovation teams. I was pleased that the TSS team had the opportunity to experiment with this type of structure and to see how well it could work for them in this competition setting.

The TSS team included students with diverse backgrounds who did an excellent job of learning from one another and supporting one another. The members of the TSS team were motivated, resourceful, and always willing to chip in and help one another out. The team members came to know and trust one another, and they came to have a greater respect for what can be accomplished by a team. I believe this particular team, especially, came to recognize the value of bringing together different areas of expertise. I noticed that when a team member needed assistance with his or her research or analysis, team members with relevant experience or knowledge would take the time to meet and work with that team member.

Through participation in this competition project, the members of the TSS team learned how much a team could accomplish in a short time. The members learned they can make a meaningful difference in the real world, and they also learned *how* to make a meaningful difference – they learned about processes, tools, and activities that allow them to accomplish such a significant feat. I think this is huge for students and emerging professionals—to be able to see that they are fully capable of creating something so extensive and to learn methods they can use to do it again in future endeavors.

One of the great aspects of this competition that is supported by this team's reflections is that students learn a lot no matter how experienced or knowledgeable they are going into it. The undergraduates benefit, and the seasoned professional who has returned to school benefits. On the TSS team, our experienced aerospace engineer learned new things about engineering teams and about aerospace, for example, and our pilots learned about the aviation world beyond the cockpit. The competition broadens perspectives, enriches understanding, and facilitates empathy and future collaboration among different groups.

The design competition was extremely motivating to the team because of its real world applicability. In addition, the competition challenges are posed in an unstructured way, which is both real world (no hand holding) and invigorating. Students have to start from scratch and they seem to really appreciate this, plus it allows them to develop a sense of ownership for and pride in their accomplishments. Students are not told how to identify, understand, or solve the problems, and this allows them to experiment with different approaches and encourages them to learn about different methodological options. I would absolutely use this competition in the future. It works very well for my students in its present form.

Katherine Kaste

You are told that Graduate school is the place where your fellow students become colleagues. I never understood this until this design competition. Here I learned that working together, asking for help and aiding others can lead to a strong piece of work.

The biggest challenge was synchronizing all of our times for us to meet outside of class. When we did figure this out, we were able to work as a cohesive team sharing ideas and working through difficulties.

The project at first seemed as though it was impossible, especially in deciding on a design in such a short period of time. However, it was amazing to see that once an idea was accepted and research began, how possessive and proud our team became of those designs which believe that is displayed in this paper. Being able to brainstorm, research and critically think about aiding such a large problem area in today's aviation was a great experience I was able to partake in. I would suggest this assignment to any other graduate class.

Heidi Klein

At the start of this project, I'm not sure I really understood what it all entailed. Early on in development, it seemed as though we really almost were not progressing and it was hard to see a final project in sight. Once we were able to settle on a concept though, things really started to come together quickly.

My favorite part of the project was working with such a unique group of people. When we sat down as a group we had two psychology experts, three pilots (two of which are flight instructors, one of which was an airline pilot), a Canadian military officer, and a future doctor. We not only learned about the project from each other but we learned about each other's lives, interests, and experiences. The experiences that led us all to get to where we are were the most fun part about the project. No two stories were alike.

As a CFI, I was extensively familiar with the flight side of the project, but it was surprising to see just how many people actually make an airport run. Each of the SME's greatly influenced the direction of our project. Along the way, we met some very helpful and informative people who ultimately helped make our project what it is.

Marshall Lloyd

I was surprised by how much I learned during this project. I initially approached it as just another assignment for just another class, but it ended up being an atypical experience. Coming from a military background, I am accustomed to working in clearly structured teams with clearly structured goals. This project, on the other hand, had very little existing structure. Early on in the process, I tried to impose structure to gain peace of mind, but this attempt was politely and resoundingly rejected. What emerged organically was a loose team structure with ill-defined responsibilities and a bare-bones schedule. This allowed team members to take on work that interested them and promoted a dynamic environment of analytical thinking. This loose dynamic encouraged the people with the right background and skill sets to collaborate on the appropriate tasks and produce maximum results.

I also learned quite a bit about air operations. I am an aerospace engineering officer and most of my career has been spent focusing on aircraft life-cycle management. For better or for worse, this has led me to view pilots as expensive. They are either breaking my planes and asking for them to be fixed, or highlighting shortfalls and asking for greater capabilities. This project forced me to look beyond the hangar and get a real feel for airport operations. This meant interacting with pilots in order to understand what goes on in the cockpit during taxiing. Furthermore, I had to look beyond the pilot to understand what everyone else is doing in order to support that aircraft's safe operation.

This experience has been invaluable and has expanded my view of systems engineering and aviation.

Kristi Lontz

The FAA Design Project has helped me not only gain a better understanding of system engineering, but more importantly teamwork and communication. There were only seven members of TSS team, the smallest of three groups assembled, and teamwork was essential in completing this project. We all came from different backgrounds and were able to pull together and design a system that we hoped would help make a difference.

Our biggest challenge was the inability to meet consistently outside of class due to conflicting schedules. Therefore, each member of the group relied on each other to complete their assigned tasks independently and be prepared to utilize class time effectively to report their status update, resolve problems, and distribute new tasks to each member. Each member was given opportunity to communicate their ideas and all were received in a professional manner. A great attribute of our team was the willingness to help each other. There was always someone volunteering to help others who needed help to complete their tasks in order to adhere to our timeline. I believe that the project completion is a success because of the manner in which we were all able to come together and work as a team to accomplish a goal.

Scott Matzke

It is always exciting for me to be involved with aviation related issues and perhaps be partly responsible for a solution to said issues. When the competition was announced in class I could not wait to get started. The most difficult part of the entire process for me was attempting to come up with a feasible solution for any of the problems for the provided categories. Thankfully, my team members were able to come up with several excellent ideas and we were able to select one quickly and run with it. A rapid selection was essential as we were on a tight deadline.

Working with a group of this size did not prove to be as difficult as I thought it was going to be initially. Class time was dedicated for meetings, so coordinating schedules was a moot issue. The main difficulties that arose were because of the fact that not everybody was as familiar with aviation as a couple of group members. I think that because of this, they might have been a little timid and unsure of their additions. Even with such a simple design, this was a project on a larger scale than I am used to. Never before have I been asked to design a system from the ground up, even if the technology in question already exists.

This was a personal project for me as well. Coming from an aviation background permitted me to view the system the way the typical user will. I did not want to help design a system that I thought would have had any negative aspects. I feel that our system would be a solid addition to almost any airport. Once pilots are briefed on the new system, I believe they will welcome it as well. As one local airport manager said during an interview, “Every little bit helps”. I would be honored, that if implemented, our system was even partly responsible for saving a life.

Aaron Paul

The FAA project taught me the different processes involved in system design. It also taught me to design an idea and analyze many different aspects like cost, user-friendliness, quality, ect. We learned to create a concept and design a system that will satisfy all users. Through this project I gained the experience of working with a dynamic team. Each individual had unique contributions. My teammates Marshall and Scott were good at brainstorming ideas, while others were good at compiling research materials, collecting, and finalizing documents.

We walked into our initial meeting with very basic knowledge on how to prevent runway incursions. We all were highly enthusiastic and energetic. We also learned that many of our individual brilliant concepts were not as wonderful after the group discussed. After two weeks of time working on the project, we conceptualized rumble strips and were able to begin the design process.

We were unable to find any previous research into the creation of rumble strip applications for runways. We are potentially the first group to make this concept a reality. Even though the idea seemed very feasible, there was tremendous lack of available data or previous research that was specific to our design.

After collecting all available and recorded data on runway incursion incidents, we began interviewing subject matter experts. It seemed like most of our subject matter expert's embraced the concept of rumble strips. A unique challenge this concept faced was the wide variety of airplanes that would be utilizing the system. It became clear to us early on that one single design would not work universally. However we were able to derive a system where specific groups at risk of runway incursions could be targeted.

We had a wide variety of industry support who provided us a wealth of personal experience and helped us generate various ideas. Through this research project I learned the importance of considering all users and stake holders before designing a system. I realized that a system should adapt to the user and not the other way around.

Wilfredo Rodríguez-Jiménez

This FAA project was an integral part of our graduate class “Systems Concepts, Theory and Tools”. It was an excellent way to get acquainted with systems engineering topics. As we progressed through the semester in terms of our exploration of different systems engineering concepts, our team was able to apply that new knowledge to develop our Tactile Stimulation System. Among the systems engineering topics that we explored in order to develop our system were: stakeholder analysis, analysis of relevant work domain, house of quality, configuration management strategies, Department of Defense architectural framework, systems modeling language, safety management system for safety risk assessment, and impact analysis.

Even though I do not have prior experience in the aerospace industry field, I enthusiastically accepted the challenge of performing both the safety risk assessment and the human-systems integration assessment. The process was arduous but I was very fortunate to have the support from my excellent teammates. Our team was international and diverse. Together we complemented each other in terms of our background and experiences. Overall, the learning process has been very rewarding.

Appendix F

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