COVER PAGE

TITLE OF DESIGN: INSPIRE

DESIGN CHALLENGE ADDRESSED: Runway Safety/Runway Incursions

UNIVERSITY NAME: Embry-Riddle Aeronautical University

TEAM MEMBER NAMES: Breanna Goring, Paul Gillett, Sarah Cullen, Michael Fehlinger, Jason Goodman, & N'diaye Diabira

NUMBER OF UNDERGRADUATES: 1

NUMBER OF GRADUATES: 5

ADVISOR NAMES: Dr. Kelly Neville and Mr. Martin Lauth

REDUCING RUNWAY INCURSIONS BY INCREASING SITUATION AWARENESS

KEEPING YOU ON TRACK

BY

Paul Gillett, Sarah Cullen, Michael Fehlinger, N'diaye Diabira, Breanna Goring, and Jason Goodman

Executive Summary

Reducing the likelihood of runway incursions has always been a top priority of the Federal Aviation Administration (FAA). The issue is more prevalent with General Aviation (GA) pilots who usually are less experienced. The prevention of runway incursions is being addressed in different ways, and more recently through the use of moving map displays. Current moving maps are displayed on Multi-Functional Displays (MFDs) and therefore require pilots to divide their attention between monitoring inside and outside of the cockpit.

As a group, we decided to address the problem of heads down time by reducing the amount of multitasking involved in single pilot operations while taxiing. A multitude of approaches were considered throughout the design process and based on the literature review, interviews and interactions with potential shareholders, we created INSPIRE (i.e., Intuitive Navigation System for the Prevention of Incursions in the Runway Environment). INSPIRE provides navigational guidance by converting taxi instructions (i.e., through the use of voice recognition software) into a laser projection displayed directly on the windshield. The guidance line is designed to increase pilot situation awareness (SA), while not overloading the pilot with complex information.

Considering the popularity of the Cessna 172 G-1000 in the GA fleet, the design of the INSPIRE system had to accommodate the space available in small single-engine aircraft. Additionally, the nominal budget of GA pilots required the INSPIRE system to be both affordable and useful. Pilots who use the INSPIRE system will experience enhanced situational awareness while navigating across airport surfaces. Consequently, this pilot navigational guidance supports the reduction or likelihood of runway incursions.

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List of Acronyms

AC	Advisory circular
ADS-B	Automatic Dependency Surveillance Broadcast
ALOS	Acceptable Level of Safety
ASDE	Airport Surface Detection Equipment
ATC	Air Traffic Controller
ATO	Air Traffic Organization
CRT	Cathode Ray Tube
EFB	Electronic Flight Bag
FAA	Federal Aviation Administration
FAROS	Final Approach Runway Occupancy Signal
FY	Fiscal Year
GA	General Aviation
GPS	Global Positioning System
HDD	Heads Down Display
HGS	Head-Up Guidance System
HUD	Heads-Up Display
ICAO	International Civil Aviation Organization
INSPIRE	Intuitive Navigation System for the Prevention of Incursions in the Runway Environment
MFD	Multi-Function Display
MVS	Making Virtual Solid
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
PFD	Primary Flight Display
RIAAS	Runway Incursion Advisory and Alerting System
RIPS	Runway Incursion Prevention System
RTCA	Radio Technical Commission for Aeronautics
RVR	Runway Visual Range
RWSL	Runway Status Lights
SA	Situation Awareness
SAE	Society for Automobile Engineers
SOP	Standard Operating Procedure
SMGCS	Surface Movement Guidance and Control System
SME	Subject Matter Expert
SMS	Safety Management System
SRM	Safety Risk Management
STC	Supplemental Type Certificate

1 Problem Statement

Runway safety is a critical component of the overall safety of the National Airspace System (NAS); the decreased separation between aircraft, vehicles, pedestrians, and other airport structures in the aerodrome environment represents a significant safety concern. On November 1, 2002, the FAA established the Runway Safety Program by FAA Order 7050.1. The Runway Safety Office, within the Air Traffic Organization (ATO) Office of Safety, was given primary responsibility for initiating the order, which required the office to work with other FAA organizations and the aviation community to identify and implement initiatives designed to increase runway safety (FAA, 2011).

Runway safety is measured by the prevalence of runway incursions, which are defined as "[an] occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and takeoff of aircraft" (FAA, 2010, p. 5). The FAA adopted this definition in fiscal year (FY) 2008; a definition which was originally developed by the International Civil Aviation Organization (ICAO) with significant input from the FAA. The FAA assesses the runway incursion data provided by airports with FAA-sponsored airport traffic control (ATC) towers using three primary metrics: the severity of incursions, the frequency of incursions, and the types of incursions (FAA, 2011).

The FAA categorizes incursions into categories A, B, C, and D, based on the severity of the incident (Table 1). The key factors used to categorize an incident are the speed and performance characteristics of involved aircraft, the proximity of the incurring aircraft to other aircraft and vehicles, and whether or not evasive action was required to avoid a collision (FAA, 2011). Incidents that fall into categories A and B are considered to be serious incursions.

Table 1. FAA Runway Incursion Severity Classification

Category	Description
A	A serious incident in which a collision was narrowly avoided.
B	An incident in which separation decreases and a significant potential for collision exists, which may result in a time-critical corrective/evasive response to avoid a collision.
C	An incident characterized by ample time and/or distance to avoid a collision.
D	An incident that meets the definition of runway incursion such as incorrect presence of a single vehicle/person/aircraft on the protected area of a surface designated for the landing and take-off of aircraft but with no immediate safety consequences.

Note. Reprinted from the Annual Runway Safety Report by the FAA Office of Runway Safety, 2010, p. 5.

The frequency data for runway incursions indicates a downward trend in the rate of serious runway incursions between FY 2005 and FY 2010, from 0.46 to 0.18 incursions per million operations, respectively. In addition, the number of incursions that result in collision is very low; between FY 2004–FY 2007, only one incursion resulted in a collision. No fatalities occurred (FAA, 2008). However, though the rate of serious incursions has declined, the total incidence of runway incursions is on the rise. The total rate of runway incursions has steadily increased from 5.2 in FY 2005 to 18.9 in FY 2010 (Figure 1).

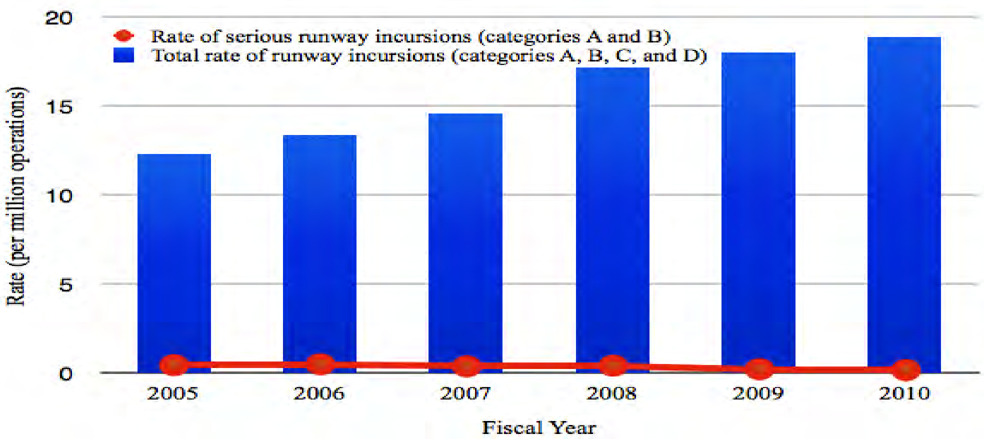

Figure 1. Trends in severe and total runway incursions. This figure illustrates the rates of severe and non-severe runway incursions per million operations by fiscal year (FY 2005 to FY 2010).[1]

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[1] *Note.* The incursion rate data for FY 2009–FY 2010, which was used to create this chart, was obtained from the *ATO Safety National Runway Safety Plan: Version 1.0,* by the Federal Aviation Administration, 2011. The incursion

In addition, it is possible that the number of severe runway incursions could be underrepresented by the FAA data. Since FY 2008, the FAA has used internationally standardized definitions to define the severity categories. As a result, many incidents that would have been classified as category B severe incursions prior to FY 2008 would now be considered category C non-severe incursions. One survey of 174 pilots showed that only 5% agreed with the FAA-assigned severity category C to an incident that occurred in 2010 at Charlotte/Douglas International Airport. Furthermore, incursions at non-towered airports—including those that resulted in collisions—are not represented in the FAA data (Chapin, 2010).

Runway incursions are further classified by type as operational errors, pilot deviations, or vehicle/pedestrian deviations. Historically, pilot deviations have been the largest contributing factor leading to runway incursions. From FY 2008 to FY 2010, 63.3% of all runway incursions have been classified as pilot deviations (FAA, 2011). Incursions classified as pilot deviations involve the "action of a pilot that violates any Federal Aviation Regulation" (FAA, 2010, p. 6). Some common examples of pilot deviations are crossing a runway hold marking without clearance from ATC, such as when a pilot fails to obey ATC instructions to not cross an active runway when following an authorized route to an airport gate (FAA, 2008); taking off without clearance; and landing without clearance (FAA, 2012). Historically, GA pilots have been responsible for the majority of pilot deviation incursions, including those that involve air carrier operations, despite the fact that GA operations comprise only 54% of the aircraft operations in the NAS (FAA, 2008). In FY 2011, GA pilots were responsible for 78.7% of the 436 pilot deviation incursions that occurred prior to June 30th (Figure 2). Furthermore, it is likely that the

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rate information for FY 2008–FY 2009 was obtained from the *Annual Runway Safety Report*, by the FAA Office of Runway Safety, 2009a. The incursion data prior to FY 2008 has been re-categorized according to the new ICAO severity categories, and is thus only an estimate.

real number of incursions involving GA aircraft is higher, as the FAA statistics do not take into account non-towered airports, which have primarily GA traffic.

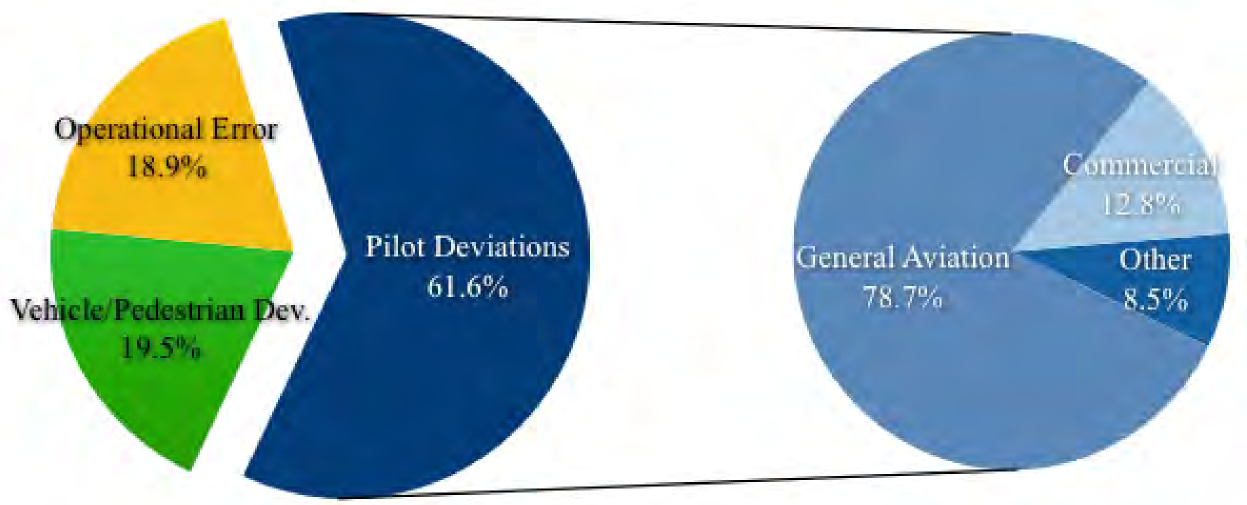


***Figure 2. Breakdown of 708 runway incursion events by type for FY 2011, as of June 30th*.**

Though the number of runway incursions that result in an accident is small, statistics indicate that the number of runway incursions increases at a rate much higher than traffic volume. This exponential increase in incursion rates, combined with the growing traffic volume in the NAS, has ensured that runway incursion avoidance has remained on the National Transportation Safety Board (NTSB) ‘‘Most Wanted’’ list for safety improvements for more than a decade. Furthermore, it is clear that deviations made by GA pilots are a significant contributor to the overall incidence rate of runway incursions. (FAA, 2012).

Most technological initiatives have sought to reduce the number and severity of runway incursions through the augmentation of pilot SA during airport taxi surface operations. SA refers to a pilot’s understanding of the other activities occurring in the aerodrome environment around them and their ability to gather relevant information, and to make appropriate decisions based on that reference information. Breakdowns of pilot SA are a key contributing factor to runway incursions. Detailed investigations of runway incursions have revealed three major contributing factors to these incidents, many of which were likely preceded by a breakdown in SA: failure to comply with ATC instructions, lack of airport familiarity, and nonconformance with standard operating procedures (SOPs). Runway confusion, a subcategory of runway incursions that involves departure from the incorrect runway, has been linked to the following contributing factors: airport complexity, close proximity of runway thresholds, and the joint use of a runway as a taxiway (FAA, 2012). Technology designed to enhance pilot SA while taxiing on the airport surface would help pilots to navigate complex aerodrome environments, thereby reducing the likelihood of runway confusion, and of runway incursions in general.

However, despite the overwhelming representation of GA aircraft in incursion data, the majority of technology initiatives to prevent runway incursions to date have been focused on air carrier operations and larger airports with primarily commercial traffic (Schönefeld & Möller, 2012). One such initiative, an Electronic Flight Bag (EFB) that will support initial FAA Next Generation (NextGen) surveillance technology, is undergoing initial testing by four air carriers with help from FAA grants. This EFB system will show ownship position on an airport moving map; however, it relies on technology not commonly found in GA cockpits. As part of another major FAA technology initiative, 23 large airports have been equipped with runway status lights (RWSL), a fully automatic safety advisory system designed to reduce the number and severity of runway incursions while not interfering with airport operations. Large airports are also often equipped with a Final Approach Runway Occupancy Signal (FAROS), which is a flashing light that is visible to pilots on approach that activates in warning when a runway is occupied and potentially unsafe for landing. FAROS operates automatically and independent from ATC (FAA, 2011). In addition, the National Aeronautics and Space Administration (NASA) has published studies on the Runway Incursion Prevention System (RIPS), and the Runway Incursion Advisory and Alerting System (RIAAS). However, the NASA studies assume the availability of Automatic Dependency Surveillance-Broadcast (ADS-B) and data links, so GA aircraft are unlikely to be covered by these systems until 2020, when all aircraft in the USA will be required to equip with ADS-B transponders (Schönefeld & Möller, 2012). The FAA is currently surveying the market for low-cost, commercially available radar surveillance systems. These surveillance systems would reduce the risk of runway incursions at small and medium-sized airports that do not have Airport Surface Detection Equipment (e.g., ASDE-3, or ASDE-X). However, it will be some time until such systems are realized (FAA, 2008).

At present, the financial and technical constraints of most GA aircraft and the smaller airports in which they operate have prevented many technologic initiatives from being implemented for GA operations (Schönefeld & Möller, 2012). However, given the overrepresentation of GA pilots in the FAA incursion data, a technical solution for GA pilots that works within the boundaries of current technical constraints is critical for runway safety. At present, positioning systems are only available at larger airports equipped with precision radar facilities; therefore, a technical solution aimed at GA pilots cannot rely on this technology to determine ownship position. Fortunately, the proliferation of GPS systems in GA cockpits has brought accurate positioning ability to virtually all aircraft (McCann & Foyle, 1995). An EFB for GA pilots that seeks to enhance pilot SA during surface operations can therefore use GPS to determine ownship position relative to the airport surface. Furthermore, since such a device will be used during active taxi, the device must not be classified as a Class 1 EFB, as this class of devices must be secured or stowed during critical phases of flight, which includes taxi (FAA, 2009b). Finally, taxi operations are clearly an "eyes-out" or "head-up" task. Pilots are required to navigate the complex aerodrome environment using airport signage, manually control the aircraft based on its position relative to visual environmental cues, remain vigilant for hazards, and maintain an appropriate safe separation from other aircraft, ground vehicles, and obstacles. Many pilots, when queried regarding the addition of a head-down display (HDD) to augment SA during taxi were concerned about the addition of a HDD to aid a predominantly head-up, eyes-out, task. For this reason, a Heads-up Display (HUD) which projects conformal (i.e., scene-linked) symbology onto the forward scene may be more suited to our safety-improvement objective (Foyle, Andre, McCann, Wenzel, Begault, & Battise, 1996). Accordingly, we have proposed the Intuitive Navigation System for the Prevention of Incursions in the Runway Environment (INSPIRE) as a situation awareness aid that is supportive of heads-up, eyes-out taxi operations. Using voice recognition software and laser displays, INSPIRE projects scene-linked navigational aids directly onto the windshield of an aircraft, with a pilot verification step and audible alarms as a built in safety. The objective of the system design is to increase pilot situation awareness through the reduction of head-down time.

2 Literature Review

As stated above, the complex nature of aviation (both commercial and general) requires a pilot's attention to be divided between multiple tasks in differing visual fields (e.g. instrument panel, cockpit, or knee-board). As Hilburn (2005) put it, the pilot is trying to "optimally divide attention between the primary visual field" (out the cockpit window for example), and "an auxiliary tool (usually in the form of a visual display screen)" (p.427). The desired end-state of HUDs is fairly straight-forward: an increase in user heads up time by integrating disparate fields of information into one localized visual area. This should increase overall SA, which Endsley, Farley, Jones, Midkiff, and Hansman (1998) define as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.” (p.iii). During a 4-year longitudinal study, Endsley (1995) found that approximately 88% of the accidents reviewed involving substantial human error (approximately 71% of the accidents) “involved problems with SA” (p.3). From this it seems logical to conclude that increased SA should lead to a decrement in SA-related accidents, including runway incursions. Since a HUD should improve SA, using a properly designed HUD should lead to fewer accidents. Deciding what constituted a “properly designed” HUD involved reviewing literature in multiple domains.

The goal of the design process (which guided our literature review) involved keeping different moving objects with a finite number of paths of motion (based on runway layouts) from occupying the same space in a 2-dimensional grid at the same time. At this level of abstraction, the problem resembled avoiding collisions while driving, with the exception that it involved bigger vehicles at possibly faster rates of speed. Additionally, Gish and Staplin (1995) indicated that generalization between aviation and automotive research might be limited based on differences in external scene content for aviators versus drivers, the use of conformal vs non-conformal HUD symbology, and the traditional use of young aviators with good vision in aviation research (Gish & Staplin, 1995). Due to the lack of complete overlap between these areas, the review covered articles for both automotive and aviation-related experiments.

2-1 Automotive Resources. In its initial conception, INSPIRE was meant to complement existing technology already being used for navigation (e.g., Garmin GPS devices). Given that GPS navigation devices have uses in automobiles, it is not surprising that the literature review led the team to eventually settle upon a design based off of an automobile navigation device being developed by Making Virtual Solid (MVS) California. The product is a factory installed device (i.e., under the dashboard) which projects a 3-dimensional red line upon the windshield of a car. The product is designed to be hooked into a GPS navigation system (e.g., Garmin), and the path of intended motion is displayed on the windshield (MVS California, 2012).

The automotive HUD research illuminated one major concern: not all HUDs are helpful, and some may even by detrimental. Gish and Staplin (1995) indicated that “to date, the research does not provide robust evidence for operationally significant performance advantages due to HUDs” (p.i). However, the researchers qualified this statement by indicating that this may be due to failure to adequately address certain parameters, such as contrast interference, cognitive capture (i.e., excessive focus on instrumentation at the expense of SA), and the use of conformal symbology (Gish & Staplin, 1995). These issues, along with those identified in the aviation research section below, helped the group to design INSPIRE.

2-2 Aviation Resources. A review of several studies conducted at the NASA Ames Research Center between 1991 and 2002 helped further guide the team towards a more effective HUD. These studies covered several important HUD topics, including conformal (i.e., scene-linked) versus non-conformal (i.e. non scene-linked) design (McCann & Foyle, 1995), information modality/presentation (Foyle, Sanford, & McCann, 1991), and placement of the display in relation to the visual field (Dowell, Foyle, Hooey, & Williams, 2002; Foyle, Dowell, & Hooey, 2001). The results suggest that conformal symbology, presented in a non-complex data form at a separation of at least 8 degrees from the center viewpoint, provides the greatest benefit to pilots.

In addition to journal articles, several FAA documents were essential in increasing group understanding of the problem domain. First and foremost among these was the FAA’s (n.d.) *Runway Safety: a Best Practices Guide to Operations and Communications*. This brochure oriented the group towards concerns related to low visibility, loss of communications, researching airport hot spots, locating up-to-date airport diagrams, and determining proper ATC phraseology. The second critical document was Advisory Circular (AC) 120-76B *Guidelines for the Certification, Airworthiness, and Operational Use of Electronic Flight Bags*. Using this document, the group determined that INSPIRE was classified (for certification purpose) a Class III Type A EFB. It also alerted the group to the concept of avoiding single point failure, in that "At least two operational EFBs are required to remove paper products that contain aeronautical charts, checklists, or other data required by the operating rules" (p. 10). The third critical document was AC 20-173 *Installation of Electronic Flight Bag Components*. This document provided the group with information on requirements for power supplies, crew accessibility, placement, cables, and labeling. With a functional understanding of existing technology, previous research (both aviation and automotive), and applicable FAA regulations, the group was ready to proceed with designing.

3 System Development Framework

3-1 Development Methods

As mentioned in the "Interactions with SMEs" section (covered later on), our team's co-advisor, Dr. Neville, introduced guest speakers from Daytona Beach International Airport to provide the team with insight on daily airport operations and challenges faced by airport operators. To learn more about the area of runway incursions, the team reviewed runway incursion data and research. For example, according to the FAA (n.d.), three runway incursions occur on average every day in the United States. Also, according to DiFiore and Cardosi (2006), 60 percent of hold short incidents are due to a loss of position awareness that is a result of pilot "heads-down" duties. The research gathered on runway incursions influenced the team to attempt to decrease pilot's heads-down time while taxiing in order to decrease runway incursions. This became the basis of the project and the purpose of INSPIRE.

In order to create a system that would decrease pilots' heads-down activity during taxi, the team first established team members' technical and academic strengths. The team included individuals with backgrounds in aviation, architecture, psychology, and human factors. The diversity of the team allowed goals and uses of INSPIRE to be seen from different perspectives. The design tasks of INSPIRE (research, risk assessment, engineering, and graphics design) were all handled collectively as a team, primarily during two standing weekly meetings. Separate meetings were scheduled with SMEs (see section Interactions with SMEs) when further information was needed.

Due to frequent contact with SMEs, the team decided on using an Evolutionary Prototyping lifecycle model (see Figure 3). Using this model allowed the team to develop INSPIRE in increments and continually modify it based on the feedback from SMEs.

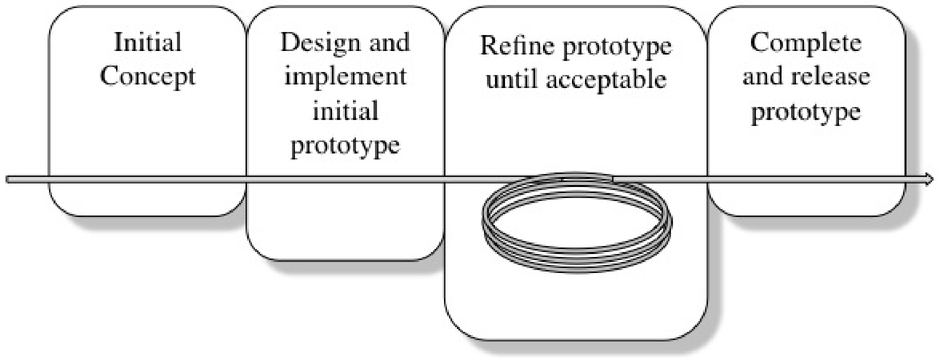


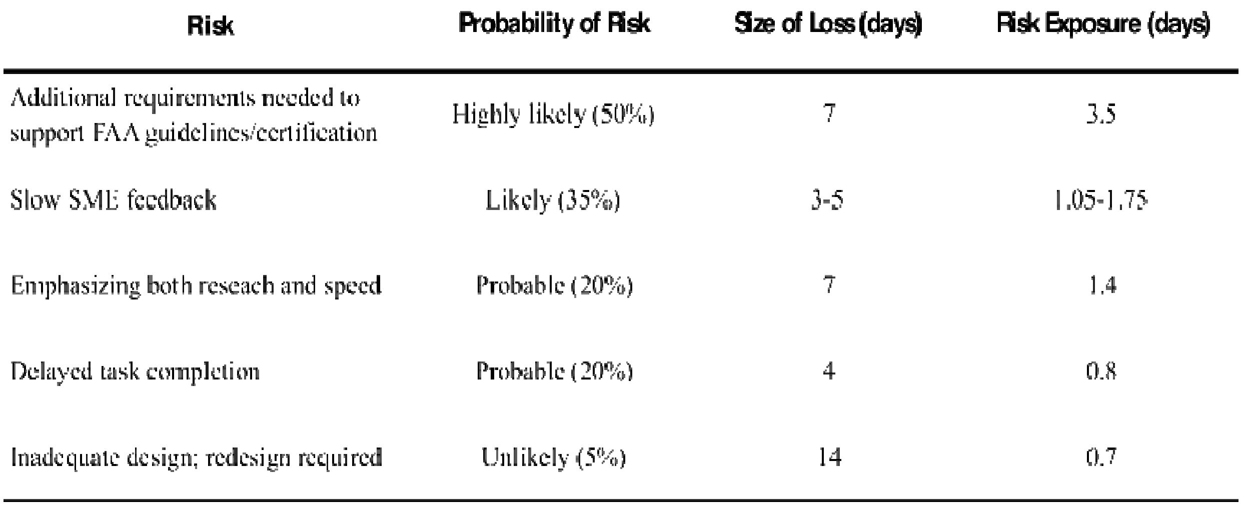
Figure 3. Evolutionary Prototype model.

According to McConnell (1996),“ Evolutionary prototyping…produces steady, visible signs of progress, which can be especially useful when there is a strong demand for development speed” (p. 147). In other words, using this model also ensured that despite a tight schedule, the team would produce at least a high level design.

3-2 Development Risks

The time frame for system delivery was very short. This meant that the team had to actively attack project risks, especially those affecting the scheduled delivery date. As a team, risks were identified, analyzed, and controlled throughout the project lifecycle with the use of a prioritized risk-assessment table (see Table 2). Using the Delphi approach (e.g., McConnell 1996), team members individually estimated each risk and its impact on the schedule and provided rationale behind it until an agreement was made.

Table 2. Prioritized Risk-Assessment Table.



Risk	Probability of Risk	Size of Loss (days)	Risk Exposure (days)
Additional requirements needed to support FAA guidelines/certification	Highly likely (50%)	7	3.5
Slow SME feedback	Likely (35%)	3-5	1.05-1.75
Emphasizing both reseach and speed	Probable (20%)	7	1.4
Delayed task completion	Probable (20%)	4	0.8
Inadequate design; redesign required	Unlikely (5%)	14	0.7

As shown in Table 2, some risks were given a greater priority than others because their probability and impact on the schedule were both high. In addressing just the top three risks, which are highest in priority, we avoided 5.95 - 6.65 days of potential schedule slips. Three of these risks and mitigation techniques will be described below.

The highest priority risk as determined by the assessment is the potential for additional requirements to emerge from either new or a better understanding of FAA certification requirements. McConnell (1996) suggests that the use of incremental development practices should be used to help manage this type of risk, so the team's decision to use an Evolutionary Prototyping model was fitting. Because of the complexity of FAA documents the team decided that this risk was highly likely. Figuring a response to this risk could take up both of our weekly meetings, the size of loss was labeled as 7 days and the risk exposure calculated accordingly. The actions taken to mitigate this risk included researching FAA requirements in the early phases of INSPIRE.

The team recognized that there was also a likely risk of slow SME feedback. It was decided that this risk could essentially result in a 3-5 day impact on the schedule. The consensus was that individuals generally respond within that time period and if it were to take any longer the team could continue refining INSPIRE while waiting, as supported by the Evolutionary Prototyping Lifecycle. This risk was mitigated by attempting to obtain SME guidance early in the system lifecycle. In doing so, the team was able to contact SMEs well in advance of team deadlines, giving them plenty of time to respond.

4 Design Research and Analysis

4-1 Stakeholder Considerations

Understanding the potential users and beneficiaries of INSPIRE (i.e., stakeholders) was critical to the project design. According to the FAA (2011), pilots are responsible for the majority (65 percent) of runway incursion and of those pilots, 75 percent are from the GA community. INSPIRE is therefore primarily geared towards GA pilots. The price has to be reasonably low to attract aircraft owners. Reliability of the product is also essential to reduce any cost associated with maintenance. The only cost future owners would be expected to pay is for software updates in response to, for example, unforeseen airport renovations. The updates would be through the use of an SD card and would include any movement areas but primarily taxiways, runways and any new hold short lines associated with installations of new glide slopes.

Controllers have to be extremely vigilant and are always scanning for potential danger. With the implementation of INSPIRE, the likelihood of less experienced pilots or unfamiliarity with an airport to be the cause of an incursion could be reduced. This would help ease the burden currently on ATC and also decrease the amount of communication between ATC and pilots. Less communication should mean improved airport circulation.

4-2 Interactions with Subject-Matter Experts

While understanding stakeholder requirements was essential for getting started, a little insight from industry subject matter experts was critical to continued design success. The INSPIRE system was developed after consultation with numerous industry experts and airport operators (See -Appendix G for the list of subject matter experts consulted). A preliminary presentation given by Martin (aka “Marty”) Lauth, a professor at Embry-Riddle Aeronautical University and a retired air traffic controller, gave us an overview of the real challenges that air traffic controllers, pilots, and airport operators face in conducting safe, efficient operations in the aerodrome environment. During his presentation, Mr. Lauth showed us a series of videos from the Office of Runway Safety Training Animation Series that showed real-life incursions. He emphasized the hazard presented by incurring aircraft, ground vehicles, and pedestrians to arriving and departing aircraft. It is this potential for danger, he said, that has ensured that the reduction of the frequency and severity of runway incursions has remained a top priority of the FAA for over a decade (personal communication, September 6, 2012). As a result of Mr. Lauth’s presentation, we narrowed down the focus of our design; the goal of our design solution—what would later become INSPIRE—would be to reduce the number and severity of runway incursions through the augmentation of pilot SA.

Following Mr. Lauth’s presentation, a second presentation was made by personnel from the Daytona Beach International Airport (i.e., KDAB). This presentation, and the subsequent question and answer session, were instrumental to our understanding of the airport characteristics that may exacerbate the frequency and severity of runway incursions. According to the KDAB personnel, a lack of clear runway signage (e.g., runway number signs, taxiway signs, and hold short lines), the concealment of existing runway signage by other objects in the environment (e.g., grass overgrowth), airport complexity, and changes in taxiways due to construction, may all increase the likelihood of a runway incursion. In addition, the presentation made by the KDAB personnel increased our awareness of existing design concepts and procedures aimed at reducing the frequency of runway incursions, as well as their relative absence at smaller airports with mostly GA traffic (personal communication, September 17, 2012). A subsequent tour of the airport allowed us to see the operational environment and associated procedures in action; it also allowed us to have a first-hand look at the runway environment, including signage and hold position markings. After the presentation and tour given by the KDAB personnel, we developed the initial design concept for INSPIRE: an intuitive HUD display that would aid in the navigation of the airport environment following the taxi instructions given by ATC, while reducing head-down time and encouraging "eyes out" during taxi periods.

After a review of the existing technology, it was decided that we would base our intuitive HUD on the Virtual Cable™, an augmented reality application for automotive technology developed by MVS—California. In an effort to better understand the technical aspects of their concept, and the feasibility of its implementation in GA aircraft, we contacted Chris Grabowski, the CEO and Head Technician of MVS. Mr. Grabowski explained how the Virtual Cable™ uses constant variations of X and Y axes to produce the effect of a Z axis extending outward from the windshield. However, since only a prototype of the Virtual Cable™ has been developed, he was unable to answer questions regarding the production cost or weight of the device. In the automotive market, for which the Virtual Cable™ is designed, product aesthetics are more important than weight. Therefore, the most important aspect of the design of the Virtual Cable™is not its weight, but rather that it can be hidden behind the dashboard of a car (personal communication, November 1, 2012).

In an effort to determine the feasibility of installing a device similar to the HUD projection unit developed by MVS in a typical GA aircraft cockpit, we contacted Mr. Lauth, who put us in contact with Lyle Sunderland, the Manager of Quality Assurance and Chief Inspector at the Embry-Riddle Aeronautical University Flight Department. Mr. Sunderland showed us one of Embry-Riddle's Cessna 172 training aircraft, and allowed us to take some photos of the area behind the instrument panel. He pointed out empty areas behind the panel where the device could be mounted, noting that "if it could fit in a Cessna, it could fit in pretty much anything." He also assured us that the weight of the device, which we estimated to be between 5–10 lbs. based on the required components, would not be an issue. Mr. Sunderland also provided us with a disk of schematics for the Cessna 172 to aid in the development of our design (personal communication, October 24, 2012).

Mr. Lauth and Mr. Sunderland also provided information for the cost-benefit analysis of INSPIRE. Mr. Lauth suggested incorporating the projected installation and maintenance costs of the device, as well as the costs incurred due to fatalities and aircraft damage as the result of an incursion, into the analysis. He provided an industry contact within the Atlanta FAA office, Dan Cilli, to obtain the accident data necessary to make this latter estimation (personal communication, November 13, 2012). Mr. Cilli stated that, during the 11 years he has been in the Runway Safety Program, he could only recall two incursions that resulted in aircraft damage and/or human death: an August 3, 2008 incursion in Reading, PA that involved a small twin-engine aircraft and an incurring van; and the Comair flight 5191 accident in Lexington, KY.

Nevertheless, he provided a link to the NTSB Accident Database, which contained the data necessary to estimate the costs incurred from aircraft damage and loss of human life as a result of incursions (personal communication, November 15, 2012). Mr. Sunderland provided the estimation of installation costs for the voice recognition system and the HUD based on pictures, schematics and documentation of our design concept that we provided. He estimated the cost for the installation of the voice recognition unit at 15–18 hours of labor, at shop rate of $75–$90 per hour, for the first unit. He noted that the installation of subsequent units would be approximately 20% faster, due to the increased familiarity of maintenance personnel with the system and its components (personal communication, November 13, 2012).

Mitch Huffman, an aerospace engineer from the FAA's Aircraft Certification Office in Atlanta, Georgia, provided guidance on the certification process for INSPIRE. He recommended that we consult the FAA Advisory Circular to familiarize ourselves with the relevant certification requirements. Mr. Huffman also provided information on the approval process for the Supplemental Type Certificate (STC) for the HUD display.

Gregory Zahornacky, an assistant professor at Embry-Riddle Aeronautical University and a retired commercial pilot with over 20 years of experience, talked to us about the Advanced Surface Movement Guidance & Control System (SMGCS), a set of systems and related procedures designed to improve the situation awareness of air traffic controllers. In particular, Mr. Zahornacky talked about the low visibility taxi plan, a SMGCS procedure that is implemented when visibility is limited to 1,200 feet on a runway. When the low visibility taxi plan is in effect for a runway, pilots must use the taxi routes designated by a special SMGCS Low Visibility Taxi Route chart to arrive and depart from the runway. Mr. Zahornacky noted that, since taxi routes are limited when the SMGCS low visibility taxi plan is in effect, our design could incorporate those limitations when charting routes based on the pilot's read-back of ATC instructions (personal communication, October 24, 2012). This limitation would serve as an additional precaution against incorrect read-back of ATC instructions while simultaneously increasing the efficiency of the system by closing taxi routes not utilized during low visibility conditions. Though the incorporation of SMGCS Low Visibility Taxi Route charts is beyond the scope of the current iteration of INSPIRE, such charts could be incorporated into future versions of the system.

The knowledge and feedback provided by the KDAB airport personnel, Marty Lauth, Lyle Sunderland, Chris Grabowski, Gregory Zahornacky, Mitch Huffman, and Dan Cilli, had a significant influence on the design and subsequent modification of INSPIRE. As subject-matter experts in airport operation, air traffic control, aircraft operation, aircraft maintenance, and HUD design, their input was invaluable to ensure that INSPIRE fulfills the needs of the system's stakeholders and represents a useful contribution to runway incursion prevention technology.

4-3 HUD Position Analysis

Complementary to understanding the risks involved in development was understanding the nature of extant HUD technology. The typical location of information displays for pilots is on the instrument panel of the cockpit. For effective SA, however, the pilot must be able to navigate an airport while maintaining an appropriate visual scan of the outside world. Navigational aids displayed in HUDs located above the instrument panel can provide information to a pilot while he or she scans the outside world. The following section reviews the placement of technology above the instrument panel across a range of aircraft types.

Figure 4, created by the team, shows the locations of HUDs used for navigation guidance in a range of aircraft types using a diagram of a Cessna 172 (C-172) cockpit. The team chose a

C-172 as the target for INSPIRE and for this HUD position analysis because the C-172 is one of the most popular aircraft in operation, and if our design can fit in the confines of a small aircraft such as a C-172, then it will be able to fit in any larger aircraft, an assessment made by two SMEs we interviewed, Gregory Zahornacky and Lyle Sunderland.

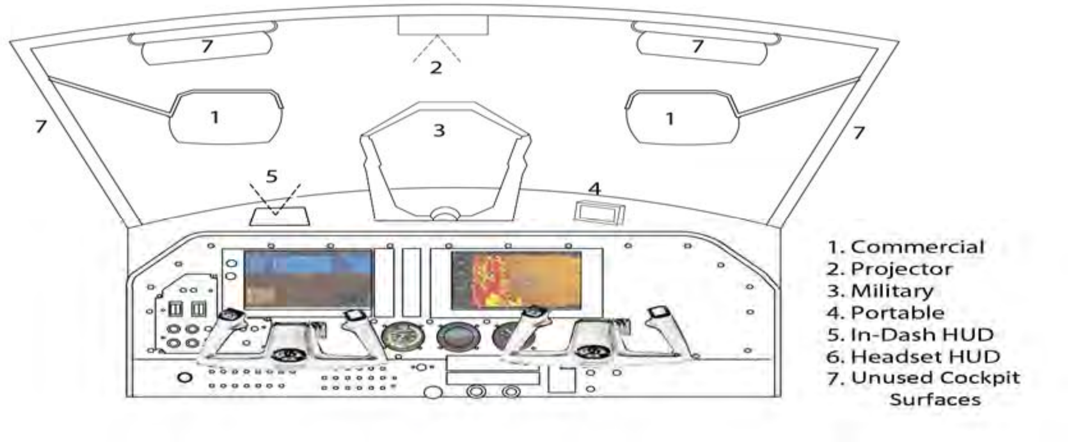


Figure 4. Placement of various HUD technologies in various aircraft.

Commercial HUD positions, labeled in Figure 4 with the number 1, display heads up navigational guidance directly at eye level. Commercial HUDs are currently being used in aircraft such as the B737, A-320, FDI 1000, FV-2000, and the MD-80. Commercial HUDs can be used to support various flight activities, and the pilot is able to choose between various primary flight displays (PFDs). The pilot can choose between different modes and can de-clutter the display of information that is irrelevant to current operations of flight. An example of a HUD with these capabilities is the MD-80 HUD, which commercial pilots only use during approach. The commercial HUD display shown in Figure 5 is a product by Rockwell Collins called the

Figure 5. HGS (Rockwell Collins, 2008)

Head-up Guidance System (HGS). The HGS displays images produced by a cathode ray tube (CRT) that is reflected off a combiner, the angled flat piece of glass positioned in the front of a pilot, at near optical infinity to the eye level of the pilot as defined in FAR 25.773 and 25.777 (Prinzel & Riser, 2004).

Some of the capabilities of HGS are to help pilots perform Category III landings (50 feet decision height), 600 feet runway visual range (RVR) and low-visibility takeoffs (to 300 feet RVR). Using a HUD like the HGS (Figure 5) can give the pilot improved situation awareness in low visibility conditions, a capability that is shared with our team's design for INSPIRE. The large amount of information displayed in the relatively small HGS display space may not allow the pilot to focus all their attention on a single problem. This clutter of information can make it difficult to simultaneously monitor information in the far domain. In contrast, INSPIRE reduces the amount of information displayed to a pilot, which should allow an increase of SA.

Projector-based head-up navigation display system.

There is limited research on projector-based systems for aircraft. The group looked at the area above the pilot's head to project information onto the windshield of the aircraft. The placing of technology above the pilot's head reduces the feasibility of the project. A C-172 does not have the space to house projection technology and this location was not investigated further.

Military head-up navigation display systems. The CMA-7100 Digital SparrowHawk HUD is a product developed by Esterline CMC Electronics and used for navigation purposes as well as system targeting for weapons. The CMA-7100 is specifically for a one-seated aircraft like an F-22. The C-172 is a far cry from a F-22 and the placement and the amount of space needed for this device are incompatible with the C-172 (see location 3 in Figure 4).

Portable head-up navigation display systems. The group discussed the idea of designing INSPIRE as a portable navigation device. As depicted in the location labeled number 4 in Figure 4, a portable device would be much like a GPS navigation unit for an automobile. A portable device can be placed on top of the instrument panel, but this placement would obstruct the view of a pilot. Our goal was to limit obstruction and use a technology that displayed information above the instrument panel in order to support out-the-window monitoring and thus SA. The portable iPad was used in previous design competition projects; however, our team has the explicit goal of supporting runway-and taxiway- awareness while minimizing head-down time, a goal the iPad does not clearly support. Devices such as an iPad displays redundant information, like an airport map, while increasing heads down time.

In-dash head-up navigation display system. In-dash HUDs are commonly found in automobiles. This placement of a HUD, as depicted in Figure 4 as location number 5, was favorable to the team. The placement behind the instrument panel avoids obstructing a pilot's view and a projection onto the surface of the windshield allows a pilot to view information in the near and far ground. As apart of the research underlying this design effort, we sought out new, cutting edge HUD designs. One such design is the in-dash Virtual Cable™ system developed by MVS California Inc. The Virtual Cable™ is a design that provides a "virtual pathway" to an automobile driver, allowing more heads up time and less time searching a map. The projected route displays future turns to give the driver increased SA in complex highway systems or a city.

Figure 6. Headset Eye HUD (CuteDevices, 2012)

Headset based head-up navigation display system. An eyepiece for a pilot integrated with the headset is yet another form of HUD (see Figure 6). This is very inventive, but the team did not see it as a feasible concept to use for INSPIRE.

Unused cockpit surfaces as display location options. Another placement option for a head-up navigation display is on one of the unused surfaces of the cockpit. Unused cockpit surfaces (i.e., places where visual obstructions already exist) represent an opportunity to place information. As depicted in Figure 4 number 7, the visors and structural supports are examples of areas that can be utilized, but these locations were not popular with the team.

4-4 HUD User Interface Considerations

After a review of the placement and type of technologies available, it is appropriate to address how information on a display should be presented. The Society of Automobile Engineers (SAE) International documents the findings of the G10 Subcommittee on Human Factors HUD Issues. A list of concerns about the impact of HUDs on flight operations in the terminal area and flight navigation in the airspace system was developed by this G10 subcommittee (SAE International, 1998). Some of these concerns are stated as follows:

- Lack of symbology across HUDs for transition from pitch to flight path reference.
- Issues regarding definition and phenomenon of “clutter”.
- Lack of scale linearity and conformity of symbology with real world.
- Whether an auxiliary heading scale should be presented in compressed format when the flight path marker is above the horizon.
- Concerns about crew coordination, mode awareness, and pilot workload with HUD use.

The above concerns that are relevant to ground navigation are addressed in our design. For example, issues regarding clutter (as in the SAE International document) were addressed by displaying useful information in a useful form to a pilot (e.g., using a navigation line). This focus on minimal functionality does away with clutter and focuses on the primary intent of the design.

5 Concept of Operation

The intent of INSPIRE's design is to reduce the occurrence of runway incursions. Our system tackles the problem in different ways by means of navigation guidance and functionality that reduce heads-down time and probability of navigational errors while enhancing situational awareness. INSPIRE achieves these goals by means of HUD graphics, alerts, and speech recognition technology, as described below.

INSPIRE uses a laser generated line that is displayed directly on the windshield showing the name and location of the up-coming movement paths (see figure 11). The color of the navigation line will be in compliance with Advisory Circular 23.1311-1B, according to which, red is displayed as a warning, amber/yellow as a caution, and green as engaged mode or flight guidance (Colomy, 2005). Magenta is a selected color to represent an active route or flight plan and this color will be used as the line in the design. Amber/yellow will project onto the lower left corner of the windshield to make the pilot aware he or she is approaching a threshold or "hot spot", where incidents are more likely to occur.

Typical navigation units mounted in aircraft are located below the pilot's field of vision. This can be problematic because they tend to increase pilots' head-down time, which may decrease SA. By projecting taxi directions directly on the windshield, less time is spent looking at the aircraft's navigational units in order to determine where the next turn might be or how soon. The pilots are always looking up and are able to verify their locations with minimum vertical head movement.

When given or copying a taxi clearance to or from the runway, both air traffic controllers and pilots are susceptible to making mistakes, many of which could be detected and corrected using INSPIRE. Air traffic controllers can from time to time provide taxi clearance that isn't correct (e.g., by giving directions that include two taxiways with no common interception). Pilots unfamiliar with the airport in question would follow blindly until the disconnection point; pilot error could occur by copying instructions incorrectly; for example, by writing the wrong taxiway or omitting parts. INSPIRE aims to minimize both types of mistakes by automatically checking and verifying taxi directions when the pilot repeats his/her clearance. Using speech recognition technology, the taxi clearance information is checked against the airport database and displayed directly on the windshield as a graphical line. In case of a mistake by ATC or the pilot, the pilot will be prompted and asked to correct the previous entry. An example of such a clearance given to a pilot could be "N123ER, taxi to runway 12 via Echo, November, November 5". During the read back, if the pilot omits one "November" and just says "runway 12 via Echo November 12", INSPIRE would alert him/her of the discrepancy. With INSPIRE, the pilot is able to correct mistakes made by him/her or by controllers before ever moving the aircraft.

INSPIRE also alerts pilots when approaching hold short lines. The alert is displayed in the pilot's central field of view, directly in front of him/her, and remains active until the pilot acknowledges the warning or the aircraft crosses the runway. The alert displays a sign representing the hold short line depicted on taxiways close to runways. The use of graphics that are similar to airport signs and symbols is to reduce the time for pilots to recognize and respond (e.g. the hold short line displayed in figure 10 by INSPIRE is similar to the one painted next to runways).

6 Device Architecture

INSPIRE incorporates existing off-the-shelf technology; specifically the Virtual Cable^{TM} ,MVS California, Garmin G-1000 with SafeTaxi software, VFS101 Pilot Speech Recognition System, and the pilot's choice of head set. Figure 7 is a diagram by the developers of Virtual Cable system that was modified by our team to represent the architecture of the INSPIRE design. As shown in Figure 7, pilot communications into the headset microphones (upper right of diagram) are transmitted to the audio panel and the VFS101 Unit. The VFS101 unit outputs to the Garmin G1000 where communication with Virtual Cable^{TM} begins to take place.

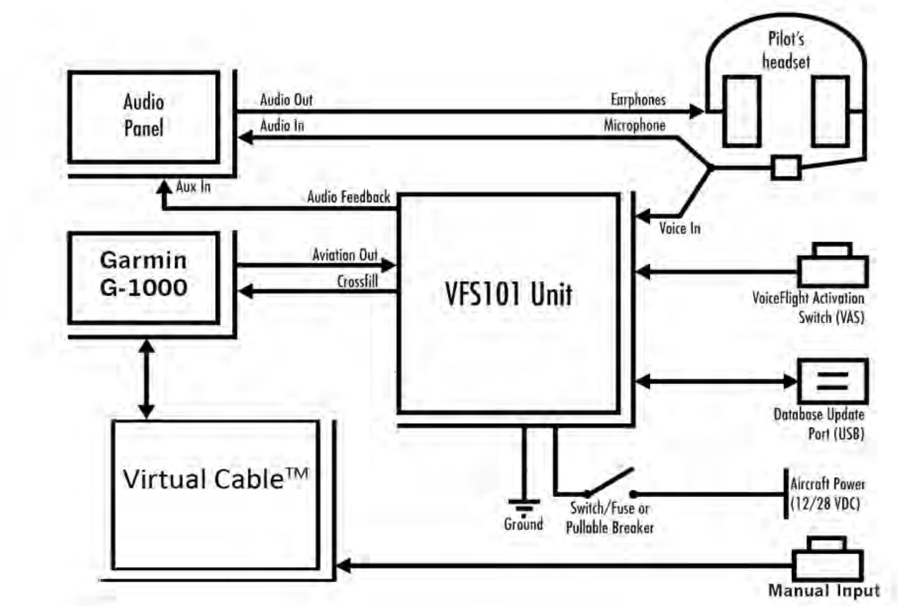


Figure 7. System Device Integration Diagram (Voiceflight Systems LLC, 2011) Modified to fit INSPIRE

The VFS101 uses the standard ICAO phonetic alphabet and is certified by the FAA. The certificate supports installation in all aircraft under 6,000 lbs. and the C-172 falls in this category. The device is small and measures approximately 3" by 5" with a weight of .75 lbs, a weight that will not impact the balance of the aircraft. The weight of the Virtual Cable$^{\text{TM}}$ unit would be less then ten pounds and would not hamper the weight and balance performance of the aircraft either. The Garmin's aeronautical SafeTaxi airport map database complies with the AC 20-153A and the Radio Technical Commission for Aeronautics (RTCA)/DO-200A.

Figure 8 is a photo taken by the team from underneath the instrument panel of a C-172. Most of the room available is from the center to the right of where the co-pilot sits. The Virtual Cable$^{\text{TM}}$ heads up guidance system would sit just off center to the right and can integrate nicely with the G-1000 and the VFS 101 Unit shown in Figure 7. Figure 9 was created by the team to illustrate how the system integrates into the instrument panel. The VFS101 can be mounted anywhere inside the instrument panel, and the only piece of technology not yet FAA certified is the Virtual Cable$^{\text{TM}}$.

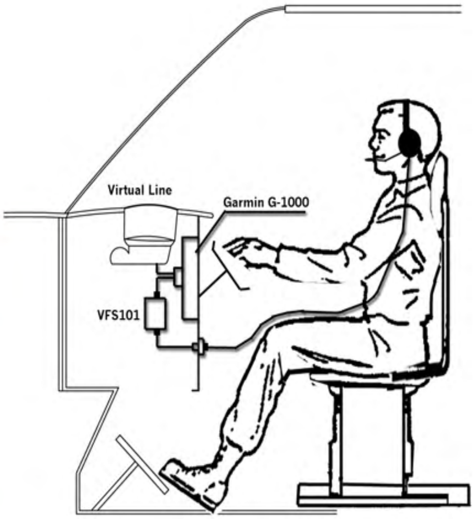


Figure 8. Behind the Instrument Panel

Figure 9. Section of Device Integration

7 Design

Given the various forms of information that can be projected onto a display and the risk of displaying so much that it becomes difficult to differentiate between near and far views, a design should minimize clutter and provide minimal functionality. Figures 10 and 11, created by the team, represents what INSPIRE would look like. After a pilot has landed, crossed the threshold and stopped for directions from ATC, the pilot confirms the ATC directions and the VFS101 begins to process the ICAO phonetic alphabet. A list of translated directions is then displayed on the lower left corner of the windshield and if the directions are correct, the pilot pushes the Nav knob on the G-1000 to view the graphical navigation path displayed by the Virtual Cable^{TM}. If the directions are incorrect, the pilot can enter the correct sequence of turns using the G-1000 interface. Once the correct directions are inputted, the G-1000 begins to work with the Virtual Cable^{TM} to display a navigation line onto the windshield. The pilot then begins to navigate the airport while maintaining a visual scan of the outside world.

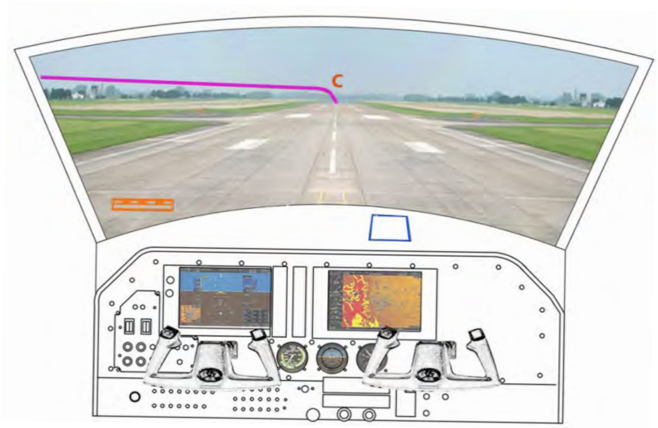


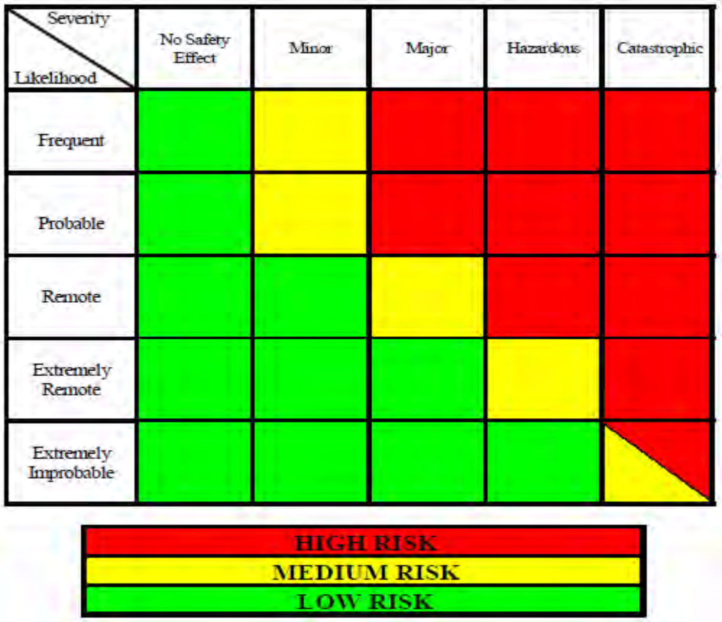
Figure 10. View of INSPIRE

Figure 11. INSPIRE Gate.

Figure 10 represents what the pilot would see while taxing at an airport. The display shows a turn to the left on Charlie and an approaching threshold, displayed on the bottom left corner. Figure 11 displays a view of the line above the horizon to allow for full visibility of the taxi way. Gate 12 is displayed on the bottom left corner and at the turn point on the windshield.

8 FAA Safety Risk Management Documents

Once the INSPIRE design was developed, it was necessary to assess safety concerns associated with the use of that design. Conducting a Safety Risk Management (SRM) analysis for this project involved using the FAA Safety Management System (SMS) for Airport Operators (found in AC 150/5200-37) and the FAA SMS Manual. AC 150/5200-37 describes SRM as a systematic, explicit, and comprehensive approach for managing safety risk throughout the airport. SRM is described as a five-phase process: describe the system, identify hazards, determine the risk, assess and analyze the risk, and treat the risk (i.e. through mitigation, monitoring, and tracking). The group followed these steps, using the predictive risk matrix (see Figure 12) to assess and analyze the risks.



Severity / Likelihood	No Safety Effect	Minor	Major	Hazardous	Catastrophic
Frequent	🟩	🟨	🟥	🟥	🟥
Probable	🟩	🟨	🟥	🟥	🟥
Remote	🟩	🟩	🟨	🟥	🟥
Extremely Remote	🟩	🟩	🟩	🟨	🟥
Extremely Improbable	🟩	🟩	🟩	🟩	🟨🟥

🟥 HIGH RISK
🟨 MEDIUM RISK
🟩 LOW RISK

Figure 12. Predictive Risk Matrix.

9 INSPIRE Risk Management

The group reviewed applicable FAA SMS documentation, spoke with aviation SMEs, and engaged in several brainstorming sessions to identify the following operational risks (discussed below) for INSPIRE: output errors, input difficulty, visual interference, lost GPS signal, loss of power, loss of communications, and over-reliance on the system. The results are summarized in Table 3.

Table 3. Risk Table.

Hazard	Probability	Severity	Risk Category	Priority
Output Errors	**Extremely remote**	**Hazardous**	**Medium**	**High**
Input Difficulty	**Remote**	**Major**	**Medium**	**Medium**
Vis. interference	**Probable**	**Minor**	**Medium**	**Medium**
Lost GPS signal	**Remote**	**Minor**	**Low**	**Low**
Loss of power	**Extremely remote**	**Minor**	**Low**	**Low**
Loss of Comms	**Remote**	**Minor**	**Low**	**Low**
Over-reliance	**Extremely remote**	**Major**	**Low**	**Low**

Output Errors

System input consists of user “repeat backs” of ATC instructions, which causes the system to display a 3-dimensional line that corresponds to the prescribed path of required movement. This introduces the possibility of two severely hazardous albeit unlikely errors: 1) Improper verification by the user (i.e., of the system’s translation of the user’s repeat back) and 2) Improper airport schematic for transcription and projection of the guidance line. In the first instance, the user may verify a translation that was incorrect, perhaps due to language difficulties (e.g., user can’t read English well) or carelessness. This risk can, in part, be mitigated by the user familiarizing themselves with recommended communications procedures, as covered in the FAA Runway Safety Best Practices Guide. With regards to the second possible error, the translation may be accurate, but the airport schematic that was uploaded may be for the incorrect airport, or it may be out of date. This can be mitigated by downloading the latest airport schematics from the FAA Airport Diagrams website (*www.faa.gov/airports/runway_safety/diagrams*). These actions should keep this risk within ALOS.

Input Difficulty

Input difficulties can be divided into two types of errors: 1) improper repeat back due to unclear ATC instructions and 2) the misunderstanding (i.e., by the system) of the pilot's repeat back. In the first instance, ATC instructions may be unclear or garbled, causing a halting or stuttered repeat back. In the second instance, the speech of the user might be misunderstood, for example, due to a heavy accent, poor enunciation, the use of homonyms, or deviations from the standard enunciation format. In any case, the mitigation is fairly straight-forward: following repeat back translation, the user is required to verify accuracy of the translation, and the user can reject a faulty transcription and try again. If there is a continued inability to verify the transcription as correct, taxiing instructions can be written and carried out in the traditional knee-board fashion.

Visual Interference

The usefulness of a HUD can be decremented if the display interferes with the ability to see a required visual field (e.g., by creating contrast interference). The potential for interference by INSPIRE is minimal, based both on placement and type of information, as well as presentation color. Line placement is based on the findings of Foyle et al. (2001); it will be projected at least 8 degrees outside the center of the primary viewing area. The beam requires minimal cognitive processing (as opposed to numerical values), so it should not create a competing cognitive load.

The line will have a default display color that is designed not to adversely affect the pilot's ability to view other objects at night, both in the internal and external scene. Interface controls will allow the user to adjust the color and intensity of the beam to fit personal preferences as well as the situation. These measures will keep the risk within ALOS.

Lost GPS signal

The system is designed to rely on GPS inputs, so the loss of all GPS data will cause the system to cease displaying a guidance line. If GPS data input cannot be restored, the pilot will be required to rely on the traditional method of taxiing. Since the system is designed to complement existing traditional skills, this risk is within ALOS.

Loss of Power

There are two areas of concern with regards to power: 1) loss of power to the unit and 2) loss of power to the aircraft. If unit power loss occurs, the pilot will be required to navigate using a knee-board and manually transcribing ATC instructions. In the event of a loss of power to the whole air-frame, accurate navigation becomes less problematic; since the aircraft has no power, it will not be able to navigate anywhere, which keeps this risk within ALOS.

Loss of Communications

The system is designed to rely on verbal user input. If communications between ATC and the pilot are disrupted, the user can still provide input by speaking the last received ATC navigation instructions. If no verbal instructions have been received, the pilot will navigate in accordance with FAA loss of Communications procedures (see FAA Runway Safety Best Practices Guide). If a navigation route is provided by other than verbal means (e.g., by flashing lights with the ATC tower), the pilot can then verbally input that path into the navigation device.

Over Reliance on System

INSPIRE is designed to reduce heads-down time, as well as facilitate the job of airport navigation. If INSPIRE proves relatively easy to learn, is widely used, and is well received by pilots, there is the potential that pilots will skimp on more time-consuming methods of navigation in favor of relying on technology. Continuous lack of practice may lead to degradation of manual skills, which could prove problematic in the event of a system failure. Since it is difficult to specify at what rate skills dissipate, mitigating this factor will be the job of the user. The user will have to decide how often to practice manual navigation in order to avoid losing skills and becoming over-reliant on the system. As long as traditional methods of navigation are covered during new pilot training sessions, this risk will stay within ALOS.

SRM Summary

INSPIRE is designed to complement (but not replace) traditional methods of navigation. The presence of only one EFB does not relieve the pilot from the requirement to carry paper charts, nor does it relieve them of the responsibility to practice sound airmanship principles. INSPIRE should be used with due care and an understanding of its limitations and risks.

10 Financial Analysis

Considering the diverse GA pilot population, cost is a significant factor in acquiring and adapting to new cockpit technology that reduces Runway Incursions by boosting pilot SA. Capabilities and limitations of the INSPIRE system (discussed in previous sections of the report) need to be considered in light of INPIRE's financial costs and benefits.

The principal costs of the INSPIRE HUD and Pilot Speech Recognition System stem from three major system elements. These system components include the Virtual Cable™ HUD, Voice Flight's Pilot Speech Recognition System unit, and Garmin's SafeTaxi electronic airport database. The projected monetary cost of each system component is $1000, $1,995, and $49, respectively (BMW of North America, 2012; Voice Flight Systems, 2011; Garmin, 2012).   With the exception of the HUD, the estimated costs are based upon manufacturers' suggested retail pricing. The HUD is specially priced according to existing BMW automotive technology.

Besides the costs of the major INSPIRE system components, there are costs associated with installation and certification, both of which are essential to achieving FAA aircraft certification and airworthiness standards. The representative GA airplane for the proposed INSPIRE technology is the modern Cessna 172SP equipped with the Garmin G-1000 glass avionics package. According to Lyle Sunderland, Maintenance Chief at Embry-Riddle, the time and cost to install both the Pilot Speech Recognition System Unit and the HUD will take about 40 hours at an average hourly labor rate of $83, respectively. After the mechanics learn the installation procedures and designated equipment locations in the aircraft, subsequent labor time and cost will likely be reduced by 20% (Sunderland, 2012). For the certification costs, our team is actively seeking certification guidance from Mitch Huffman, an FAA Aerospace Engineer. Without the certification criteria, the total cost to retrofit a C-172SP G-1000 with all of the INSPIRE system components is about $6,364.

In addition to the equipment, installation, and certification costs, training pilots to use the INSPIRE system is critical to safe and effective system operation. Using the representative C-172SP G-1000, a Certificated Flight Instructor with an Instrument Rating will teach each pilot the essential features of the HUD and Pilot Speech Recognition System over the time span of a 3-hour flight. The pilot will learn to readback and confirm appropriate ATC taxi instructions on the G-1000 Primary Flight Display, become familiar with HUD orientation, lines, symbols, and operate SafeTaxi on the G-1000 Multifunction Display. Using Air Daytona's pricing schedule, the cost of the pilot training for the INSPIRE is the sum of the aircraft hourly rate and the flight instructor's hourly rate. At a combined rate of $170 per hour, the estimated cost for three hours of pilot training is about $510. Training 20 pilots to use the INSPIRE system would cost $3,400.

Besides the pilot training, retrofitting a flight school fleet of 20 C-172SP G-1000 airplanes with the INSPIRE system realistically demonstrates the technology's affordability and utility. The total cost to retrofit a fleet of 20 C-172SP's would be the combination of the equipment, installation, and certification costs plus the pilot training time. These first year costs amount to $130,680. Annual maintenance of the INSPIRE system consists of Garmin SafeTaxi database updates as well as software and navigation updates for the Pilot Speech Recognition System. Since Voice Flight Systems provides free software and navigation updates for the Pilot Speech Recognition System, the only annual expense is the $195 Garmin SafeTaxi database subscription (Garmin, 2012). Updating 20 C-172SP G-1000 aircraft with the SafeTaxi database would cost $3,900.

While the costs of the INSPIRE system are extensive, the benefits of preventing human fatalities, reducing serious injuries, and mitigating aircraft damage justify the monetary investment. According to the Department of Transportation guidance, the FAA assigned the treatment value of $5.8 million to a human life (FAA, 2008). On Comair flight 5191, the pilot and copilot's shared decision to depart on the wrong runway cost 49 human lives. This confusion or lack of positional (situation) awareness on the airport surface likely contributed to the deaths of 47 passengers, a flight attendant, and the captain (NTSB, 2007).   The first officer was the sole survivor of the crash. He sustained serious injuries (NTSB, 2007).   The 49 souls lost on Comair flight 5191, whose lives were valued at $282.2 million, caused tremendous emotional trauma for families and friends. Besides the aircraft accident victims, the Bombardier

Regional Jet sustained substantial damage or a total hull loss in the amount of $22.5 million (Business & Commercial Aviation, 2012). If the INSPIRE HUD and Pilot Speech Recognition System had been installed on Comair flight 5191, the captain and first officer's enhanced SA would have likely mitigated the runway confusion event, and consequently saved 49 precious human lives. Comparing the benefits to costs, protecting human lives and salvaging the airplane would have saved $306.7 million. In the event of GA Runway incursion incidents, these preventative benefits of human life and aircraft damage remain highly applicable. Refer to Table 4 for a complete summary of the cost and benefit analysis of INSPIRE.

Table 4. Summary of Cost & Benefit Analysis

Item	**Estimated Costs**	**Estimated Benefits**	**Total Benefits**
Pilot Speech Recognition System	$1,995		
Virtual Cable Heads-Up Display	$1,000		
Garmin G-1000 U.S. SafeTaxi Database (One-time update)	$49		
Installation	$3,320		
Certification	TBD		
Total Retrofit Cost (per aircraft)	$6,364		
Fleet of 20 C-172SP's	$127,280		
Pilot Training	$3,400		
First Year Cost	$130,680		
Garmin G-1000 U.S. SafeTaxi Annual Service	$195		
Pilot Speech Recognition System: Software & Navigation Updates	$0		
Annual Cost	$3,900		
One Fatality		$5,800,000	
Hull Loss: Bombardier RJ		$22,500,000	
49 Lives Saved		$284,200,000	
Total Benefit			$306,700,000
1 Year (B-C)	$130,680	$306,700,000	$306,569,320
2 Year (B-C)	$3,900	$156,250,000	$156,246,100
3 Year (B-C)	$3,900	$87,000,000	$86,996,100
4 Year (B-C)	$3,900	$58,000,000	$57,996,100
5 Year (B-C)	$3,900	$29,000,000	$28,996,100

11 Real World Impact

The INSPIRE system design concept reinforces the leading runway safety initiatives at the NTSB and FAA. The INSPIRE HUD and pilot voice recognition system strongly support the NTSB's 2013 top transportation priority to improve the safety of airport surface operations. Like the NTSB, one of the FAA's top goals is to reduce the risk of runway collisions as well as the frequency of runway incursions (FAA, 2012). INSPIRE's system technology supports the reduction of runway incursions involving wrong runway departures, collisions between aircraft, and collisions between aircraft and ground vehicles.

The most recent serious runway incursion event involved a wrong runway departure. In the early morning darkness on August 27, 2006, a Bombardier Regional Jet (CRJ-100) operating as Comair Flight 5191, destined for Hartsfield-Jackson Atlanta International Airport (ATL) in Atlanta, Georgia, attempted takeoff from the wrong runway at Blue Grass Airport (LEX) in Lexington, Kentucky (NTSB, 2007). Out of the 50 people onboard the aircraft, the captain, flight attendant, and 47 passengers sustained fatal injuries. The copilot sustained serious injuries. Impact forces and post-crash fire destroyed the aircraft (NTSB, 2007).

The National Transportation Safety Board cited the flight crew's failure to use visual markers and resources to track the aircraft's position on the Blue Grass Airport surface during taxi and verify appropriate runway alignment prior to takeoff as the probable cause of the mishap. This significant finding about the pilot and copilot's loss of SA prompted the NTSB to recommend installation of cockpit moving map displays or runway alerting systems to address the safety concern (NTSB, 2007). INSPIRE fulfills these recommendations.

12 Commercialization

The INSPIRE HUD and pilot voice recognition system is designed for U.S. GA pilots. The affordability of the system outweighs the significant cost of human lives and substantial aircraft damage. The usability of the system benefits the pilot by providing visual cues, familiar airport signs or symbols, and interactive textual feedback from the GPS via pilot voice read-back. Considering the FAA's current and future efforts to upgrade obsolete technology for the NextGen Air Traffic Control System, the INSPIRE system will likely be successful because it digitally augments GA pilots by providing taxi guidance to mitigate runway incursions or collisions. The system's minimal training time, ease-of-use, and runway safety benefits are all attractive features for GA pilots who operate at busy, complex airports or unfamiliar airfields.

A potential market for the INSPIRE system exists worldwide. The GA Pilots in the international community would greatly benefit from the HUD and pilot voice recognition system at a variety of airports with joint use runways or confusing taxiway and runway intersections. To accommodate these pilots, the pilot voice recognition software would need to be adapted to match GA pilots' foreign dialects. Also, the Safe-Taxi airport diagrams for the countries in question would need to be uploaded into the Garmin G-1000 to provide the pilot with accurate taxi guidance on the airport surface.

13 Conclusion

INSPIRE is a navigational aid designed to reduce runway incursions by augmenting pilot SA through the use of HUD technology. Extensive group research and interactions with subject matter experts indicates a high feasibility for product implementation; it is easy to use, cheap to purchase and install, and has decent marketability. Additionally, the safety concerns associated with its use pale in comparison to the risks it will help mitigate, including the reduction of accident related expenditures, injuries, and deaths.

Appendix A: List of Student and Staff Contacts

Faculty Advisor
Dr. Kelly Neville
Associate Professor
Human Factors & Systems
nevillek@erau.edu

Team Member
Paul Gillett
gillettp@live.com

Team Member
Michael Fehlinger
mjf295@gmail.com

Team Member
Ndiaye Diabira
diabiran@my.erau.edu

Faculty Advisor
Martin Lauth
Assistant Professor
Applied Aviation Science
Lauth16d@my.erau.edu

Team Member
Breanna Goring
goringb@my.erau.edu

Team Member
Jason Goodman
goodmaja@my.erau.edu

Team Member
Sarah Cullen
cullens@my.erau.edu

Appendix B: Description of the 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 in 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

Paul Gillett

Early on in the project, I became the leader of the group. Once word got out that I was one of the ROTC instructors across the street, I guess it became logical to the group for me to take charge, so that's probably how it came about. One day I just started giving directions, and people started doing what was directed. From a leadership standpoint, then, this project has been a good reminder of what it's like to head up a team when you have no formal/legitimate power. Whereas in a Military setting the delineation of authority is very clear, our group was communal in terms of authority; each member had as much as the next. Thankfully, the group members were sufficiently mature that this did not present a real obstacle; very little time was spent arguing over competing points of view.

From an instruction standpoint, the FAA competition project provided an excellent venue to incorporate material learned in class in a very real and pertinent fashion. It is easy enough to read several pages on the waterfall life cycle model, write a paper about SysML, or discuss the details of general systems theory; it is quite another to practice these concepts in a working environment. While not all the material covered was directly helpful to the project's completion, most of it complemented the project in one fashion or another. In truth, towards the end of the class, the group found that it had incidentally completed a number of different items required for the final report.

In terms of challenges preventing project completion, the team had to deal with competing priorities in the individual lives of its members. Quite apart from the numerous assignments in the systems class itself, some of the members of the group are also full time employed, or active members in groups outside of the University. Overcoming this challenge involved sacrifice and understanding on the part of each group member.

With regards to our hypothesis development process, the Systems Development section of the report covers some of the specifics. We got together and started brain storming appropriate topics and ideas. When we realized we didn't have forever to come up with ideas, we chose one that appealed to all the group members on at least some level.

Industry participation in the project was useful, and not just because its required for points. The "Interactions with SMEs" section details some of the finer points, but basically industry provided the sanity check to our design. More importantly, the SMEs made sure we covered details that we didn't even know we had to cover.

For my part, I learned the starting steps for proper system development. As an aspiring Human Factors and Systems engineer, understanding the steps involved in this process is critical to future success. In so much as I am already employed by the US Navy, the learning that took place didn't necessarily prepare me for the workforce so much as complement what I already know from my time on active duty. I have found a great deal of application for the material I have already learned, and I anticipate a good deal of future good will come from having participated in this project.

Michael Fehlinger

This project has given me a new perspective of working with team members where initially I wasn't formally introduced. Remembering back in working with groups in my architecture classes, we usually knew who could do what and what to expect from individuals. It was interesting to be apart of a group with a diverse education background and be able to come together as a team to complete the FAA design competition. My background in architecture allowed me to illustrate a few design ideas and eventually contribute to the overall design of the project. As a group we chose runway/runway incursions as a direction for this competition without any rebuttals. I'm usually prepared to discuss a few alternative ideas in meetings, but we seemed to be on the same page as far as the overall picture of the project.

The opportunity to interact with subject matter experts was new to me. It was extremely beneficial to get the feedback from professionals in the industry to help improve our design. Meeting with Lyle Sunderland who is the Flight Department Chief Inspector at Embry-Riddle allowed the team to view inside of the Cessna C-172 where it became evident our design could be envisioned and the feasibility of the project began to take shape. It was a bit of a puzzle to try and piece together what existing technologies can be used to create INSPIRE, but the responsibilities and contributions of each team member allowed this project to be, in my eyes, a success.

N'diaye Diabira

The initial start of the project was quite interesting to say the least. The team was comprised of individuals from different background. We all approached the problem from different views. It wasn't until we went around the table and figured out each other's strength and weaknesses were we able to make progress. Once we started though, there was no stopping us!

I learned a lot from this project. I came to appreciate what engineers do and how precise they have to be in preparing requirements for a given system. To design a system, you have to understand not just what you're building but also who the final recipients are and how they intend to use it; their financial limitations are also very important because it doesn't matter how well designed and effective a product is if it cannot be sold.

This project gave me the chance to practice what I learned throughout the semester, from different design models to coming up with a list of requirements and interacting with SMEs. The project also made me aware of how dangerous incursions are and the need to come up with a feasible solution. Hopefully, INSPIRE will do just that or at least be a stepping stone for what will be a great system.

Sarah Cullen

INSPIRE was developed during the course of Dr. Neville's Systems Concepts, Theory, and Tools class, which brought together a group of students from a variety of educational and vocational backgrounds. The INSPIRE project was the first time that I have worked with such a diverse group of my peers, and it has been a valuable learning experience. Most of my teammates have backgrounds in Aerospace, but for a few—such as myself—the learning curve has been steep.

I have always held a special interest in aviation. However, until I came to study at Embry-Riddle Aeronautical University, this interest was limited to watching Discovery Channel aviation documentaries and attending air shows. My educational background is in psychology, and most of my previous research experience was gained in an industrial/organizational lab; therefore, I have always lacked the domain knowledge to pursue my interest in applied aviation research. Of course, I still have much to learn, but this project has been an enjoyable first step into the workings of civil aviation.

Our team developed our hypothesis after meeting with Marty Lauth, an experienced air traffic controller, and a team of experts in airport operations from Daytona Beach International Airport. Together, they introduced us to the threat that incursions present to runway safety and discussed some of the contributing factors that our design could mitigate. We decided to target the problem of head-down time; specifically, that a reduction in head-down time would increase pilots' situation awareness thereby reducing the risk of them incurring an active runway. Noting the overrepresentation of GA pilots in the incursion data, our design solution was an intuitive HUD designed for the GA cockpit.

The knowledge that I have gained through our interactions with subject-matter experts in airport operations is extensive: an understanding of the daily operations of airports, control towers, and aircraft; the interaction between these entities to ensure safe maneuvering area operations; the threat incursions present to this safety; the contributing factors to incursions; and the current and future initiatives to reduce the incidence of incursions. Industry contacts were critical to our conception of INSPIRE's design, integration into the aircraft, estimated cost, and certification.

Throughout the project, I was fortunate to have team members who were patient enough to explain the more elementary aspects of traffic flow in the maneuvering area, radio communications, and cockpit instrumentation, which made my understanding of the higher-order information possible.

However, despite my lack of domain knowledge, I believe I was able to contribute to the project in a meaningful way. Once I gained an understanding of the research problem and the information sources available, my research background enabled me to delve into the data with a fresh perspective. The synthesis of my research efforts with those of Paul and Brianna, the technical and design considerations developed by Michael, and the impact analyses and valuable pilot's perspective of Jason and N'Diaye resulted in a product that is greater than the sum of its parts. It is perhaps ironic that, after spending a semester "down in the weeds" trying to understand the isolated system components discussed in our introductory systems class, the emergence of INSPIRE from the efforts of such a diverse and seemingly disconnected group of people is a perfect example of the complex interactions Dr. Neville was trying to get us to see all along.

Breanna Goring

Working on INSPIRE was the first time I've worked with such a diverse group of people. Being the only undergraduate I was a bit overwhelmed and questioned my usefulness to the team. However, after getting to know my teammates and learning of everyone else's proficiencies, I realized that I too was an asset to my team.

Conducting his project allowed me to apply the curriculum I was learning in class to a real-world situation. SME's and lifecycle models were terms I were familiar with but actually speaking with experts and following a lifecycle gave me a greater understanding and appreciation for systems engineering.

All in all, I would say that this project was a success. I genuinely enjoyed proposing a solution to a problem and conducting research to defend that solution. I learned a lot about runway incursions as well as gained insight on daily airport operations and challenges faced by airport operators. What I will take away from this experience is the adaptability one must have to work with a diverse group of people and the importance of time management.

Jason Goodman

The FAA Design Competition offered a meaningful learning experience. This practical project provided the opportunity to apply systems engineering concepts, methods, and tools. Our team selected the Runway Safety/ Runway Incursions design challenge. After significant research and discussion, our group developed an innovative cockpit system to improve pilot's situation awareness (SA). Our INSPIRE (Intuitive Navigation System for the Prevention of

Incursions in the Runway Environment) System augments pilot’s situation awareness (SA) on the surface of the airport by reducing pilot’s head-down time.

Despite the innovative system design, our team encountered a few challenges during the competition. One challenge involved selecting a topic for the Runway Safety/Runway Incursion design challenge. The group discussed research studies, existing technologies, and winning ideas from previous competitions. Our design concept emerged from the MVS-California in dashboard Head-Up-Display (HUD) and Voice Flight’s Pilot Speech Recognition System. These two different audio and visual technologies combined to form INSPIRE, a navigational guidance system for GA pilots. Communicating with the appropriate Subject Matter Experts for the Cost-Benefit analysis presented another challenge. Kelly Neville recommended contacting a Human Factors Engineer at Gulfstream Aerospace, to procure certification guidance. Unfortunately, Daniela Kratchounova wasn’t available to provide certification advice. However, Mitch Huffman, an Aerospace Engineer at the Atlanta Certification Office, offered helpful regulatory and non-regulatory guidance for pursuing FAA certification for the HUD.

Overall, the FAA design competition afforded useful learning opportunities. Specifically, I learned to distinguish between the different categories of runway incursions, perform cost benefit analyses, and research the monetary value of a human life in an aircraft accident. These techniques will be highly beneficial to my future career in aviation safety.

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Appendix G: Subject Matter Experts

Subject Matter Expert (SME)	Affiliation	Position	Contact Information
Rhett Bradley	Daytona Beach International Airport	Fire Commander	rbradley@co.volusia.fl.us
Daniel Cilli	Federal Aviation Administration	Contract Support to Runway Safety CSSI Team; System Analyst	daniel.ctr.cilli@faa.gov
Chris Grabowski	Making Virtual Solid —California (MVS)	CEO; Head Technician	ctg@mvs.net
Justin Grindell	Daytona Beach International Airport	Airport Operations Agent; Duty Manager/Trainer	jgrindell@co.volusia.fl.us
Mitch Huffman	FAA Atlanta Aircraft Certification office	FAA Aerospace Engineer	Mitch.huffman@faa.gov
Martin Lauth	Embry-Riddle Aeronautical University, Applied Aviation Science Department	Air Traffic Control Tower Instructor; over 27 years of experience with the FAA as an air traffic controller, training specialist, and a first line supervisor.	martin.lauth@erau.edu
Rich Mather	Daytona Beach International Airport	Airport Security Coordinator	rmather@co.volusia.fl.us
John M. Murray	Daytona Beach International Airport	Operations Supervisor	jmurray@co.volusia.fl.us
Lyle Sunderland	Embry-Riddle Aeronautical University, Flight Department, Fleet Aircraft Maintenance	Manager of Quality Assurance; Chief Inspector	lyle.sunderland@erau.edu
Tom Vannieuwenhoven	Daytona Beach International Airport	Ground Handling Supervisor	tvannieuwenhoven@co.volusia.fl.us
Gregory Zahornacky	Embry-Riddle Aeronautical University, Aeronautical Science Department	Assistant Professor; over 20 years of experience as a commercial airline pilot	gregory.zahornacky@erau.edu