

COVER PAGE

Title of Design: AIRIP: Advanced Integrated Runway Incursion Prevention

Design Challenge addressed: Runway Safety/Runway Incursions/Runway Excursions

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Advanced Integrated Runway Incursion Prevention

*Increase Communication, Increase
Situational Awareness, Increase Safety*

By:

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Executive Summary

This paper disseminates the lifecycle process our design team used to engineer the Advanced Integrated Runway Incursion Prevention (AIRIP) system. AIRIP increases runway safety by inexpensively augmenting the current Airport Surface Detection Equipment, Model X (ASDE-X) system. ASDE-X has been implemented at 35 of our Nation's busiest airports to combat runway incursions and enhance safety. Continual increases in runway incursions at airports equipped with ASDE-X suggest that its implementation alone is insufficient. Current ASDE-X alerts improve situational awareness (SA) of air traffic controllers (ATC) but inevitably are delayed as they are relayed to pilots. The time difference of an averted mishap and a catastrophe can be a matter of seconds. Rather than wait for ATC to process and divulge an ASDE-X-generated warning, AIRIP allows both pilots and controllers to receive this highly time-sensitive information simultaneously.

AIRIP has been designed to fill a dangerous gap in the current ASDE-X set-up. AIRIP would instead immediately broadcast an ASDE-X warning via radio transmission to pilots in the runway environment. AIRIP would automatically alert pilots instantly to ASDE-X outputs allowing quicker initiation of the appropriate evasive action.

Our diverse team collaborated to develop AIRIP using human factors and systems engineering methods and design processes. These methods included a comprehensive literature review, stakeholder analysis, safety risk management assessment, human systems integration planning and with the elicitation of feedback from multiple subject matter experts (SMEs). AIRIP is a cost effective solution that addresses one of the most critical safety-improvement needs identified on the NTSB's "Most Wanted" list.

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List of Acronyms

ACs: Advisory Circulars

ADS-B: Automatic Dependent Surveillance- Broadcast

AIRIP: Advanced Integrated Runway Incursion Prevention

AMASS: Airport Movement Area Safety System

ASDE-X: Airport Surface Detection Equipment, Model X

ASSC: Airport Surface Surveillance Capability

ATC: Air Traffic Control

AXSL: ASDE-X Safety Logic

CAST: Commercial Aviation Safety Team

dB LIN: Unweighted Decibels

GA: General aviation

GNSS: Global Navigation Satellite System

ICAO: International Civil Aviation Organization

ILS: Instrument Landing System

NAS: National Airspace System

NEAR Lab: NextGen Advanced Research Lab

NOTAMs : Notices to Airman

NTSB: National Transportation Safety Board

PIC: Pilot in Command

RIMDAS: Runway Incursion Monitoring, Detection, and Alerting System

RWSL: Runway Status Lighting System

SA: Situation Awareness

SMEs: Subject Matter Experts

SMS: Safety Management System Manual

VHF: Very High Frequency

1 Problem Statement and Background on Problem Area

Both the Federal Aviation Administration (FAA) and the National Transportation Safety Board (NTSB) consider runway incursions to be one of the most serious safety concerns in aviation. From 2004 to 2007 there were approximately 250 million operations in airports with towers, with 1,353 of these classified as runway incursions (FAA, 2011). Following the 2008 release of a new definition of runway incursions, the annual number of incursions increased dramatically compared to the number per year in previous years. The year of 2008 alone saw 1,009 runway incursions over the course of 58.4 million operations (FAA, 2011).

The NTSB clearly identifies runway incursion prevention as one of the most sought after safety improvements in aviation (e.g., Jones & Prinzl, 2006). According to the FAA's *Runway Safety Report* of June 2008, the official definition of a runway incursion is, "any unauthorized intrusion onto a runway, regardless of whether or not an aircraft presents a potential conflict" (Runway Safety Report, 2008b, p.4).

There are six general categories of runway incursions (ICAO, 2007, p.15).

- Aircraft/vehicle crossing in front of an aircraft landing
- Aircraft/vehicle crossing in front of an aircraft taking off
- Aircraft/vehicle crossing the runway-holding position marking
- Aircraft/vehicle unsure of its position and inadvertently entering an active runway
- Breakdown in communications leading to failure to follow ATC instruction
- Aircraft passing behind another aircraft or vehicle that has not vacated the runway

Runway incursions can also be categorized by error type: operational errors (OEs), pilot deviations (PDs), and vehicle/pedestrian deviations (V/PDs). Operational errors are

strictly errors by air traffic control personnel, whether that means an improper clearance onto an active runway or an unsafe distance allowed between aircraft. A PD occurs when a pilot violates an FAA regulation, and a V/PD is any incident where a vehicle or pedestrian is present on a runway without ATC clearance (FAA, 2009c).

Lastly, runway incursions are classified by level of severity. These categories range from “A”, which is assigned to the most severe incursions (closest to an actual accident), to “D”, which is assigned to the least severe incursions. Figure 1 provides definitions for each category of runway incursion.

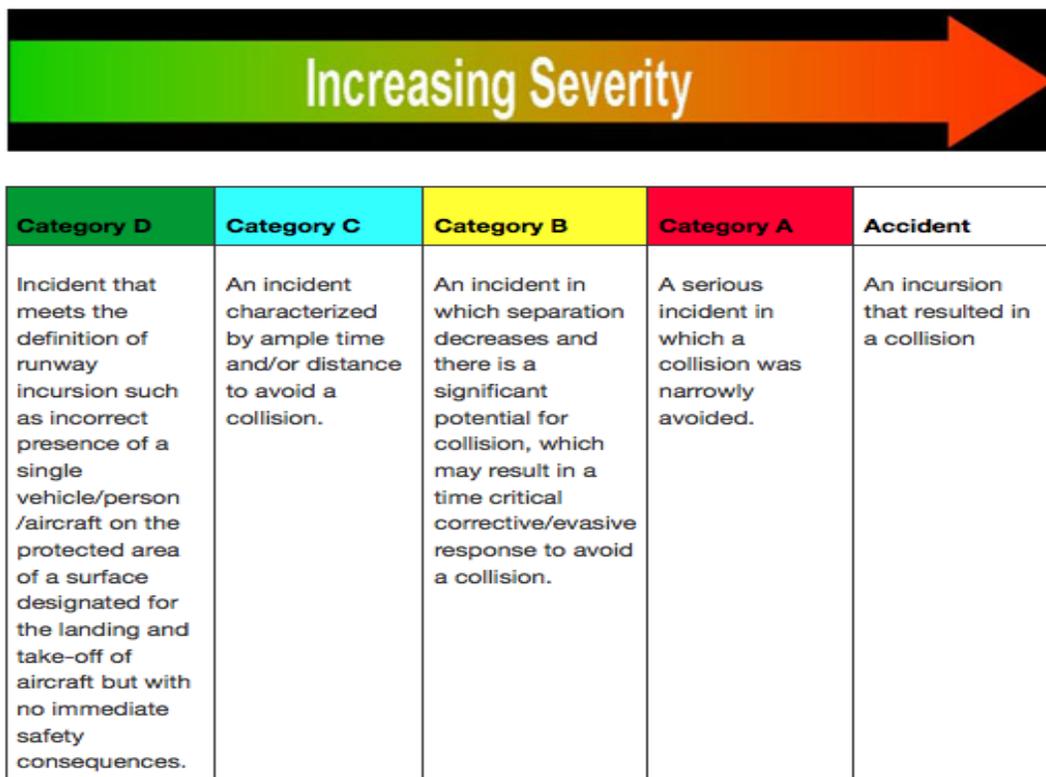


Figure 1. Runway Incursion Classification by Severity (FAA, 2009c)

According to the FAA’s National Runway Safety Plan (2009c), most runway incursions are caused by PDs. From 2004 to 2007, PDs accounted for 55% of runway incursions and they increased in 2008 to 63% (FAA, 2011). These deviations can be the

result of a miscommunication between ATC and a pilot or a pilot's loss of SA. For example, the pilot might mistake their location or believe they are cleared to enter a runway when they really are not (ICAO, 2007).

According to a 2002 study by the U.S. Commercial Aviation Safety Team (CAST; 2002, as cited by the Airline Pilots Association, 2007), it is possible to reduce runway incursions by 95% by improving technologies that increase pilot SA and providing alerts of potential risks to both pilots and ATC.

Our design, the Advanced Integrated Runway Incursion Prevention (AIRIP) system, will overcome lost SA by directly alerting a pilot of a possible incursion. AIRIP will be integrated with the ASDE-X system to provide an automated audio warning of a possible incursion directly to pilots. The benefit of our system is the reduction in time it will take to notify pilots of a possible incursion. One problem with the current ASDE-X system is that it only alerts ATC of possible incursions. ATC has to deduce from the situation which pilots are involved and manually notify them over the radio. AIRIP will eliminate the time span for ATC to notify pilots by directly transmitting a warning to pilots. The warning will be similar to the one transmitted to ATC from the ASDE-X system. Not only does AIRIP cut down on notification time, it will also decrease workload for ATC. The warning will be aircraft call sign specific in order to reduce confusion between pilots. This warning will be conveyed through a mandatorily monitored frequency at AIRIP equipped airports. AIRIP will help to mitigate safety risks by promoting runway incursion avoidance.

Our team extensively reviewed literature, interviewed a variety of subject matter experts, analyzed existing systems and other methodologies designed to prevent runway

incursions to create AIRIP – a simplistic solution promoting runway incursion avoidance at airports throughout the United States in the most economical, efficient manner possible. The ease of implementation and low cost will allow AIRIP to be actualized at any airport that is supported by the ASDE-X system. This report describes our system engineering process approach from initial concepts and research through conceptual and preliminary design phases. We describe how we identified the AIRIP concept as a plausible strategy for reducing runway incursions, the design of the auditory characteristics of the AIRIP alert, the integration of AIRIP with ASDE-X and runway operations, and how AIRIP will address stakeholder priorities and concerns. We also provide a cost-benefit analysis, implementation and commercialization plans.

2 Related Technology

To gain a solid understanding of the runway incursion avoidance project scope we began extensive research into existing technologies and analyzed a variety of potential solutions.

2.1 Airport Surface Detection Equipment, Model X (ASDE-X)

The Airport Surface Detection Equipment, Model X (ASDE-X) is new existing technology recently implemented at thirty-five of the nation's busiest airports in order to reduce the frequency and severity of runway incursions. ASDE-X is a surveillance system used by air traffic controllers for the prevention of runway incursions. Its Saab Sensis Multi-Sensor Data Processor integrates a variety of sources— surface surveillance radars, multilateration sensors, the Automatic Dependent Surveillance-Broadcast (ADS-B) system, and aircraft transponders— to track the movement of aircraft on an airport surface (FAA, 2011). When a runway incursion is detected, ASDE-X alerts ATC directly

through auditory alarms and visual displays (SAAB Sensis, 2012b). The controller's interface to ASDE-X is a colored display of the airport map that includes the current positions of all aircrafts and vehicles on the surface and specific aircraft identification (FAA, 2011).

2.2 Automatic Dependent Surveillance-Broadcast (ADS-B)

The FAA is also working towards transforming ATC from a ground radar-based system a satellite-based system using ADS-B. Integrating the precision and reliability of GPS with aircraft avionics and ground receivers is a monumental supplement increasing safety in the National Airspace System (NAS). ADS-B can superimpose the location and trajectory of properly equipped aircraft to controllers' computer displays and on cockpit moving maps according to Takemoto and Jones of the FAA (2010). This was a standalone technology that was often paired with the Airport Movement Area Safety System (AMASS). AMASS collected and analyzed the tracking data from ADS-B and alerted ATC with a visual alert on their monitoring screens as well as an auditory alert in the tower. The two technologies worked together to predict and prevent potential runway conflicts (Trexler, 2004). The main strength of ADS-B is that it allowed controllers and pilots access to the same information. Pilots could see other ADS-B equipped vehicles in the air and on the ground from inside their cockpits, and controllers were able to view synchronous movements on the entire ground surface. This improvement is especially beneficial during low visibility weather conditions. Particularly if visibility is poor, ADS-B provides a supplemental aid to SA helping pilots and controllers visualize the spatial relationships of aircraft and their surrounding environment. Accuracy, clarity, simplicity

and improvement of SA were the main benefits of this operating model (Takemoto & Jones, 2010).

2.3 Runway Status Lights (RWSL)

ASDE-X has great potential as a source of reliable and detailed airport surveillance data that can be leveraged to support a variety of airport systems. One such system is called Runway Status Lights (RWSL). This system is integrated with ASDE-X and utilizes the radar and detection components. RWSL consist of red light bulbs embedded in the pavement's surface. When the runway is occupied, the lights come on in the area in which the ground-based radar detected the threat. Situations in which the lights turn on are potential incursions, unsafe conditions for crossing an intersection, and unsafe conditions for beginning a takeoff. After the lights come on, pilots must hold their position until given clearance to proceed from ATC.

The benefit of this system has been recorded by the FAA as a 70% reduction of runway incursions where implemented (Takemoto, 2009). Weaknesses of this system include getting the attention of the pilots involved. The pilots must be looking out and ahead in the cockpit to see the visual alert. If the pilot is distracted or focusing his attention inside the cockpit, this alert will go unnoticed. Because of regulations, the lights must only be viewable by the aircraft meant to be signaled, this requires the lights to be specifically directional reducing visible light emanating towards incorrect target locations. Because aircraft are different heights and sizes, the angle and projection of the lights may not accommodate all aircraft structural designs and therefore may not effectively reach all operators. Pilots may not see the RWSL indication because certain aircraft body type and position may block the trajectory of the light possibly causing the pilot to miss the alert

completely. RWSL systems augment runway safety but leave room for unfulfilled requirements, strategies and tools.

2.4 Runway Incursion Monitoring, Detection, and Alerting System (RIMDAS)

A forthcoming technology that has not yet been implemented is the Runway Incursion Monitoring, Detection, and Alerting System (RIMDAS). RIMDAS is a low cost, flexible, and scalable system that will directly alert pilots and ATC of a predicted incursion by an audio alarm. It offers the benefit of increased, joint SA of pilots and controllers. Unique advantages of RIMDAS are its robust monitoring system and low implementation cost. The sensors RIMDAS utilizes are inexpensive, independent, and match the performance of those currently used in ASDE-X systems. Each ground based sensor, called a 'mote', detects acoustic energy, infrared energy, and vibration. A mote will collect and store information while receiving current or stored data and transmitting it to surrounding motes. Each mote passes information by transmitting to an adjacent mote until the final destination is reached. These transmitters can communicate even if one or more motes in a series fail (Squire et al., 2010). False alarms are also drastically reduced from the RIMDAS system by the collaboration in computation from multiple sensors - a robust mark of this system. When an incursion is detected, an auditory alert is sent simultaneously to ATC and to aircraft radios. A single mote has a price tag of \$25 while an airport requiring 40,000 feet of monitoring will have a system life-cycle cost of \$623,592. A similarly sized airport would spend \$5.1 million on an ASDE-X system (Squire et al., 2010). The motes and corresponding technology have widespread use although the system itself has not been implemented. Despite the many benefits of RIMDAS, at this point it has not been prototyped or implemented at any airports. Also, as

with any system, it has areas in which improvement is needed. Since RIMDAS is not yet actualized, much time would be put into adapting the system to meet federal regulations, and a lot of money would have to go into the implementation. Since AIRIP is a supplement to ASDE-X which currently exists at 35 airports, meeting federal regulations will not be as significant of an obstacle, and implementation will be far less expensive. Another way in which AIRIP will improve upon RIMDAS is that AIRIP will send the alert over a secondary monitored frequency so that all pilots monitoring that frequency will hear the alert. The alert will specifically address the appropriate aircraft's call sign eliminating confusion. We believe that with broadcasting the alert over a secondary radio frequency, AIRIP will not only increase the SA of the pilots directly involved in the ground conflict, but also that of the operators of other vehicles in the conflict proximity. AIRIPs call sign specificity will help to eliminate further complications associated with pilot reactions to such a warning.

3 Concept of Operation

The AIRIP design concept is based on our literature review and what we have learned from SMEs during interviews and facility tours. These research activities were instrumental in our design of a feasible and affordable system concept that will reduce the probability of runway incursions and increase safety. AIRIP will relay ASDE-X alerts of possible runway incursions over a secondary radio frequency monitored by the pilots. The operation of the system is described in the following section.

The targeted population for the use of AIRIP is commercial and general aviation pilots who fly to ASDE-X equipped airports. AIRIP would work in conjunction with the ASDE-X system. ASDE-X enables ATC personnel to detect potential runway collisions

by providing the position and identification of aircraft and transponder-equipped vehicles at the airport, as well as aircraft flying within five miles of the airport (Jones, 2010). ASDE-X receives data from a variety of sources such as the surface movement radar located on the ATC tower, multilateration sensors, ADS-B, the terminal automation system and aircraft and ground vehicle transponders (Jones, 2010). ASDE-X also consists of the ASDE-X Safety Logic (AXSL), which enhances ATC situation awareness by detecting and alerting ATC about a wide range of potential collision situations; for example, when two aircraft are moving toward each other in a potential head on situation, and when aircraft are landing or departing on an occupied runway, as well as crossing a hold short line of an occupied runway.

The current ASDE-X system alerts controllers with an aural tone followed by a voice message such as, “Runway 29 occupied” via a direct hard line from detection processors to the controller. Since ASDE-X only alerts air traffic controllers of potential runway incursions, an additional alert sent directly to the pilots is needed in order to reduce the delay between ATC receiving the alert from ASDE-X and pilot receiving the alert from ATC. When runway incursions are detected, AIRIP will send an automatic auditory alert directly to all of the aircraft monitoring the ASDE-X alert frequency at the same time as the alert is sent to ATC. AIRIP will relay the same alert for positive detection of a pending incursion simultaneously from the processors, to aircraft pilots and vehicle operators over the secondary Very High Frequency (VHF) monitoring frequency. This approach is the fastest way to alert pilots and controllers to the impending dangerous situation.

Following the alert, ATC will provide pilots involved with specific instructions for avoiding the incursion. The AIRIP alert will start off by emitting a continuous tone of 500 Hz and 40 dB LIN (unweighted decibel) tone for one second, which will be immediately followed by a call-sign specific message informing the involved/implicated pilots of a potential incursion. This alarm sequence is both described and justified in Human-System Integration section of this report. A detailed diagram of how AIRIP would be operated and used by pilots is shown in Figure 2.

AIRIP simply requires aircraft to be equipped with a transponder, and dual VHF communications radios in order to monitor a secondary alerting frequency. Most GA aircraft are already equipped with these installations. Since the change to the current system is more procedural, it doesn't require any recertification cost for installation and use of new hardware on aircraft. This advantage makes the fiscal feasibility of implementing the AIRIP safety system well within reason for scheduled and non-scheduled commuters as well as GA operators.

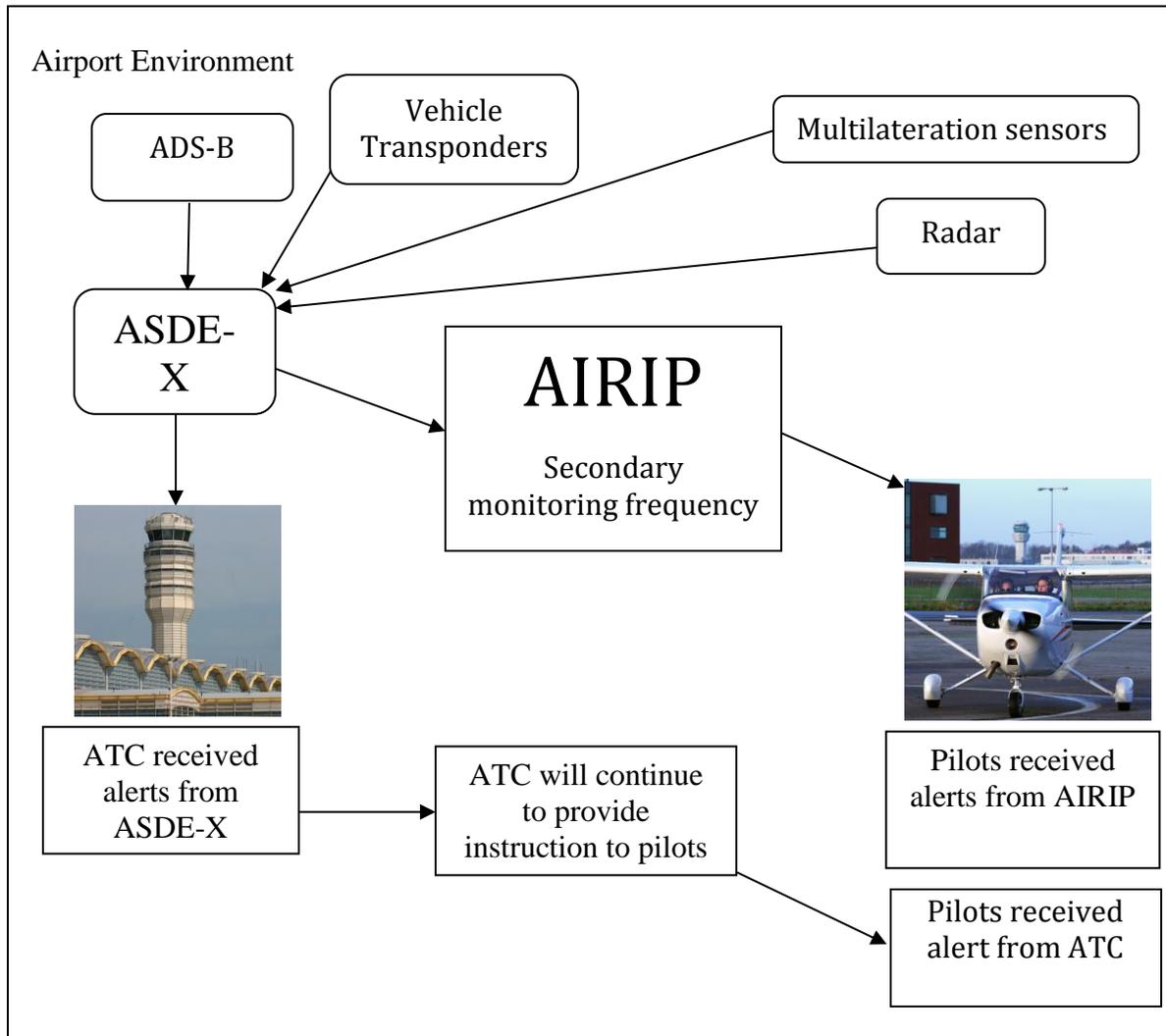


Figure 2. Concept of AIRIP operation

Pilot in Command (PIC) decision making processes, risk management and adherence to runway incursion avoidance procedures should be initiated as soon as possible for safe evasive actions to be executed. In an emergency situation, PIC of aircraft and vehicle drivers need to make prompt, rational, life-saving decisions while

controllers still provide assistance and conflict resolution instructions. A feasible early warning system is proposed with the use of AIRIP.

Overall SA of the pilots is immediately heightened by the AIRIP transmission alert. Reaction time of pilots from the time of the alert will instigate correction for avoidance of a potential for disaster sooner, increasing safety. This systematic enhancement will certainly help to reduce the chances of Category A and B runway incursions.

4 Human System Interaction

One of the most important aspects of a system is how well it addresses users' goals, the demands they face, and their activities. Since AIRIP involves an auditory warning sent to pilots, it is vital that the needs of the pilot are considered in the design of the alarm. It is important that the alarm be designed at a high enough pitch and amplitude to sufficiently warn the pilot of a potential incursion.

Haas and Edworthy (1996) found that the best combination of frequency, pulse interval, and amplitude for audio warning systems is a tonal frequency of 500 – 800 Hz, a pulse interval 0ms, and amplitude of 40 unweighted decibels (dB LIN) above ambient noise. In their comparison of auditory alert tones, Haas and Edworthy also found that using these levels results in the shortest response time to the alarm. Therefore, the AIRIP alarm will start off with a continuous sound at 500 Hz and 40 dB LIN for one second. Even though research specifies these frequencies, intervals, and amplitudes as being the best for alarm tones, it is important that we verify that these truly are the best levels for our system. Therefore, we plan to test and evaluate a variety of different alarm designs through simulations in a laboratory setting.

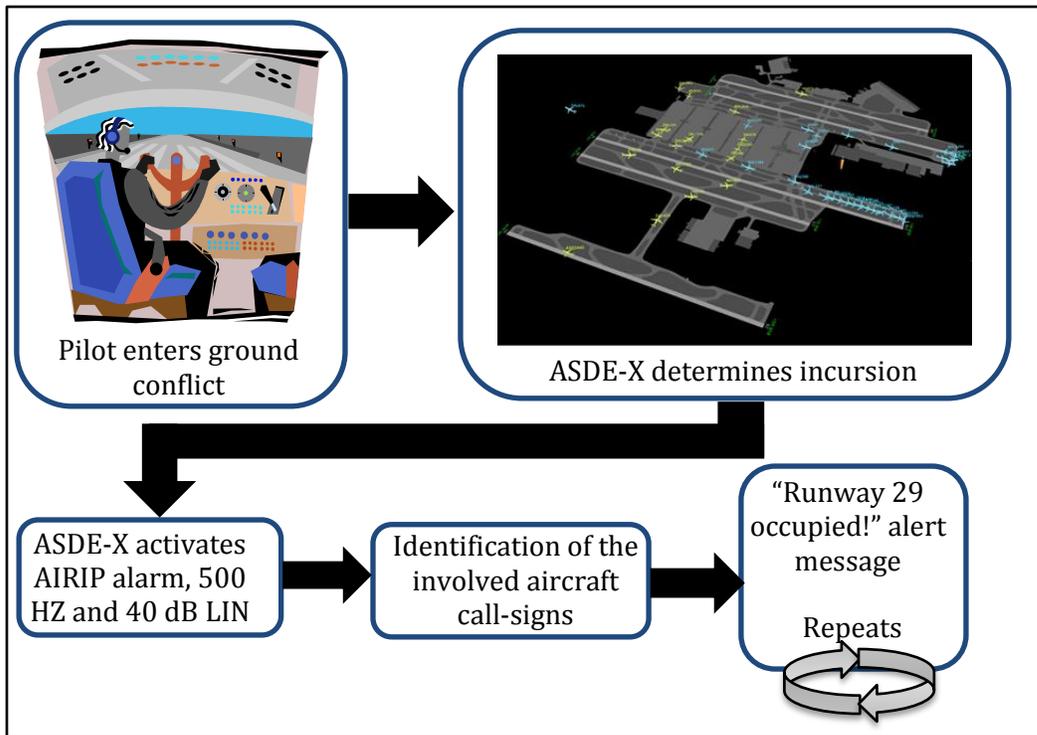


Figure 3. AIRIP Flow Diagram

Additionally, since the AIRIP alarm will be broadcast over a secondary radio frequency and will thus be received by all the pilots monitoring that frequency, a critical aspect of the alarm design is that it is also call-sign specific. Since the ASDE-X system identifies the call-signs of all the aircraft preparing to land or take-off at the airport, the AIRIP system will use ASDE-X to send the alert to the pilots. This will enable the alarm to specifically identify, by call-sign, the aircraft in danger of an incursion. Therefore, following the initial 1 second warning tone, a verbal message will be sent over the monitor frequency. This message will first identify the one or more implicated aircraft by call-sign, followed by the message, “runway occupied,” or “incursion alert” depending on the location of the incursion. This will be repeated until ATC contacts the pilots on the ground with instructions. For aircraft preparing to land, the system will calculate whether

or not the pilot has time to abort the landing and if so, the alert will also tell the pilot to go around (see Figure 3).

By incorporating each of the above features into the design of the AIRIP system, the risk of the alarm not being sufficiently detectable by the pilots is virtually eliminated. Also, by sending these alerts directly to the pilot, rather than to the controller who must then relay the alert to the pilot, their reaction time for avoiding the potential incursion is greatly decreased. Not only will this system improve the reaction time of the pilots involved in the potential incursion, but it will also improve the SA of all the pilots monitoring the secondary frequency. This is important because even if they are not involved in the incursion, it is important for them to be aware of its occurrence so they are prepared to avoid the location of the potential incursion if necessary.

5 System Development Methods

The design team developed the AIRIP design concept gradually and iteratively as we progressed through the project, an approach that is consistent with the Evolutionary Prototyping Lifecycle Model (e.g., McConnell, 1996; see Figure 4). In

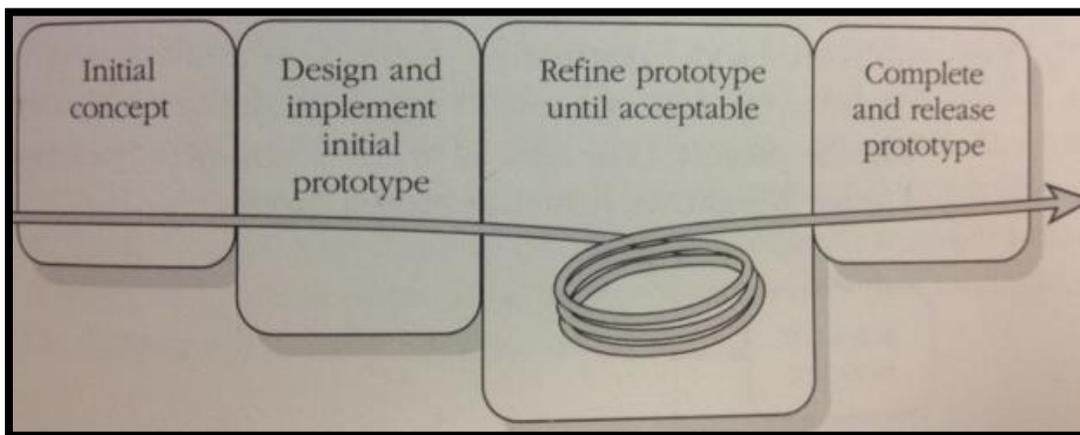


Figure 4. The Evolutionary Prototyping Life Cycle Model (Adapted from McConnell, 1996). Note, Box sizes represent the amount of time typically spent in each phase

accordance with the Evolutionary Prototyping Life Cycle Model, the AIRIP team first came up with the initial concept, design, and drafted the initial prototype. As our team continued to research and present the prototype to various SMEs, the design was elaborated and new prototypes were drafted. Evolutionary prototyping is appropriate because our requirements changed rapidly. The advantage of this life cycle model is that it allowed us to look for new ways to improve AIRIP during the project and to develop and refine the AIRIP requirements over the course of our effort. Further, this iterative life cycle model increased our chances of designing a system that would be considered useful by its users (McConnell, 1996).

5.1 Overview of the Design Process

In the beginning of the project, our team decided to design a system to reduce runway incursions. On the basis of our initial research and brainstorming, we came up with an initial concept, which was to install a red and green light on the runway hold short line. After that, our team identified stakeholders, stretched paper-based prototypes, and talked to SMEs about the feasibility of our design. However, after reviewing more literature on runway incursions, we realized that red and green lights had already been implemented at some airports in the form of the Runway Status Lighting System (RWSL).

Since we had decided to utilize an evolutionary prototyping approach, our group was able to be flexible about revising our design. Thus, we spent numerous group meetings coming up with different system concepts for mitigating runway incursions, while continuing to review literature and seek SME feedback. After almost a month of researching and debating what our new product should be, we decided to concentrate on an auditory alert to pilots to supplement the ASDE-X system. We presented our idea to

Professor Martin Lauth, a former tower controller, and based on the feedback we received, it seemed that such a system could be useful. Our team continued to research the concept, reading and seeking inputs from SMEs with various backgrounds to refine and evaluate the AIRIP design.

5.2 Project Risks

Our team encountered many challenges and project risks during this effort. Some of the risks that we encountered were the limited schedule, the amount of knowledge we had to gain in a very short time period, the amount of work to be done, and the difficulty of defining and sticking to a manageable project scope. In order for us to mitigate these risks, our team identified and addressed the potential risks systematically (Table 1).

Table 1. *Overview of the Development Risks Encountered*

Type of Risks	Team's Approach
Three Month Schedule	<ul style="list-style-type: none"> • Schedule enough time for design • Create a timeline and established deadlines
Lack of Knowledge	<ul style="list-style-type: none"> • Seek SMEs • Conduct literature review • Attend airport tour and ATC tower tour
High Workload	<ul style="list-style-type: none"> • Delegate workload evenly • Establish good team work
Expansion of Scope	<ul style="list-style-type: none"> • Use customer oriented practices, such as implementing features that are necessary for the users • Focused on what users really need instead of what they may want. The latter can be addressed in future AIRIP versions.

6 Interactions with Industry Experts

Interactions between industry experts and our team were crucially vital throughout the process of creatively engineering our design. Each interaction with experts increased our knowledge, prompting multiple design revisions as we learned more about

specific stakeholders' desires, goals and needs. Conducting interviews for research greatly augmented our understanding of the most advanced aviation runway safety systems currently in place, in test phases and under development. Where the United States NAS currently stands in the breaking front of aerospace technology couldn't have been explained to us better than by subject matter-entrenched industry professionals.

During interviewing, we realized there is no direct, immediate alert to pilots of a possible runway incursion even at the nation's busiest airports that host the most cutting-edge, innovative technology. The advancement that comes closest to a direct warning to pilots is provided by the RWSL systems. The reason most of us have never seen a RWSL in use is one downside of the system: it's exorbitantly high project lifecycle cost averaging about nine million dollars over the course of five to eight years (Federal IT Dashboard, 2012.) Our solution, AIRIP, is a simple, instantaneous alerting method that will flexibly work just as well for airline captains as it will for the weekend and leisure GA airman.

6.1 Martin Lauth

The first industry expert we established contact with was Martin Lauth, our project co-advisor and an ATC Tower Instructor at Embry-Riddle Aeronautical University with over 27 years working in ATC and recent experience working on multiple FAA-sponsored NextGen research projects. We brainstormed our original idea of a simple red light/green light system with Mr. Lauth and we addressed how these signals in particular could have a certain amount of interference with current ATC light-gun signals from the tower. It also became quickly apparent how costly it would be to

change that much physical infrastructure on an airport surface. Another negative aspect we realized about this first idea was that it would increase controller workload.

We decided we needed to find out more about existing technology and eventually we entered the realm of automated surface detection systems such as ASDE-X. Mr. Lauth arranged a tour of the Orlando International Airport ATC tower for some of our team members to see how the ASDE-X system actually works. An employee there displayed the system in action for demonstration purposes on a closed runway. We also toured the ASDE-X controller training facilities to see how controllers are introduced to its use and operation. We saw some of the most state-of-the-art ATC facilities and were surprised to find a serious need for improvement in the area of human system interaction when it came to the ASDE-X displays and interfaces.

ASDE-X has had great success; we learned of the procedures in place with the system and also found room for improvement. Back on campus we watched a few animations of events where the ASDE-X system proved it did have flaws, demonstrating that runway incursion incidents of great severity were still occurring while the system was in use. One problem that was very apparent was the length of time between ATC receiving the ASDE-X automated alert and then notifying the pilots over the radio efficiently with instructions was unacceptably long, about four very critical seconds.

Determining how to reduce this time and get a faster alert to the pilots so that they could begin taking evasive action sooner became our focus. Pilot and vehicle deviations frequently involve GA aircraft. GA operating costs are comparatively low, so we brainstormed ideas that wouldn't create undue cost to GA operators. Special consideration to GA operators is necessary because they are participants in the majority

of runway incursions, so we designed the aircraft user side of AIRIP around equipment that is standard to most GA aircraft: communication radios. AIRIP can help to reduce these PDs, vehicle deviations and operator errors leading to runway incursions with a simple, cost effective implementation plan.

6.2 Carlos Castro

In order to research relevant, emerging, innovative technology to enhance, we decided to try and learn as much as possible from sources who are actively working towards similar goals for the FAA. This approach led us to contacting experts in the field who work on FAA NextGen research and development. We wandered into the building that houses the NextGen Advanced Research (NEAR) Lab at the Embry-Riddle Aeronautical University campus, the Advanced Aircraft Flight Simulation Center and set up a meeting to speak with Carlos Castro, a NextGen Project Manager. In the meeting with Mr. Castro we discussed advanced runway and airport surface detection and alerting systems like ASDE-X and RWSL and potential problems and short comings with current technologies and their uses. We discussed the idea of integrating the newest systems of surface detection equipment with a secondary monitoring frequency for alerting pilots. We also discussed the use of transponders on all NAS aircraft and airport vehicles so that ADS-B paired with surface detection systems to reference position and provide alerts to vehicle operators facing possible runway and taxiway incursions.

Mr. Castro brought risks to our attention if using only transponders for position, including transponder failure, an incorrect beacon code, or inappropriate mode selected by an operator. Our assessment and mitigation of these risks is outlined in Table 5: Identified and Assessed Hazards and Mitigation Priority for AIRIP System.

We specifically sought the most cost effective way to appeal to the safety and success of the NAS. These considerations led us to contact other subject matter experts closely involved with the most current innovations and implementations of runway safety equipment and systems.

6.3 Don Gunderson

Dr. Kelly Neville, our instructor and project co-advisor provided us with some expert contacts as our design was developing. Our team reached Don Gunderson, a former Air Traffic Controller with 10 years of Navy experience and 24 years of work with the FAA. Mr. Gunderson was one of the eight original members of the ASDE-X work group who designed the system. We knew we had a valuable reference in Mr. Gunderson as a seasoned, entrenched professional.

Mr. Gunderson is a training lead for ATC operators of ASDE-X, RWSL, and Airport Surface Surveillance Capability (ASSC) efforts, prepping controllers for their use of and integration with these new systems and accompanying changes to their work environments. ASSC is one of the newest systems which will soon be tested (ASSC, 2011). The key change it brings to current surface detection system is the elimination of the costly ground radar elements, instead solely relying on transponder operation and ADS-B position mapping. Mr. Gunderson spoke with us about the idea to remove the ground radar component from the current surveillance system, and switch to the efficient multilateration of transponder signals through ADS-B to determine position and threats instead and he explained why efforts such as ASSC are leaning this way. ASSC systems are more financially economical as well as functionally efficient, compared to systems using ground radar, providing fewer false alarms and nuisance alerts to controllers. We

talked about the ASSC system's future implementation learning that it will soon be tested at Cleveland-Hopkins and San Francisco International Airports and how GA operators in those environments would still be at a high risk for runway incursions and related incidents and accidents. In particular, the high cost of accurate visual displays for SA and the complexity of the certification for such devices for GA operators are deterrents ranking high above allocated budgets of smaller businesses and commercial operators.

Problematic false and nuisance alerts from misidentification of targets by current ground radar used with the ASDE-X systems were also explained by Mr. Gunderson. False alarms in the form of radar returns that detect and alert controllers identifying false targets such as drifting snow, rain and returns of other nuisances posing little or no threat to operations are costly and detrimental. These problematic alerts unnecessarily increase ATC workload, may hinder traffic flow, and cost operators money in the event of warnings leading to unnecessarily aborted take offs or go-arounds. He also explained to us the current response of eliminating ground surface detection radar all together and operating runway incursion avoidance systems solely on data from ADS-B and vehicle transponder – identified positions and trajectories. We discussed the potential of AIRIP to be effective in cohesion with the newest ASSC systems under development as well.

Mr. Gunderson agreed that our proposal for an instantaneous alert to pilots could aid in improving SA and reduce the chances of potential runway incursions leading to harm, although he had reserves about the risk of pilots making impulsive or erratic evasive actions in a heated decision time. Pilots would need additional training and standardized operating procedures to successfully mitigate the dangerous elements associated with taking evasive action upon receiving an alert. There is a need to test any

procedures and practices in a simulation prior to introducing this system to the real world. These studies for instruction would be best accomplished through testing simulated scenarios with resources like those provided at the Florida NextGen Testbed.

6.4 Wade Lester

The next industry expert our research led us to was Wade Lester, director of technology at the Florida NextGen Testbed. Mr. Lester provided a personal tour of the facilities and described various demonstrations and tests of the latest, most advanced equipment using live test crews in real time settings recently performed there.

We walked through the two different testbed sectors, one for private research and development companies to come in and test prototype software; the other for FAA research and demonstrations. This facility gave us a much clearer idea of how AIRIP could be tested for efficiency and potential problems from each user position. By testing and analyzing scenarios with accurate measurement parameters using a facility such as the NextGen Testbed, designers may develop software, systems and procedures for the safest most creative approaches possible to improve aviation safety and efficiency.

In our discussion with Wade Lester, an aid to SA provided by a secondary monitoring radio frequency, as used with some close parallel simultaneous Instrument Landing System (ILS) approaches was addressed. Mr. Lester saw the potential for our innovative design to provide a simplistic yet far-reaching safety improvement generalized for most all NAS users. Tightly juxtaposed movement areas paired with a high volume of traffic in busy airport environments create problems that can be role-played for the creation and testing of solutions at the NextGen Testbed. With our target users' close spatial proximity, a need for speed is elevated for pilot response times and decision

making in critical situations. At the NextGen Testbed AIRIP could be evaluated and analyzed as a means for faster pilot responses to these incursion alerts.

6.5 Steven DeHart

Our team watched an animation with audio of a runway incursion that left us gripping our arm rests in frustration over a bird's eye perspective on a potentially lethal situation unfolding. The time it took to get the pilots involved to initiate evasive action after given a verbal instruction from ATC was unacceptable. We addressed this concern in a teleconference with Steven DeHart, a Senior Research Engineer at the SAAB Sensis, developers of the ASDE-X system, a U.S. corporation that provides high-level engineering, manufacturing and lifecycle design support to top aviation authorities and organizations

We dialoged with Mr. DeHart about the integration of wireless multilateration sensors within the aerodrome and surrounding environment as well as where there was potential to work in a VHF transmitter from the surface detection safety logic system to automatically warn pilots in the area a runway incursion is detected. We discussed the benefits to this expedient way to raise pilot SA and he agreed with Don Gunderson in raising concern over what the pilots may do once alerted. Risk exists in pilot susceptibility to human error, poor judgment or impulsive decisions upon receiving a surface surveillance alert. Pilots taking assertive, evasive action prior to sufficiently grasping the entire scope of the scenario may only exacerbate a potentially dangerous situation. Still, we determined that any alert is better than grabbing their attention too late, or providing no warning at all.

Table 2, Expert Interviewee Contact References is a list of the most credible human sources we had direct contact with throughout our research. Contact was in the form of face-to-face interviews, tours, and conference calls. Table 2 provides industry experts titles, current positions, and contact information.

Table 2. *Subject Matter Experts' Contact Information*

Industry Expert	Area of Expertise	Contact Information
Carlos Castro	NextGen Advanced Research Lab (NEAR Project Manager)	(386)226-7019 castroc@erau.edu
Don Gunderson	Air Traffic Control training at SAIC	(262)893-6535 donald.gunderson@saic.com
Martin Lauth	Air Traffic Management instructor at ERAU	(386)323-8976 martin.lauth@erau.edu
Steven DeHart	Senior Research Engineer at Saab Sensis Cooperation	(315)445-5092 steve.dehart@saabsensis.com
Wade Lester	Director of Technology at Florida NextGen Testbed	(386)226-6418 lesterw@erau.edu
John Murray	Daytona Beach International Airport Ops Manager	

7 Stakeholder Analysis, Results and Implications

Throughout the design process of AIRIP, continuously considering a variety of stakeholders and their position and influence on our product was a necessity. The FAA is certainly the most heavily weighted stakeholder in the implementation and design of AIRIP because of their legislative influence and funding. We also considered other entities who were heavily integrated with and affected by our design as well, including pilots, air traffic controllers, passengers, air carriers, airport operators, and hardware/software engineers.

We learned progressive monitoring and analysis of stakeholder concerns throughout the project development phases are critical activities that require diligent

attention to detail. Stakeholders may want a variety of attributes, and some may have conflicting desires. Design teams and engineers should consider and evaluate as many different links to the product’s development and implementation as possible to assess the role and importance of each entity. Attaining feedback from financially influential contributors as well as from end-users to gauge satisfaction is crucial to AIRIP’s success. We diagrammed stakeholder involvement throughout the life cycle of our design process as depicted in Table 3, Stakeholder Lifecycle Involvement.

Table 3. Stakeholder Lifecycle Involvement

<u>Lifecycle Stage</u>	Source of Information	Resource	Control	Monitor
<i>Research</i>		ATC	Developers	D E V E L O P E R S
<i>Initial Concept</i>	ATC/Developers/Airports		Developers	
<i>Design Prototype</i>	F A A	F A A		
<i>Refine Prototype Until Acceptable</i>		Airport operators	F A A	
<i>Complete and Release Prototype</i>			ATC/Airport	
<i>Analysis of Functionality</i>		FAA/Airport operators/Developers		

Designer’s flexibility and creative abilities for adaptation are imperative traits when working toward successfully meeting stakeholder goals in a finished product. Integrating stakeholder desires will also allow a development team to continuously correct the project path in the right direction at critical decision points so that a user-

friendly, useful system is ultimately produced, and requirements are met. In the remainder of this section we address each key stakeholders interests, contributions, and effects.

7.1 The FAA

Ultimately the FAA has the power to make or break our design. FAA funding could be allocated towards the research and development of AIRIP. Testing the effectiveness of system prototypes in a lab like the Florida NextGen Testbed in Daytona Beach is an excellent way to debug and address possible system errors in an active, accurate setting, without compromising safety. This type of research and development lab requires a certain amount of funding to run and maintain and the FAA provides a large part, if not all, of that support. Because of the FAA's significant influence on the future of AIRIP, our team would need to educate the FAA about the design and the promise it holds to improve runway safety as traffic flow increases.

7.2 Pilots

We informally interviewed multiple professional pilots during our design work and asked them to envision passing through AIRIP equipped airports. Feedback we received from pilots strongly and unanimously favored the idea of implementing AIRIP. Pilots are a valuable source of information for this project because they are one of the end-users that will demonstrate and test whether or not our proposed system is practical, efficient and safe and provide user feedback for further development. This system could save a pilot and their passengers' lives so it is very important to pilots and commercial operators. Airline pilots and GA pilots alike will benefit from this low-cost, easy to implement system.

GA pilots are responsible for a large percentage of runway incursions and AIRIP is a low-cost way to enable them with a high-level alerting system that will reduce pilot reaction time and improve runway safety. AIRIP requires no addition of aircraft equipment installation nor certification. All that is needed is simply dual two-way VHF communications radios and a transponder. With this basic equipment, GA pilots passing through larger ASDE-X equipped hubs will receive runway incursion alerts just as quickly as pilots of commercial aircraft with their more expensive and advanced technology such as electronic flight bags and heads-up or glass cockpit displays.

7.3 ATC

Air traffic controllers share a similar stake as pilots; they would be another operator involved in the use of AIRIP itself. Assessing the usability and practicality of our design would not be possible without controller input. AIRIP will be directly linked into the system operated by air traffic controllers so referencing these veterans of the field and gaining their feedback during our visit to the busy Orlando tower was intrinsically useful in our system development process as well. They agreed that ARIP would be exceedingly beneficial to both pilots and controllers. AIRIP's effect on ATC is one of redundancy in the safety they provide, especially during periods of high controller workload or when they are fatigued.

7.4 Air Carriers

Airline operators are affected by our design because as we hone the capabilities of AIRIP, passenger safety will increase congruently with the FAA's goal of reducing the Commercial Air Carrier Fatality rate to zero. Reaching the next level of safety will boost passenger comfort and revenue for airlines and commercial carriers as passengers feel

safer to fly about the country. Without passengers' comfort in aerospace travel, the airlines and a lot of aviation operations would not exist. They are a driving force supporting the aviation industry and our economy; their comfort and safety is unquestionably of the highest priority.

7.5 Airport Operators

Airport operators and managers also hold weight in our project design because of their role in changes to fixed transmitters and other equipment that may need to be reconfigured on the surface. The cost of the integration of AIRIP with currently installed ASDE-X systems must fall reasonably within airport operator budgets. Although these changes will not be extremely drastic or costly, airport managers will need to be involved with the elements related to implementation of equipment at their airports. We summarized the weighted influence of stakeholders and the value each holds on our system design in Figure 5 (below), Stakeholder Influence of Affluence. This figure represents the amount of influence different entities have on our design financially and in system development and support.

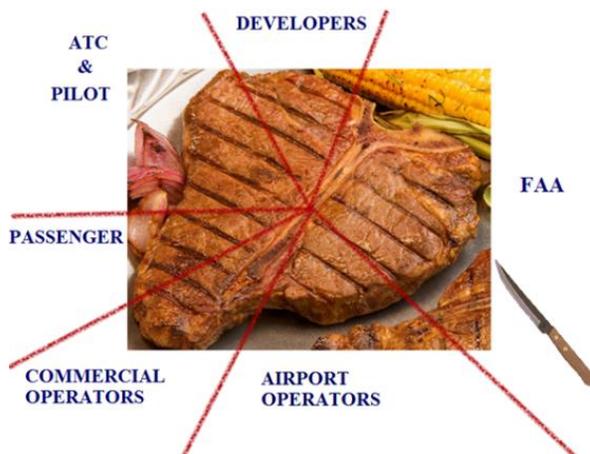


Figure 5. Stakeholder Influence of Affluence

8 Safety and Risk Management Analysis

The FAA's Safety Management System (SMS) Manual identifies five phases for hazard identification and risk assessment (see Figure 6). The five phases include describing the system, identifying hazards that exist in the system, analyzing the risk by identifying the likelihood and magnitude of the potential hazards, assessing the risk by ranking the hazards according to their severity and likelihood, and treating the risks (FAA, 2008a). We will be using the SMS approach to assess and treat the potential risks in our system. Additionally, to better understand the difference between hazards and risks, we used the following definitions:

- Hazards are any condition, event, object, or circumstance that could lead to or contribute to an unplanned or undesired event (FAA, 2009b, p. 1-2).
- Risks are the future impacts of a hazard if it is not controlled or eliminated. Risks are estimated based on severity and likelihood of the potential effect of a hazard (FAA, 2009b, p. 1-5).

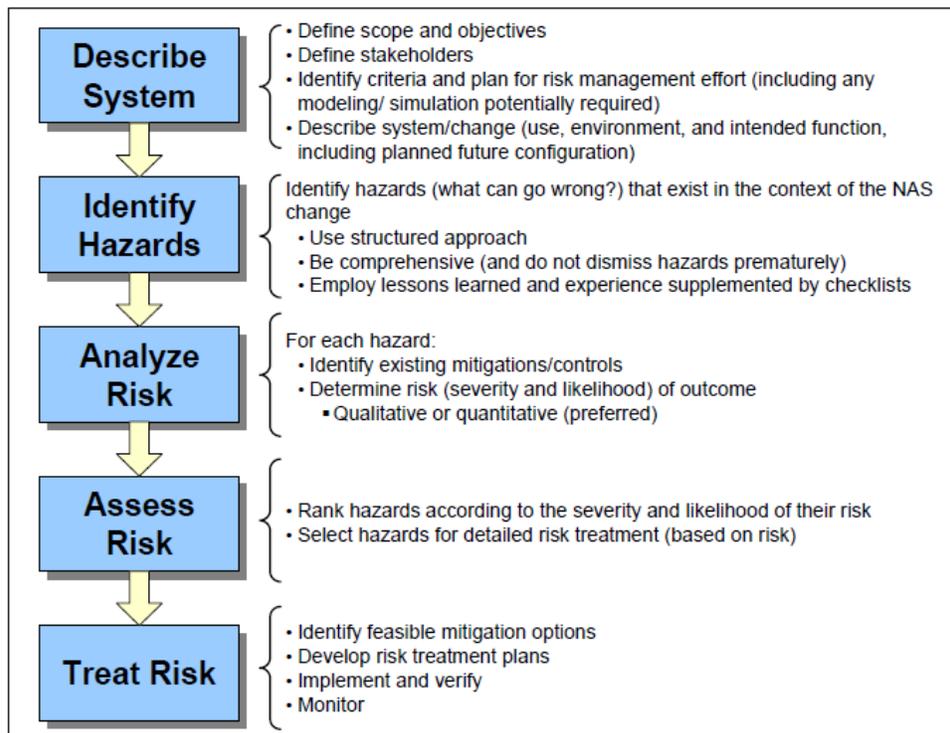


Figure 6. Summary of FAA's Safety Risk Management Process (FAA Safety Management System Manual, 2008a, p. 31)

8.1 AIRIP Safety and Risk Management

During the second stage of our Safety Risk Management process, we were able to identify nine main hazards that exist in our system. Many of these hazards were identified during interviews with SMEs and through our own research and deductive reasoning. The identified hazards are believed to be consistent from airport to airport and from user to user.

The hazards our team identified have been organized based on their level of importance, and the potential likelihood and severity determined for each based on the above risk matrix (see Table 4). Once AIRIP risks were classified according to the risk assessment matrix, it was possible to identify methods for mitigating each risk. Finally,

upon identifying these methods, detailed plans for risk mitigation were developed and, if our development work were to continue, managed.

Table 4. Risk Management Matrix (Modification of matrix from: FAA Safety Management System Manual, 2008a, p.44)

Severit Likeliho	Insignificant (minor problem easily handled by day to day processes)	Minor (some disruption—extra time/resources required for damage control)	Moderate (Category D or C incursion)	Major (Category B incursion)	Catastrophic (Category A incursion)
Almost Certain (> 90% chance)		ACCEPTABLE		UNACCEPTABLE	
Likely (50%-90% chance)			ACCEPTABLE WITH MITIGATION		UNACCEPTABLE
Moderate (10%-50% chance)	ACCEPTABLE				UNACCEPTABLE
Unlikely (3%-10% chance)		ACCEPTABLE		ACCEPTABLE WITH MITIGATION	
Rare (< 3% chance)					ACCEPTABLE

These hazards and their assessments are listed in Table 5 and will be presented in greater detail below. Some hazards listed in Table 5 result from some form of radio wave attenuation; others are caused by human error and equipment failure. The list below is not exhaustive; though, it does list what we found to be the most significant hazards associated with the AIRIP system.

Table 5. *Identified and Assessed Hazards and Mitigation Priority for AIRIP System.*

Hazard	Likelihood	Severity	Risk Matrix Category	Mitigation Priority
Misidentification of aircraft to notify	Rare	Moderate-Major	Acceptable w/mitigation	High
Failure of alarm to activate	Rare	Moderate-Major	Acceptable w/mitigation	High
Unsafe pilot response to alarm	Moderate	Moderate-Major	Acceptable w/mitigation	Medium
Pilot fails to monitor secondary frequency	Moderate	Moderate-Major	Acceptable w/mitigation	Medium
Transmissions block alarm reception	Unlikely	Moderate-Major	Acceptable w/mitigation	Low
Attenuation of signal	Unlikely	Moderate-Major	Acceptable w/mitigation	Low
Inappropriate transponder setup	Unlikely	Moderate-Major	Acceptable w/mitigation	Low
False alarms from radar returns	Rare	Minor	Acceptable	Low
Transponder failure	Rare	Moderate-Major	Acceptable w/mitigation	Low

Most of the above hazards result in the pilot not receiving the AIRIP alarm or receiving it later than expected. While this does present a hazard to the pilot, it is important to note that the pilot will still receive the alert from ATC even if they don't receive the immediate alert from AIRIP. Therefore, these hazards are significant but still should not result in the catastrophe that would occur if they received no alarm from either the AIRIP system or ATC.

False alarms and signal interference are both significant hazards associated with the ASDE-X and AIRIP systems. False alarms occur if ASDE-X alerts of an incursion when none exists. This scenario would result in confusion and could be dangerous if a pilot takes improper evasive actions such as aborting a high speed takeoff or performing a go-around. ASDE-X is estimated to accurately detect impending incursions 90% of the

time. One likely cause of a false alarm is poor weather conditions because precipitation can interfere with the radio signals used by ASDE-X for radar returns as well as voice transmissions to monitor aircraft position. Specifically, heavy precipitation can result in false alarms and signal attenuation. However, ASDE-X can handle up to 16 mm/hour of rainfall which is classified as a downpour, the most severe rainstorm rating (Met Office, n.d.). Furthermore, these hazards have been addressed by designing the AIRIP system so that it uses ADS-B rather than ground radar. This should significantly reduce issues with false radar returns, radar attenuation, and identification of the wrong aircraft when activating the alarm because ADS-B is able to track aircraft with much greater accuracy than ground radar due to the fact that it uses data from Global Navigation Satellite System (GNSS) technology to gain an accurate fix on the aircraft's position (FAA, 2010b).

Hazards resulting from radio interference, such as other transmissions interrupting alarm reception by pilots and attenuation of alert signal transmission are rare. The only time an alarm could be blocked by another transmission is if the pilot is actually holding down the microphone button at the same time the alarm is being sent. Radio attenuation may result from poor weather similar to the radar attenuation discussed above as well as physical barriers that block the signal. However, it is not likely that this interference will completely block the signal. More likely this radio attenuation will result in a small degree of static. To mitigate this risk, we have designed the alert to be at a high enough pitch and amplitude to be audible even through minor static.

Other hazards resulting from electrical interference, such as excessive delay in reception of the alarms and alarms not being activated at all will be mitigated through proper installation, operation, and maintenance of the AIRIP system.

Human error is another category of hazards that is of concern with the AIRIP system. Three examples of possible hazards within this category were identified. The first example is the possibility of pilots failing to monitor the secondary frequency that will be used to send the incursion alerts. This hazard will be mitigated by training the pilots to monitor the secondary alert frequency during all phases of landing and take-off. A second hazard is the possibility of the pilot failing to correctly setup the transponder. This may involve either selecting the incorrect transponder mode or inputting the incorrect beacon code. If the pilot were to setup the transponder incorrectly, this would result in the pilot not receiving the AIRIP warning. To mitigate this potential hazard, an addition of transponder code verification will be made to the pilot's checklist and practical test standards. The third hazard in this category involves the possibility that the pilot makes a poor decision due to time pressure and lack of SA. Seasoned pilots would much rather receive a direct notification of potential danger *immediately* in order to quickly begin assessing the situation and using aeronautical decision making procedures. In the current systems, time taken for the message to pass through multiple handlers is inefficient and dangerous. It cannot be predetermined exactly what any given pilot would think or do in this situation. This risk will be hard to assess with the variety of variables involved, but we determined that any alert is better than grabbing their attention too late, or providing no warning at all. Simulation-based testing could be conducted to evaluate this risk and

evaluate procedural, design, and training strategies for mitigating this risk, if it is found to be valid.

9 Summary of Literature

Throughout the process of developing AIRIP, we relied heavily on relevant literature. Our literature review contributed to the success of our project in several ways. The review of literature helped us to better understand the regulations enforced by the FAA, familiarized us with existing technology related to runway safety, and helped us gain the technical knowledge we needed to advance our design idea. In addition, FAA statistics gave us a better idea of runway safety and specifically runway incursions by informing us of types and prevalence.

A large amount of background knowledge and assistance came from FAA documents and reports (FAA, 2011) and the International Civil Aviation Organization's (2007) *Manual on the Prevention of Runway Incursions*. The ICAO manual helped us to better understand runway incursions by defining an incursion and providing detailed information about specific incidents that would be considered incursions. The FAA documents elaborated further on incursions, types of incursions, and reasons why each type tends to occur. They also gave statistics regarding the prevalence of runway incursions and how many of each type of runway incursion occur each year. For instance, the FAA's *National Runway Safety Plan* (2011) says that the majority of runway incursions are caused by PDs.

The ICAO (2007) also supplied us with a useful SA checklist. This checklist was developed for all members of the flight crew as a strategy to mitigate runway incursions. It is a simple set of reminders for all crewmembers to perform certain tasks before the

takeoff or approach of the aircraft. This is just one example of a measure taken by the ICAO to reduce runway incursions. Along with the SA checklist, the manual also explained *runway hot spots* and their role in runway incursions. As further evidence for the significance of hot spots as contributions to runway incursions, Jeppesen Sanderson is standardizing hot spots on its airport charts in efforts to increase SA of pilots and thereby decrease runway incursions (AeroNews Network, 2007). These concrete examples of solutions for reducing runway incursions helped us to understand what makes a solution effective and to appreciate the variety of possible solutions.

Once we better educated ourselves on the problem of runway incursions and began to develop our solution, we used other literature to help improve our design. There was extensive research done on the ASDE-X system in order to determine its relation to AIRIP (e.g., SAAB Sensis, 2012a). By increasing our knowledge of the ASDE-X system and what it does we were able to integrate the AIRIP with the ASDE-X to develop an even better design

10 Implementation

The first process involved in the implementation of the AIRIP system is gathering the physical needs for the system to be implemented at ASDE-X equipped airports. Integrating AIRIP with a system that is already in place is a way to reduce the direct costs of implementation.

When the ASDE-X system predicts a runway incursion, it sends an audible signal directly to the tower where it is received by air traffic control. To implement AIRIP, ASDE-X will be given an additional transmitter for routing of the same audible signal received by air traffic controllers directly and simultaneously to pilots and ground

operations vehicles over the monitored frequency. Instead of additional equipment being installed in the cockpit, AIRIP uses the existing communication – two-way VHF radios that can be found in any aircraft flying in and out of an ASDE-X equipped, towered airport. Integration costs are estimated to be minimal with the ASDE-X system because the only step that needs to be taken is the addition of a radio transmitter. The addition of another transmitter is a positive feature of AIRIP because it keeps the cost very low. It will be placed in the air traffic control tower where line of sight is guaranteed to the entire airfield.

As part of the AIRIP implementation process, pilots would need to be made aware of this new system in place. Pilots and operators would need to be educated in AIRIP usage through training by instruction, Advisory Circulars (ACs), Notices to Airman (NOTAMs), airport diagrams, terminal charts, and approach plates indicating where to monitor which additional frequency before entering the terminal airport area. Each one of these sources provides the airport information and sometimes critical information that a pilot would need to know.

Implementing AIRIP does not require a whole new design and therefore could produce major benefits for little investment. Our design is feasible, according to our SMEs and should be accepted by the aviation community because monitoring a frequency for certain types of information is nothing new. This can be seen, for example, in Simultaneous Close Parallel approaches where the pilots of the approaching aircraft on close parallel runways transmit and receive on one assigned frequency and monitor another to ensure no radio disruption.

10.1 Estimated Deployment Time

The purpose of AIRIP is to extend the capabilities of the ASDE-X system. Initial simulation-based testing would be the most practical way to test this prototype. This testing could take place at the Florida NextGen Testbed with live crews. Successful simulation-based testing could validate AIRIP's benefit operations as a precursor to real-world implementation. Upon validation, AIRIP could then be initially implemented at one or two trial airports that will serve as an active testbed, possibly at San Francisco International, as verification and safety testing progresses. During testing, planned scenarios will be played out during nighttime or other low-traffic periods. This should take no longer than six months to a year's time. Pilots and air traffic controllers will give their feedback and critiques and these will be addressed in the final implementation of the AIRIP system. Each year further, there should be, at minimum, seven additional airports that have this system installed. That gives the system a total time for deployment of five years for all 35 airports equipped with ASDE-X.

11 Cost Benefit and Impacts Analysis

Runway incursions cost the aviation industry over \$100 million per year in repairs, injuries, and inspections (Honeywell, 2009). The most severe incursions, class A and B, account for only 2% of yearly incursions but are the most hazardous and costly. Assuming a Pareto distribution of expense, 80% of runway incursion expenditures are found in A and B while C and D account for only 20% of the cost. That means \$80 million a year is being wasted because pilots taxi without clearance past the hold short line. With an average of 29 class A and B incursions per year from 2000 to 2010 (Garvin

et al., 2012), the average cost per A or B incursion is \$2,758,620.69. (FAA, 2010a; Garvin et al., 2012).

Table 6. *Incursion Cost by Classification*

Distribution of Runway incursions		Yearly Average From 2000-2010	Direct Cost Per Incident	Assumed Cost Distribution Mitigation Priority Percentage	Value
A	1%	14.2	\$2,758,620.69	80%	\$80 Million
B	0.32%	14.4			
C	36%	N/A	N/A	20%	\$20 Million
D	63%				

11.1 Cost Benefit Calculations

To assess the potential savings resulting from adoption of AIRIP across the thirty-five airports currently using ASDE-X, we analyzed the potential effectiveness of AIRIP by evaluating the probability of incursion detection as well as the potential reduction in time it takes for a pilot to react to an impending incursion. This analysis is described below.

The first step of this savings analysis is to determine AIRIP’s potential failure in detection rate. AIRIP’s effectiveness relies on ASDE-X, which has a minimum detection probability 90% and a maximum triangulation error of 6.6 ft. Weather is also a factor for the ASDE-X system; however, research suggests we do not need to consider it in this analysis. Heavy rains can result in false alarms and block detection (FAA, 2009a); however, ASDE-X can handle up to up to — of rainfall which is classified as a downpour, the most severe rainstorm rating (Met Office, n.d.).

To determine the overall benefit of AIRIP, we needed to be able to calculate the potential reduction in time for the alert to be received by the pilot as well as the reduction

in the distance traveled by the aircraft if AIRIP is implemented. Data needed for this calculation include, normal aircraft taxiing speed, time it takes for ATC to relay the alert, and reaction time for the pilots once they receive the alert. Planes normally taxi at a speed of 20 knots; therefore, for our calculations, we assumed a ceiling of 25 knots for taxi speed. This translates to about 33 to 42 feet per second. Additionally, pilots take corrective action about two seconds after receiving an alert (Jones, 2004; Young & Jones, 2001). At a rate of travel between 20 and 25 knots, pilots can stop their aircraft in as little as 76 feet, depending on the size and weight. Assuming it takes ATC four seconds to process an ASDE-X alert, contact the pilot, and relay a course of action, it will still be an additional two seconds before the pilot begins to bring the plane to a stop. During these six seconds the aircraft will have traveled about 228 feet. This is a best case scenario. In the worst case, the aircraft may continue to travel after the pilot takes action for over 300 feet. If the original ASDE-X alert had been transmitted to the pilot immediately, the stopping distance could be reduced between 150 and 225 feet. That would be a 67% reduction in distance traveled, which could be the difference between overshooting the hold short line and a fatal collision.

11.2 Real-World Impact Analysis

ASDE-X is a revolutionary design that has transformed air traffic control. Thanks to ASDE-X, air traffic control is able to run ground operations during inclement weather, as well as monitor traffic that in some cases are out of line of sight. By integrating AIRIP into the ASDE-X system, AIRIP will significantly benefit from the *Safety Logic* aspect of ASDE-X that uses advanced algorithms and computers to detect runway incursions and possible dangerous situations that a human could overlook or even mistakenly cause.

In 2002 CAST, a team comprised of government and private aviation safety experts, conducted the largest study and gathered the most data on runway incursions. CAST determined that if a technology that increased shared SA by alerting both ATC and pilots of a runway conflict, 95% of runway incursions could be eliminated (Air Line Pilots Association, 2007). If 95% of runway incursions were truncated in their severity by 67%, as this analysis proposes, runway incursions would fall off the NTSB's most wanted list. The \$100 million cost associated with runway incursions would cease to burden the industry and could be spent on other safety measures or technology.

The cost of implementing this system at an airport would be minimal since all the ASDE-X and radio communications already exist and are in place. The only addition that needs to be made is to install an additional radio transmitter in the control tower to allow ASDE-X to broadcast the AIRIP alert to the pilots and ATC. This will be a small and inexpensive upgrade. Pilot training costs would be negligible to the FAA as the practical testing for airmen and manuals are periodically updated. Training costs are incurred by pilots in their pursuit of certification and would not increase significantly. Given the CAST-projected 95% decrease in runway incursions and an estimated decrease in 67-98% in incursion distance, the savings in repairs, injuries, and inspections will more than pay for installation costs, even if significantly higher than estimated. If the estimations of CAST and this paper hold true, class A and B incursions will go from costing the industry \$80 million per year to \$3.9 million, see Table 7. If this is the case it will take only about three months for this system to pay for itself once implemented.

Table 7. *Projected Savings*

Class	Yearly Average From 2000-2010	Direct Cost Per Incident	Yearly Cost	Projected Yearly Occurrence	Projected Yearly Cost
A	14.2	\$2,758,620.69	\$80 Million	0.71	\$3,944,827.59
B	14.4			0.72	

12 Commercialization Potential

AIRIP is a focused technology that caters to larger high volume airports that are primarily used by commercial traffic and commercial pilots. GA pilots should take extra precaution to familiarize themselves with these airports and their procedures in preflight planning prior to using the facilities. It is not uncommon for certain types of activities and operations to be banned from larger airports or regulations enacted. Still the goal of advancing aviation safety by equipping *all* GA aircraft with dual communication radios and an altitude-encoding transponder remains due to the high cost of acquisition and installation. GA pilots who wish to access these busy facilities will need to comply with procedures and required equipment which should not be a problem for those with business transitioning through the country’s thirty-five largest airports. Even having a transponder and one communication radio would still allow the aircraft access as they would receive the ASDE-X alert from a controller congruent with today’s system.

12.1 Growth of AIRIP technology

The potential growth potential for AIRIP to propagate to additional markets remains limited as ASDE-X remains in a small market that targets high capacity commercial aviation airports. For the foreseeable future, AIRIP will only be available to ASDE-X equipped airports across the United States and the world. ASDE-X and ASSC equipped airports are expected to increase in number beyond the original thirty-five as

the system's benefits and its potential to support secondary systems such as the RWSL system and AIRIP become a clear return on investment in safety.

13 Conclusion

The busiest airports in the United States have employed ASDE-X in order to reduce the incidents of runway incursions and increase safety. According to the FAA, runway incursions have increased in spite of the implementation of ASDE-X. Therefore, it is clear that additional actions need to be taken to reach their stated goal. AIRIP has the capabilities to mitigate the short comings of the current system. The lower cost associated with AIRIP also makes it a more tenable solution.

Appendix A: List of Student and Staff Contacts

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Appendix B - Description of University

On December 17, 1925, exactly 22 years after the historic flight of the Wright Flyer, barnstormer John Paul Riddle and entrepreneur T. Higbee Embry founded the Embry-Riddle Company at Lunken Airport in Cincinnati, Ohio.

In 1965, Embry-Riddle consolidated its flight training, ground school, and technical training programs to Daytona Beach, Florida. Expansion of the University began when a former college in Prescott, Arizona, became the western campus of Embry-Riddle in 1978.

In addition to its two traditional residential campuses, Embry-Riddle Worldwide provides educational opportunities for professionals working in civilian and military aviation and aerospace careers. Of today's more than 150 Worldwide Campus locations in the United States, Europe, Asia, Canada, and the Middle East, the majority are located at or near major aviation industry installations, both military and civilian.

Though it began as a school for pilots and aircraft mechanics, the University now offers more than 40 undergraduate and graduate degrees and provides the ideal environment for learning. Degrees at ERAU include Aviation Business Administration, Aerospace Engineering, Human Factors and Psychology, Safety Science, Homeland Security, Engineering Physics, and more. Even though Embry-Riddle is primarily a teaching institution, research plays an important role for students and industry. The focus is on applied, solution-oriented research. ERAU combines an impressive faculty with state-of-the-art buildings, laboratories, classrooms, and a diverse student population. Embry-Riddle's students represent all 50 states and 126 nations.

As aviation and aerospace continue to evolve, so does Embry-Riddle. The University is committed to the expansion of opportunities for students to work more closely with the aviation industry in the United States and in other countries. Guiding the process of evolution are dedicated teachers, administrators, alumni, trustees, and advisory board members who share the students' love of aviation and who strive to ensure Embry-Riddle's continued position as the world's premier aviation and aerospace university.

Appendix E: Team Evaluation

Taylor Martin

I feel that participating in the FAA Design Competition provided a very meaningful learning experience for me. This was my first graduate level class, and as a current undergraduate student I was extremely excited and eager to work on such a significant project. Not only was I able to learn a lot from our extensive research, but I was also able to learn valuable knowledge from my teammates.

A huge challenge for my team and I was settling on the initial design for the competition. We knew right away we wanted to focus on runway safety. Therefore, I was able to immediately start background research on runway safety and more specifically runway incursions. The problem we kept encountering while trying to settle on a design was the issue of already existing systems. We would collectively agree on a design and begin background research, only to find that a system identical to our idea already existed. This significantly pushed back our project deadlines from where we wanted them to be originally. We solved this problem by doing extensive research on existing systems and talking to subject matter experts about related ideas.

We decided upon a design after researching similar existing systems and throwing around several different ideas. After weeks of brainstorming sessions we came up with our design, the AIRIP. We immediately and collectively agreed that it was the best idea to date and we decided to go with it. Once deciding on a design we were able to meet with industry experts and tour the ATC facilities at the Orlando International Airport. These experiences in the industry were extremely relevant and helpful in the improvement of our design. We were able to gain extensive knowledge on the ASDE-X system and talk to leading experts in the industry.

Lastly, I will walk away from this experience with a significantly greater knowledge of the FAA and specifically the problem of runway incursions, and the ability to work with a large diverse group on an extensive project. Although, I know that my time at Embry Riddle as a graduate student will present several more learning opportunities, I feel certain that the lessons learned from this project will be ones that stay with me forever.

Chelsea Iwig

The FAA Design Competition provided a very meaningful learning experience for me. Prior to this project I had no background in system design and no clue as to what all went into the system design process. Also, I had very little knowledge of the aviation industry aside from my experience as a passenger. This project opened my eyes to the challenges faced by the FAA in mitigating hazards in a variety of different domains related to airport operations and aviation safety. Therefore, this was an immensely beneficial experience in that it provided me with useful knowledge of the aviation industry as well as of the design process in general, which will prepare me for a future career in Human Factors.

My team faced a great deal of challenges during this project. One of the biggest challenges my team faced was in coming up with the idea for our design. This process required participating in many weeks of brainstorming sessions before we finally came up with our current idea. Also, meetings with industry experts were very helpful in sorting out the details of our design. Without these meetings with SMEs, our design would have been significantly lacking in implementation details. In addition to the benefits gained from SME interviews, the high level of cohesion within our group was also very helpful. Frequent meetings early on quickly resulted in my group becoming a highly cohesive team in which all members contributed

While this project was a huge challenge, it has taught me more about the system design process than any classroom lecture ever could. Also, as I do not come from an aviation background, I have learned a great deal about the aviation industry through completing this project. Additionally, being a part of this team helped to further develop my teamwork skills as it demanded a great deal of coordination, collaboration, and communication. Overall, I know that the lessons learned over the past several months of working on this project will continue to be of great benefit toward future projects that I will participate in.

Ying Liu

The great opportunity of participating in the FAA Design Competition was a meaningful learning experience for me. During the course of project development phase, I was able to gain a lot of knowledge about runway incursions, and how it remains to be a problem in aviation operation. Another thing that I learned in this project was the importance of teamwork. Without my teammates' cohesion we would not have been able to complete this project within the three month time period.

The biggest challenge that we encountered was coming up with a meaningful design that would help prevent runway incursions. We struggled during the project development process because we realized many of the design idea we came up with were already in use. Therefore, our team decided to augment existing systems and fill a gap where they were lacking. After numerous meetings and conference calls with SMEs, our team finally came up with the AIRIP system.

Our team started developing our hypothesis with a literature review to provide us with some insights on technologies that are currently in use and others that are still under development. After we developed our hypothesis of a feasible system to prevent runway

incursions; we sought SMEs to gain more insight and asses details. Based on the feedback we receive from the SMEs, we modified and improved our system.

Meeting with SMEs and attending an airport tour, our team was able to gain knowledge on the ASDE-X system. The knowledge we gained from the industry experts was extremely meaningful and useful.

Assessing the current industry in the project was extremely helpful because I was able to gain new insight and knowledge about runway incursions. Being able to participate in such a project provided research experience that I can use in the future. Furthermore, I learned to stay on top of a schedule and the importance of meeting deadlines for successful project development. Lastly, I learn the importance of team spirit. I would not have successfully completed the project without the intellectual and moral support from my team members.

Devin Liskey

I learned many valuable things about the aviation industry. Talking with different SME's and visiting Orlando ATC were probably the most enriching opportunities that this competition provided. The chance to see ASDE-X working in real time made me truly appreciate the complexity of the system.

The major obstacle we had to overcome was coming up with a topic that was both original and feasible. We had several very good ideas but they were either already implemented or too costly. I guess we didn't ever 'overcome' this problem; we just kept churning out ideas until we found a unique and cheap idea.

We had a round table discussion amongst ourselves. We considered every group member's ideas and the input from our SME's.

The tour provided by Orlando Airport's ATC was meaningful and useful. Before we saw the tower our project was mostly theory and only as real as the pictures we saw online. When we saw the controllers and system in action we got a clearer and deeper understanding of ASDE-X.

This study provided hands on experience with researching and interacting with SME's and industry experts. In future studies I will be more capable and skillful when working on projects like this one.

Thomas Harter

I learned many things about systems engineering and the overall process needed to work on such a large project. As a pilot, I was able to see more than the perspective of the pilots, but of other occupations in the aerospace industry, and how they all work together.

We had to change our project topic many times. Every time we came up with a design we all agreed upon, we did research and found a similar system still in place. Also integrating into current technology is a challenge because there is so many things already out there.

As a group we considered many things. Input from SME's and our own respected fields of study were all considerations in our final design. We also visited the Orlando air traffic control tower as it showed up real time use of the ASDE-X system. This tour was the most useful of anything that we did throughout this project. We got great feedback and input from industry experts that use this system every day.

I learned that group cohesion is very important. And in industry you have to be able to work well in groups. It helped me acquire the skills to be successful in the workforce by broadening my understanding of the aerospace industry as a whole.

William Lively

The FAA design competition was a meaningful learning experience for me because it provoked the most in-depth and relevant research I've ever participated in. Involvement in the competition also built upon my personnel management and project deadline skills by collaborating with five other team members.

Our team was challenged by selecting a meaningful idea for our design submission that would be feasible to create. This hurdle was progressively overcome through immersing ourselves in the subject matter through speaking with SMEs on conference calls and in person, as well as visiting the Florida NextGen Testbed, the NEAR lab, the Orlando International Airport Tower and through thoroughly researching current systems and emerging technology to discover deficiencies and determine where improvements are needed.

As a full-time certified flight instructor (CFI) at ERAU this topic held a great deal of importance to me. Not only was I happy to contribute knowledge from my aviation background, but I learned an immense amount of new information that applies directly to the future of my profession and related fields of interest.

In the iterative design process of developing our hypothesis and system, we tackled the problem of runway incursions and sought to reduce them using the most state of the art approaches in existence. In order to hone in on what developed into the AIRIP system, interactions with industry experts were crucial - although some were more helpful and open to sharing than others, we couldn't have done it without them.

There doesn't seem to be a better way to prepare aspiring professionals for the workforce and future research than the FAA design competition. Throughout the competition we faced

many of the real world challenges that any professional system engineering team might. This was an invaluable, practical learning experience. I feel privileged and ecstatic to be a part of this great movement and life-changing opportunity.

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