FAA Airport Design Competition for Universities
Design Package Submission Form

Participating individuals or teams are required to submit the design package using this form. In additon, one hard copy of the full proposal plus the original of the Sign-off (See Appendix D in Design Submission Guidelines) form must be mailed to the Virginia Space Grant Consortium, 600 Butler Farm Road, Suite 2253, Hampton, VA 236666. All electronic and hard copy submissions must meet the 5 pm (Eastern Daylight Time) deadline on April 20, 2007. It is strongly recommended that a mail service that certifies delivery be used. All submissions will be acknowledged via email.

By proposal submission, Competition participants are agreeing that their proposal may be publicly shared. In addition, participants are giving permission that photographs that may be taken as part of Competition activities can be used for public information purposes and to promote the Program.

If you have questions regarding the Design Package submission process, you can contact the Virginia Space Grant Consortium between 8 a.m. and 4:30 p.m. EST on weekdays at 757/766-5210. Click here for Detailed Submission Guidelines.

Full competition guidelines and all updates are posted on the Competition Website:
http://www.faa.gov/runwaysafety/design_competition.htm.

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Design Challenge Area:	Runway Safety/Runway Incursions
Specific Challenge Selected:	Expanding situational awareness of pilots and ground operators on the airfield. Ideas include, but are not limited to: 4 Direct warning systems to alert pilots that they are approaching a runway and if the runway is occupied.
Level(s) of students(s) involved:	Graduate
Estimated number of participants:	0 Undergraduate 5 Graduate 1 Faculty Advisors 0 Other, please describe:

Four components of the Design Package in PDF Format.

Executive Summary

Main Body

Required Appendices

Optional Appendix

Approve/Reject:

(•) Approve ( ) Disqualify

Reasons for Disqualifcation:

Submit

Executive Summary

Title: Runway Incursion Monitoring, Detection and Altering System (RIMDAS): A Proposed Solution for Prevent Runway Incursions

Authors: Jane Barrow, Kevin Durkee, Jennifer Moore, Carl F. Smith, & Peter Squire

Proposal Summary:

Runway incursions are a persistent problem that has resulted in some of the most catastrophic aviation accidents in history. Though multiple solutions have been leveraged in an attempt to reduce runway incursions, recent trends indicate that runway incursions are again on the rise (FAA, 2007). As air traffic continues to increase, the need for a solution to mitigate or eliminate runway incursions becomes even more urgent.

Several systems have been proposed previously, but many of these systems are expensive and can only be justified for the busiest airports. Recent advances in wireless sensors provide a method for deploying an inexpensive detection network that can directly warn pilots of potential runway incursions. This system could prove to be an effective low-cost alternative for small to medium-sized airports who can not justify the cost of more expensive detection systems.

The Runway Incursion Monitoring, Detection and Altering System (RIMDAS) was specified through the use of a user-centered system design process, incorporating multiple analyses and task modeling frameworks to identify the required functionality and structure of the system. The purpose of this document is to present a design solution, (emphasizing several scenarios that illustrate the core system design concepts), discuss future directions, and note current system constraints.

I. Problem Statement and Background

March 27, 1977. Tenerife, Canary Islands. Pan Am flight 1736 collides with KLM flight 4805 while taxiing onto an occupied runway. The accident killed 583 people, in what is widely considered the worst civil aviation accident in history. The catastrophic outcome spurred numerous changes in global aviation policies, ranging from improved operational procedures to the introduction of technology intended to prevent accidents on the runway (Bruggink, 2000).

October 8, 2001. Milan, Italy. Scandinavian Airlines jetliner SK686 collides with a Cessna CJ2 business jet, killing 118 people. Following the accident, several recommendations were proposed for Italian aerodromes, including improvements to pilot training and enforcement of ICAO standards.

Despite over 30 years and countless improvements to aviation safety, both accidents resulted from the same persistent problem: runway incursions. A runway incursion occurs when aircraft, ground vehicles, people, or other miscellaneous objects on a runway come close enough to violate the FAA standard for aircraft separation (Federal Aviation Administration, 2005b). While incursions of the magnitude described above are infrequent, each runway incursion holds the potential to become the next major aviation disaster. The problem has been researched at great length, yet experts remain stymied by its underlying causes.

Runway incursions across the world repeatedly illustrate several causal factors. Common causes include pilot miscommunication with air traffic control (ATC), unfamiliarity with the airport, low visibility weather conditions, and insufficient display of runway markers (Bruggink, 2000; Flottau, 2001). Many of the issues noted seem relatively straightforward to prevent; however, any combination of the factors listed above sets the stage for a pilot or controller mistake to translate into a runway incursion.

The Design Challenge

The challenge presented by the FAA Airport Design competition was to expand the situational awareness of pilots and ground operators in the airfield to prevent runway incursions. Specifically, this design challenge focused on the design of a direct warning system to alert pilots as to whether an approaching runway is occupied or not. Designing a system to provide warnings, however, requires a deep understanding of the many issues surrounding runways and runway incursions. Any new design opportunity begins with the existing situation, and this is especially true when designing innovations for the aviation domain. Designs intended for aviation, by nature, will have to occur within the problem space defined by current aviation conditions. This problem space includes not only the pilots (direct users of a warning system), but the tasks the pilots intend to perform, the tools the pilots leverage to complete their tasks, and the environment within which the task or tasks are performed (Boehm-Davis, 2006). Given this, the following section provides a summary of the team's insight into the current conditions surrounding runway incursions.

Issues Surrounding the Design of a Direct Warning System

Understanding the issues that surround runway incursions allowed the design team to focus in on the system solution that could provide the highest value. Several issues were investigated, including the current conditions surrounding runway incursions, state of the art systems being implemented, and the limitations of currently available solutions. Each of these aspects was influential in various stages of the team's approach.

Current Conditions of Runway Incursions. The FAA considers reducing runway incursions a top priority, and the potential danger is highlighted by its inclusion in the NTSB Most Wanted List since its inception in 1990 (National Transportation Safety Board, 2007). Nonetheless, the number of incursions more than doubled throughout the 1990's, and U.S. towered airports experience an average of about one incursion per day (Federal Aviation

Administration, 2005b). This corresponds to 5.4 runway incursions per million aircraft operations from fiscal year (FY) 2001 through FY 2004. Nearly 11% of these were classified as the more serious categories A or B. While there has been a steady decrease of incursions over the past 5 years, the reduction rate has flattened and the FAA remains cautious that another escalation may occur (Federal Aviation Administration, 2005b).

Pilots. Pilot deviations account for more than half of all runway incursions (55% from FY 2001 through FY 2004), far exceeding operational error by ATC and vehicle/pedestrian deviations as the leading type (Federal Aviation Administration, 2005b). General aviation (GA) pilots are the most prone group, accounting for 74% of all incursions despite representing only 57% of all airport operations. Moreover, four out of the five total collisions from FY 2001 through FY 2004 involved GA pilots. This startling disparity has been linked to "back to basics" procedures such as incorrect use of ATC language by inexperienced pilots (Kelly, 2002). These facts highlight GA pilots as the highest need population for any proposed solution.

Air Traffic Control. Operational errors by ATC account for roughly one-quarter of all runway incursions (25% from FY 2001 through FY 2004; Federal Aviation Administration, 2005b). While this statistic falls far behind the rate of pilot errors, ATC error trends showed an increase of 29% from 2002 through 2004. Nearly 75% of these incidents involved an aircraft crossing and/or entering a runway due to ATC giving erroneous instructions. These incidents often occur due to cognitive limitations such as forgetfulness or a failed strategy, and they highlight the need for ATC workload to be supplemented in some way.

Vehicles/Pedestrians. Deviations by vehicles or persons accounted for 20% of errors from FY 2001 through FY 2004 (Federal Aviation Administration, 2005b). This statistic shows a drastic decrease of 33% throughout this time frame. It is possible this trend is the direct result of the FAA training and procedure initiatives. Regardless, this appears to be a problem currently being remedied, as it constitutes a relatively small percentage of runway incursions and the trends show improvement. The design team's focus remained primarily on pilots and ATC in light of this information.

FAA Policy Level on Runway Incursions. The FAA's goal is to reduce the most serious runway incursions, categories A and B, from the current 0.60 incursions per million operations to 0.45 by 2010 (Federal Aviation Administration, 2005a). This leaves only three years to reduce these serious incursions by 25%. Current trends suggest that this goal is unlikely to be reached, especially with passenger traffic expected to grow to more than one billion within the next 8 years (Fiorino, 2004). There is also concern that existing solutions have achieved their maximum effect, as evidenced by the recently flattening reduction rate of incursions (Federal Aviation Administration, 2005b). An innovative, flexible solution available to all airports is greatly needed to accomplish this goal.

State of the Art Runway Incursion Warning Systems

There is an expansive repertoire of currently existing solutions contributing to aviation safety; many of which are useful, but none of which can fully prevent runway incursions. The FAA has employed a combination of approaches in recent decades, modifying their use of technology, operating procedures, and training methods (Federal Aviation Administration, 2005b). The NTSB particularly emphasizes technological applications by recommending that all airports with scheduled passenger service install a ground monitoring system (National Transportation Safety Board, 2007).

Until recently, none of these systems focused on technology for the aircraft itself (Jones, 2002). Rather, the focus has been predominantly on the airport environment and enhancing situational awareness for ATC. These differing schools of thought on handling incursion warnings are reflected in two general categories of systems: 1) the traditional controller oriented approach, and 2) the more contemporary pilot focused approach. The following sections examine the most prominent examples within each category.

ATC-Oriented Runway Incursion Prevention Systems

ASDE-3. Among the most prevalent systems at high activity airports is the ASDE-3 (Airport Surface Detection Equipment – Model 3). This system provides ATC with a mapped electronic display of airport ground traffic. Its purpose is to serve as a surveillance system that supplements visibility from the control tower. The system particularly helps controllers manage the orderly movement of aircraft and ground vehicles when visibility is poor due to rain, fog, or night operations. However, ASDE-3 has limited potential for two main reasons: a) the inability to autonomously detect runway incursions, and b) the lack of identification tags, which prevents ATC from identifying specific aircraft or vehicles on the display (Baron, 2002).

AMASS. The first issue with ASDE-3 regarding incursion detection has already been addressed with the development of AMASS (Airport Movement Area Safety System). This system is a supplementary add-on to ASDE-3 that provides conflict prediction and alerting logic based on the position, direction, speed, and acceleration of aircraft and vehicles. Whereas ASDE-3 displays the movement, AMASS interprets when a potential threat exists and will warn ATC visually and aurally. While AMASS has been credited with preventing at least four major accidents (Croft, 2005), the system suffers from various technical flaws. For instance, it tends to lose accuracy in poor weather conditions, often mistaking precipitation for incursion threats and sounding false alarms (Croft, 2005).

ASDE-X. The second issue with ASDE-3, regarding the lack of identification tags, is addressed by its state-of-the-art update, ASDE-X. This new system incorporates data from multiple sources: SMR (Surface-Movement Radar), new multilateration sensors that interact with aircraft transponders, ADS-B sensors (Automatic Dependent Surveillance-Broadcast) that broadcast critical flight information, and terminal automation systems (Sensis Corporation, 2007). The system then combines this data to provide ATC with highly accurate identification, position, and trajectory data for aircraft within a five-mile range of the runway. By combining data from independent devices, ASDE-X does not suffer from the weather-related errors of ASDE-3/AMASS (Croft, 2005). In fact, the only major barrier for ASDE-X pertains to the feasibility of getting it into airports, rather than its actual performance. The FAA has managed to fund only eight ASDE-X systems so far due to its large cost, drawing ire from the ATC community (Federal Aviation Administration, 2005b; Carr, Portner, & Girton, 2005).

Direct Warning Systems

Recently, the NTSB has shifted focus away from ATC oriented solutions. They now recommend that detection systems relay alerts directly to the cockpit, rather than having ATC mediate alerts (National Transportation Safety Board, 2007). The reasoning behind the direct warning concept is based on the limited amount of time available for crews to react to a runway incursion. Faster recognition of a threat, even by mere seconds, could be the difference between a major accident and a narrow aversion. Few systems currently meet the direct warning standard, but several developers are leading the way in this approach.

RIPS. The National Aeronautics and Space Administration (NASA) is one of the biggest proponents of the cockpit warning concept, as shown with their work in developing the Runway Incursion Prevention System (RIPS). While its incursion prevention capabilities are comparable to ASDE-X, the goal of RIPS is to better inform pilots of runway traffic and communicate warnings directly to the cockpit (Jones, 2002). It uses a head-up display (HUD) to provide real-time navigation via synthetic vision. At the same time, a head-down display of the runway, known as the "moving map," allows the flight crew to iteratively monitor runway traffic prior to taking off or landing. Although RIPS has performed well in tests and is considered a promising system (Max, 2000), like ASDE-X it is held back by the high cost of its sophisticated technology.

ARIPS. An elaborate technical approach may not be necessary for a solution to reduce runway incursions. Several forthcoming systems demonstrate this possibility, using affordable technology while still providing a direct warning to the pilot. For instance, Norris Electro Optical Systems recently gained FAA approval for their Autonomous Runway Incursion Prevention System (ARIPS) (Norris Electro, 2006). This system uses ultraviolet lights stationed on the runway along with other detectors, creating a network of trip wires on runway borders and crossings. If ground vehicles set off the sensors during a landing scenario, the runway status indicators are changed to alert the pilot. The simplicity and cost-effectiveness of ARIPS takes a "less is more" approach that future systems may do well to imitate.

RWSL. Another option is the Runway Status Light system (RWSL), which uses surface radar data to detect approaching aircraft and automatically triggers red runway lights to warn ground vehicle operators to avoid the area (Eggert et al., 2006). It is compatible with most existing technology, making it a flexible supplementary solution.

Although ARIPS and RWSL fulfill the direct warning recommendation of the NTSB, they suffer from limitations. Both systems are currently limited to *visual* alerts to the pilot and from *outside* the aircraft, which may not consistently capture a pilot's attention. Despite these solutions being more affordable, there appears to be a tradeoff with the effectiveness of its alert capability. Balancing these tradeoffs then becomes a critical aspect for system designers.

Limitations in Current System Designs

Considering the attention that runway incursions receive, this raises the question of why the problem still exists in an age that thrives on technological solutions. Perhaps the best approach to this question is to analyze the currently existing solutions and determine what is failing. Upon doing so, the design challenge becomes clearer and some of the identified faults help to guide the design team's solution.

Cost. Affordability is one of the biggest obstacles to designing an effective solution. Some of the most advanced systems, such as ASDE-X, are operational at very few airports due to its massive cost. It is possible that widespread use of this technology would result in a large reduction of incursions, but this is not realistic until it becomes affordable for widespread use. The challenge is not simply to implement cheap technology per say, but to design a system that would maximize the cost-benefit tradeoff, making it a comfortable investment. Another cost-related factor is the flexibility of a proposed solution. This deals with whether a design is easy to install without incurring many indirect costs, such as structural modifications or changes to operating procedures. It would certainly be difficult to find viable equipment that fits the mold of being flexible, but low-cost.

Adaptability. Another challenge is finding a system that is adaptable to the countless types of errors that people make, many of which can be unpredictable. Most runway disasters allude to the fact that human error is at the root of most runway incursions. While it may be impossible to prevent human error altogether, a more attainable challenge is developing an error tolerant system; that is, a solution that can instantly and autonomously detect when a potentially disastrous mistake is committed, and ensure that a counteraction is carried out. While many current solutions are based on this approach, none of them are flawless in their execution. The various errors of pilots, controllers, ground crews, etc., commonly evade the detection capabilities of all current solutions, including the elaborate functioning of ASDE-X (Federal Aviation Administration, 2005b). A solution is needed that can react to even the most unforeseen of errors.

Alerting. An effective system must detect an incursion as early as possible, allowing enough time for the pilot to react accordingly. Many current systems do not consistently fulfill the time-sensitive nature demanded by the situation. Tying into this need is determining how to relay information to the cockpit quickly and appropriately through a specific modality without overwhelming the pilot. Considering the task complexity of cockpit operations, selecting a method for informing the pilot is among the most vital challenges of a direct warning system. Among these decisions are what form the alert should take, whether to provide instructions for conflict resolution, and whether the alert should be handled differently depending on the situation. This collection of issues makes incursion prevention a complicated project.

FAA Efforts. The FAA has been proactive in their initiative to improve air safety. Such efforts include improving training methods, further educating pilots on procedures, providing detailed investigation of incidents, and not least of all to implement state-of-the-art systems such as ASDE-X into high need airports. But each approach has realized only marginal improvements, while air passengers increase in numbers and available air space continues to shrink. Something has to budge, and recent data suggests that air safety is starting to lose the fight. Further complicating the problem is that the best solutions are expensive, and too few systems currently alert pilots directly. It is from these concerns that this design team conceptualized a solution, and hopes to close the gap of runway incursion dangers.

II. Summary of Literature Review

A breakdown of this design challenge suggests that many decisions must be considered to attain the goal of a functional incursion prevention system. Empirical evidence from several research domains, particularly human factors psychology in aviation, played an influential role in the planning of the team's solution. The literature impacted the design approach in three broad phases of preparation: concept development, incursion detection methods, and generating crew alerts. The concept development refers to the team's general set of objectives prior to narrowing down specific design features. Incursion detection and crew alerts refer to the precise details of the two major system components.

Design Concept

It is impractical to specify the various individual functions of a system without first clarifying a set of conceptual goals. These would include topics such as:

Automation. One intriguing notion for an incursion prevention system is to use a high degree of automation, due to its potential for rapid threat detection while reducing human-induced errors. Research has shown, however, that automated systems can lead to other problems such as complacency, over reliance, decision biases, and unbalanced workload (Parasuraman & Riley, 1997). Therefore, the design team must consider which system components should be computer-controlled rather than human-controlled. To address this question, Parasuraman, Sheridan, and Wickens (2000) classified four distinct areas of human information processing that automation is capable of replacing: 1) information acquisition, 2) information analysis, 3) decision selection, and 4) action implementation (see Figure 1). In their conclusion, Parasuraman et al. (2000) propose that a *suggested* decision should be automated, but the final decision should remain human controlled.

Information Flow. With the automation framework in place, and realizing that human integration is needed, the next facet to consider is who should directly interact with the system: ATC or pilots? As previously mentioned, the NTSB (2007) currently recommends direct incursion warnings to the *pilot*, but this reason is based primarily on the need to accelerate response time (National Transportation Safety Board, 2006). While this is an important factor, another legitimate reason is that dense air traffic environments tend to make controllers more error prone (Metzger & Parasuraman, 2001), and these are circumstances in which runway incursions are more likely. Therefore, the concept of a direct pilot warning provides two desirable qualities: expediting conflict aversion and relieving ATC workload.

Human-System Interaction. The final conceptual goal to determine is the level of interaction that the users (i.e. pilots) should have with a system. Parasuraman et al's (2000) model clarified that this solution should have a high level of automation in regards to detection and processing, while the pilot is primarily responsible for deciding (aided by an automated suggestion) and performing the action. But should pilots have *any* level of interaction with the automated components (i.e. detection and processing) or should they take a hands-off approach by letting the system handle these responsibilities?

Casner (2006) found that pilots who were kept "in-the-loop" on automated navigation tasks, rather than taking a passive role, showed better situational awareness. This improved awareness may enable pilots to make a more optimal decision in the event of a runway incursion. However, concerns with pilot workload and task complexity (Chou, Madhavan, & Funk, 1996) suggest that iterative runway monitoring may burden pilots and increase risk for pilot-induced accidents. This concern is particularly relevant for GA pilots, who typically fly solo-operated aircraft and are already more prone to runway incursions (Federal Aviation Administration, 2005b). While both arguments have valid points, a "constant situational awareness" concept could prove cumbersome, as well as expensive to implement. Therefore, an *alert*-focused system would leave surveillance solely to the automated components, only notifying pilots when runway incursions are identified. The key is implementing a reliable form of technology so that human supervision is not required.

Incursion Detection

With empirical research guiding the concept of a direct pilot alert system, it is important to address the system components themselves. The first of these pertains to detection and processing of potential runway threats.

Algorithms. Assuming the chosen technology for this design project accurately detects the raw characteristics of a target, there must be a mechanism in place to interpret the data and decide if a runway incursion is imminent. Recent operational testing of the most state-of-the-art systems reveals that algorithms already exist that can fill this need. For instance, NASA evaluated and compared two incursion detection algorithms suitable for their RIPS system: Runway Safety Monitor (RSM) and PathProx (Jones, 2005). RSM in particular detected an exceedingly high percentage of the various runway scenarios tested, and could be an ideal mechanism for data processing. However, for these processing capabilities to be fully operational, one must consider how to calibrate the system threshold for ideal target detection.

Signal Detection Theory. Parasuraman, Hansman, and Bussolari (2002) discuss the system threshold issue in terms of signal detection theory (SDT) with ASDE-X functionality, and a similar approach may be used for this solution. The threshold, also known as beta, refers to how liberal or conservative a system should be when deciding whether a threat exists. A liberal beta would detect a high number of false alarms while missing very few legitimate threats, whereas a conservative beta would minimize false alarms, but may be prone to missing threats. The detection sensitivity (d') of the technology would need to be tested in order to accurately weigh this tradeoff. Safety-oriented systems traditionally set a liberal beta so as to prevent misses (i.e. failing to alert the pilot that a runway incursion exists), even at the expense of some false alarms. However, the associated increase in false alarms may result in automation mistrust, which could lead pilots to ignore the system altogether (Parasuraman & Riley, 1997). Combining accurate detection equipment with a proven algorithm, such as RSM, could result in an ideal system that would detect the vast majority of runway incursions, while still keeping false alarms to a minimum.

Crew Alerts

While accurate detection is a vital element of a solution, this function is rendered useless if pilots are not properly alerted. A cockpit alert serves as the interface for the automated module to communicate with the pilot, indicating when evasive action is needed. Given that pilots work in a multifaceted environment with sensory cues competing for attention (Ho et al, 2004), crafting a salient alert is among the most important components for this system. Furthermore, the *manner* in which pilots are notified will affect their ensuing task performance (Wickens & Hollands, 2000), and the unexpected task-switching already leads to a loss of time and performance (Rubinstein, Meyer, & Evans, 2001). The challenge is to find an alert that simultaneously captures attention, facilitates optimal decision-making, and leads to proper action implementation.

Modality. There are three sensory modalities that could reasonably fulfill the alert function: visual, auditory, and tactile. While *multi*modal feedback may deserve future consideration (Sarter, 2000; Jones, 2005), this design project has a cost-effective focus that may only allow for one selection. Sarter (2000) explains that current flight decks already strain the visual modality with a wide array of data monitoring tools, and that other modalities should be considered. Tactile cues could be a useful alternative since they are omnidirectional and underutilized (Sarter, 2000). However, Gilliland and Schlegel (1994) found that tactile cues may degrade task performance, even if it improves situation awareness. The third choice, auditory, is perhaps the most efficient means of conveying information in the cockpit.

Auditory Cues. In terms of delivering a highly detectable alarm, sound has been shown to be more salient than vision (Ho et al, 2004). In RIPS operational testing, Jones (2005) found that pilots noticed the auditory alerts before noticing the graphical alerts. Wickens and Hollands (2000) point out the auditory channel's ability to take input from any direction. Additionally, auditory alerts typically do not interfere with the most pressing tasks such as controlling the aircraft, given the ability for auditory and visual processing to occur simultaneously (Iani & Wickens, 2007). For selecting one suitable form of alert, the auditory modality overwhelmingly shows the most promise. The final step is determining how best to utilize the auditory modality when communicating runway incursions to the pilot.

III. Problem Solving Approach to the Design Challenge

The Design Process

Designing a successful direct warning system for runway incursions requires the design team to adequately account for all possible incursion scenarios. The ability of the team to accomplish this goal rests entirely on their ability to generate a comprehensive, explicitly specified analysis approach. To ensure that the design team considered all possible aspects of the design, a hybrid human factors research and development plan was used (Figure 3.).

This design process focused on two major stages of the design process – the *Needs Analysis* stage, in which various analyses are used to determine the needs of the user, task, environment, and system. This is followed by a *Conceptual System Design* phase, in which the functions of the system are defined through further analysis and identification. This information can then be fed forward into a formal design concept, which can then be *Prototyped and Evaluated.* Each of these stages elicited valuable and unique information, and is detailed below.

Needs Analysis. One of the first topics to be addressed by the group is the multiple needs that a direct warning system should address. While this may seem straightforward at first glance (pilots need to be warned), the use of a warning system on an airfield has the potential to interact with any independent actor in the airspace. To assist in determining the scope of the analysis, the design team employed a framework proposed by Gray and Altmann (2001). Their framework – called the cognitive triad - specifies that users accomplish specific tasks through particular devices within the environmental context that the user, task, and system reside (Figure 4).

Following from this framework, a fully informed design requires complete awareness of the unique characteristics of each aspect of this triad. As Boehm-Davis (2006) has noted, however, each section of the triad should not only be evaluated singly, but in combination. That is, the interaction of each component with one or both components produces behavior and requirements above and beyond the behavior and requirements observed with each aspect of the triad singularly. A designer can only hope to provide a complete solution when each aspect of this triad and its associated interactions has been fully explored and understood in the context of the environment the triad operates in. To accomplish this, the design team applied a variety of methodologies – some to singularly assess each design aspect, others to assess several aspects of the triad in concert. The methodologies and their insights are listed below.

Competitive Analysis of Aviation Design Environment. Prior to any identification of tasks, users, or scenarios, the design team focused on identifying the current state of the art in runway incursion detection. To do this, the design team used converging information sources to develop a greater view of the scope and depth of current and future automotive technology, including popular press, official FAA documents, corporate press releases, and published industry standards. From this body of work, several important, high level trends relevant to the design of runway incursion systems were extracted:

- *Current designs utilize multiple forms of information to aid in accurate detection of potential incursions.* For example, ASDE-X uses both GPS and SMR to accurately detect potential runway incursions. Several systems attempt to use several information sources to account for limitations in each.
- *There is a trend toward alerting the pilot directly rather than notifying air traffic control.* This seems to be due to the time constraints of impending incursions. The time required to transmit a message from tower to pilot takes up to 4 seconds, while many incursion incidents occur in 1 second or less.
- *Most information being transmitted to pilots is relayed through visual channels.* Current solutions have proposed the use of displays to directly transmit the information to pilots. RIPS and ASDE-X both rely on the use of visual information to assist the pilot.

The competitive analysis assisted in the identification of several high-level value statements found in most current and proposed designs. This information helped define the scope of the project for the design team by identifying both current areas of innovation (Air Traffic Control and Direct Warning Systems) and areas of interest for the most relevant user groups (Pilots, Air Traffic Control, and Ground Operations).

Interview Methodologies.

While competitive analysis allowed the design team to "set the stage" in terms of current systems, interviews were used to directly engage the potential users of a direct warning system. The use of interviewing methodology has several benefits crucial to informing the design of any system. First, interview methodology ensures a common frame of reference between the elicitor and the expert being interviewed. In creating a new direct warning system, the interviews allowed the designers to directly leverage pilot guidance in assessing the utility of current and/or proposed practices. Interviews were especially useful for extracting knowledge that many experts assumed to be understood. Interviews also allowed designers to "talk through" current system issues, identify solutions, and immediately evaluate generated concepts with a subject matter expert (Hoffman, Shadbolt, Burton, & Klein, 1995). By investing time into understanding the benefits, limitations, and opportunities in the aviation domain, the design team was able to begin discussing system design using the common language of pilots' needs and expectations.

Unstructured Interviews. The design team's interviews first used unstructured interviewing, a free form interview technique in which the interviewer creates an open dialog between themselves and the subject matter expert (Cooke 1999). This technique requires the interviewer to ask open ended questions designed to access the expert's knowledge on a given subject. For example, the interviewer could ask a pilot to talk about their own runway incursion experiences. This technique is especially well suited to knowledge elicitation work early in a design process, as it does not require domain expertise on the part of the interviewer, and is well suited to moving in whatever conceptual direction the expert wants to proceed (Cooke 1994).

For the design team, there were several high value conceptual questions that required answers before further investigation could proceed. First, the design team wanted to know what tasks pilots were most likely to be performing when runway incursions were likely to occur. Secondly, the design team wanted to understand the specific nature of the tasks pilots were performing when they were approaching, departing, or taxiing on the runway. To gain this information, the design team contacted multiple experts, including pilots, air traffic controllers, and human factors experts in aviation for a series of unstructured interviews. (see Section V – Description of Interactions with Airport Operators and Industry Experts).

Each expert was contacted and asked a series of questions created to generate design relevant information. These questions included information regarding the nature of the task. This interview methodology provided valuable insight into the not only the users, but the tasks and tools relevant to each user group. This interview process yielded the following concepts:

- *A list of the tasks generally performed by pilots across situations.* These tasks included items like taxiing from the hangar to the taxiway, taking off, pre-flight procedures, and perceiving the details of other objects on the runway (including ground crew, other planes, motion near the runway, etc.). Examples tasks are provided in Table 1.
- *Attentional and cognitive demands on the runway.* Pilots stressed the demands of the several tasks, and how attention may get drawn to areas away from the outside view. Several pilots noted that pre-flight procedures required on the taxiway often drive visual attention away from the outside scene. One pilot noted that he felt most at risk during pre-flight operations.
- *The presence of incursion "hot spots" and how pilots approach these areas.* While several FAA documents have identified certain "hot spots" that have shown greater incidents of runway incursions. Pilots gave the design team direct feedback as to strategies to detect incursions when in a "hot spot", and why specific spots seem to have more runway incursions than others.

This provided the design team with insight into the design problem; pilots require rapid notification of impending errors, but often are visually engaged inside the cockpit. Designing a warning system to support pilots would involve attracting the pilot's attention to potential incursions without completely distracting from the task at hand. The interviews also alerted the design team that the modality chosen for the design task would have to be taken into account.

Structured Interviews. The research team, having gleaned large amounts of information from several unstructured interviews with pilots and industry experts, proceeded to perform several structured interviews with two pilots. The intention of this structured interview process was twofold; first, structured interviews allowed the interviewers to more accurately and directly assess task qualities such as priority, frequency, and relevance of the generated tasks to tasks performed on the runway. Second, this interview process gave the interviewers the ability to "drill down" into each task to understand its essential task components (Cooke, 1999). This was essential in gaining the insight necessary to analyze common runway tasks.

Both structured interview sessions leveraged the task lists generated through unstructured interviews. Interviewees were then walked through each task in detail, identifying how task steps may occur in context, external issues that might affect task completion, and application of strategies to each task. This served not only to validate the current set of tasks generated through unstructured interviews, but also to expand upon the initial tasks in sufficient detail to allow analysis and modeling of common runway tasks.

Scenario-based Use Cases

Having now observed users and the tasks users perform, the design team set out to create several scenarios to further inform their design process. These scenarios were created to virtually "test" how many of the tasks generated might operate in a naturalistic setting. By ensuring the generalizability of tasks through contextual evaluation, the design team could ensure that any designs decisions based on the current task list would be representative across a wide variety of tasks.

Creating Personas. Personas were used by the design team to assist in centering tasks around the user group they were intended to represent. Just as importantly, the use of personas allowed a shared model around which the design team could communicate their tasks. The personas were created from the design team's experience interviewing pilots, literature review of common scenarios, and demographic information from major aviation reporting sites (FAA, 2005a). Examples of four of the personas used are included in Table 2.

Use Cases. Scenarios were created from these task descriptions in order to encourage the team to think through the implications of the existing task and of any new designs (Carroll 1995). Use cases are generally intended to capture the intended system behavior without capturing exactly how this behavior is implemented. At this stage in the analysis, use cases allowed the design team to talk in terms of what they intended the system to do under different circumstances without explicitly discussing how these tasks would be completed (Carroll 1995). Later in the design process, many of the scenarios generated here formed the basis of the prototype storyboards that would specify location and system action. A subset of these use cases are presented in Table 3.

Several interesting observations were gleaned from the generation of scenario based use cases. Many of the use cases produced were similar to the initial task list (Table 1); however, the implementation of these tasks within the context of the environment or a specific goal often shifted the priority of a task. For example, scenario based use cases explicitly specified different types of adverse conditions, such as low visibility or crowding which must be accounted for in the design. Second, the scenarios identified several key points for the design team. First, it became apparent that the amount of time aviators could spend head down was minimal, arguing for the use of as shallow an interface hierarchy as possible in the design. Also, as many tasks seemed visual in nature, the scenarios seemed to argue against a visual solution.

Second, several tasks considered within the context of their use seemed best suited by displays or technology that would allow the operator to keep their visual attention on the runway. This could include the use of auditory alarms, tactile feedback, or digital information displayed on the windshield. One of the strengths of scenario based use cases is its ability to assist the designers in creating domain-specific solutions without insisting on the method by which the solution is implemented. This allowed the design team to create multiple solutions that could be evaluated during the design process.

Task Analysis

The understanding of the tasks performed by the user in context is an essential part of conceptualizing the design space. While interview techniques had specified a group of representative tasks, to objectively compare any novel interactions against the current requirements requires an explicit and objective analysis of the goals and actions of the current task. To do this, the design team used a series of task analyses that expanded on the prior tasks identified via interviews. To better understand the tasks that the interface would need to optimize, the researchers employed several forms of task analysis across the most frequent and high priority tasks. The design team, therefore, performed a number of task analyses, most significantly hierarchical task analysis (HTA), and operational sequence diagrams (OSD) to inform the design team of the core structure of each task. These activity-based models were used as representations of the tasks for the design team's reference, and are detailed below.

Hierarchical Task Analysis. Hierarchical Task Analysis, or Hierarchical Task Decomposition, is a process by which the researchers break down a task into steps at lower levels of detail (Kirwan 1992). This is a process of developing task descriptions in terms of the operations users carry out to meet a particular operation's goals. This analysis is especially important in understanding the specific steps, or sub-goals, necessary to meet a system's goals (Kirwan 1989). In this project, the hierarchical task analyses were used to understand the requirements of the tasks performed during all phases of flight where aircraft were on the runway. This process also assisted the design analysts in identifying crucial aspects of each task that any innovation must be designed to optimize and support.

For example, the task analysis for landing (Figure 5) identified a linear sequence of actions that must be completed in order to optimally perform the task. More importantly, this series of nested tasks requires constant monitoring for multiple decisions that must be made on the descent. This process requires a decision point in which pilots must decide on the appropriateness of their actions dependent on the current runway status and ATC clearance (See Landing, Figure 5, Steps 5.1-5.5). From the interviewing techniques used, the research team was able to conclude that much of the adjustment involved in the landing task was the minute coordination of decisions and actions, and that distraction from out the window or motor actions would likely reduce situational awareness instead of augmenting pilots' detection abilities.

In contrast, the hierarchical task for pre-flight and take-off maneuvers shows a highly structured, nested routine of tasks, many occurring prior to the final taxi and takeoff. Interestingly, the task analysis (Figure 6) indicates that all actions during takeoff require constant visual attention out the window, while many of the taxi-related activities directed attention to issues in the cockpit. This provided several insights to the design team. First, the direct warning should be directed most forcefully to pilots on the taxiways, who are more likely to be distracted away from the outside environment. Second, once the pilot has initiated their takeoff procedures, any warning should only serve as an advisory to scan the environment, not to abort the take-off procedure. These insights can be used to guide procedures for a direct warning system, with clear rules for warnings predicated on the aircraft's current position.

Operational Sequence Diagrams (OSD). The use of task analysis techniques is best served in identifying the structure and constraints of a given task; however, the level of detail at which these analyses are performed is a function of the objectives of the analyst (Kirwan & Ainsworth, 1992). Thus, while analysis of the representative tasks assisted the research team in understanding the requirements of each task to be completed, a more detailed analysis could include communication between the pilot and air traffic control. This analysis could support the use of different modalities or procedures for a direct warning system. With this concept in mind, the researchers followed the HTA's with a series of OSD's designed to address the user's needs within the context of the system.

Operational sequence diagrams (OSD's) can be described as a sequence of control actions or information gathering activities (Kirwan & Ainsworth, 1992). The design team used a specific type of OSD known as partitioned OSD's. This form of hierarchical modeling not only further constrains the hierarchical analyses performed, but provides the analysis team with the ability to compare the restrictions on communication of information within each task in the context of the system. For example, using the OSD an analyst can conclude that (during landing) the pilot's attention is divided primarily amongst performing manual tasks and visual perceptual tasks within the cockpit, with the exception of two to three auditory tasks of communicating with air traffic control. When using an informational task analysis, the OSD's of taking off and landing show a heavy visual attention requirement (See Figures 7 and 8). In both cases, the OSD's would indicate that an auditory alarm would be most effective to directly warn the pilot without distracting from the normal operating task in landing or taking off.

Similar to use cases, this was performed in order to understand the specific interaction requirements of the task prior to making any assumptions about the modality or character of the information presented. This combination of use cases and analyses proved to be an extremely effective method of systematically and methodically defining and evaluating the tasks that must be accounted for in a novel warning system.

IV. Description of Technical Aspects

Connecting the User and System Design with the Technical Solution

System and User Design Conclusions. The design approach above identified several general needs for the system and user. Scenario-based use cases and competitive analyses identified the need for a system that could not only detect incursions, but directly warn the pilot. A review of the current systems indicated several issues. One of the most pressing issues is the large financial cost associated with the development and maintenance of current runway incursion detection systems. This substantial cost creates a monetary barrier, in which airports that could benefit from incursion detection systems can not justify the expense. This presents an opportunity for designers to develop a low-cost alternative to support these airports.

User assessment, conducted along with task analyses, indicated that a pilot's visual modality was occupied for the majority of all tested maneuvers, leading to the conclusion that the auditory modality would be best for alerting the pilot. This was supported by communications with pilots and the human factors literature (reviewed in Section I), and appears to be the most parsimonious solution to alerting pilots without distracting completely from the primary task. Therefore, the team explored technologies that could (1) detect a potential incursion and (2) communicate an auditory warning directly to the pilot.

Technical Solution. Having identified the system's issues and the manner by which to notify pilots of potential incursions, the design team focused on the technical innovations necessary to optimize a system to detect runway incursions. One potential solution explored was the use of low-cost wireless sensors to detect a potential incident, relay a message to a centralized server, and then send a signal directly to pilots before a potential runway incursion occurs. This could provide a rapid means of directly communicating to the pilot (under 500 ms), while maintaining a detection system at a low cost.

This approach brings up several basic questions. First, how can wireless sensors detect something moving as quickly as a plane? Second, how can a wireless sensor system be considered low-cost? And finally, how will pilots receive a signal? The answer to all of these questions lies in a group of networked sensors, commonly known as MOTES.

Advances in microelectronics and wireless communication has increased the use of low-cost networked sensors to support and augment the capabilities of larger, higher-cost sensors in areas such as monitoring, detection, and surveillance (Jacyna & Tromp, 2006). The sensor nodes within these systems can range from large stand-off sensors to micro-sensor platforms called MOTES or smart dust. Originally intended for military application, MOTES have been used and validated in a variety of different environments and operational conditions – (See Figure 9).

MOTES support an array of sensing possibilities. Typical MOTES (Figure 10) have a sensor, an on-board processor, and communication capabilities (e.g. wireless or optical) that allow them to connect together into a distributed network. A MOTE periodically samples one or more sensors, stores the values in memory, listens to an incoming packet, then transmits the current or stored data. Devices pass a message to a neighboring MOTE which, in turn, passes the message to another nearby MOTE, and so on, till the message reaches a specific destination of interest. These types of distributed networks are very robust and can continue to perform even if some of its communication paths fail to operate (as illustrated in Figure 11).

MOTES have rapidly become a Commercial Off The Shelf technology, and a number of companies, manufacture these devices (e.g. Crossbow: www.xbow.com). As depicted in Figure 12, it is expected that within the next year production and sales of these wireless sensors will double. The most significant limitation for these sensor systems is energy, which can constrain MOTES communication ability or processing power. MOTES typically operate off a small power supply (e.g. AA batteries), but if a netted sensor system is not concerned about energy demands (i.e. connected to some type of electrical grid or other stable source of power) then the other significant challenges such as communication and processing are also significantly eliminated (Personal communication with Dr. Garry Jacyna March 5, 2007). Given this understanding, the design team will be exploring a MOTES-based solution that is powered by the airports electrical grid.

The Runway Incursion Monitoring and Direct Alerting System (RIMDAS)

Netted sensor systems can perform a variety of different applications. Of specific interest to the problem of runway incursions is the ability to detect, classify, and track objects: this could range from people to planes. Researchers have demonstrated the ability to use low-cost netted sensor systems to perform these tasks (MITRE, Leading Edge Articles, 2006). Implementation of such a system with purposes of monitoring potential runway incursions and then directly warning pilots will be referred to as the Runway Incursion Monitoring and Direct Alerting System, or RIMDAS. RIMDAS employs the validated methods of wireless sensor networks to detect, classify, and track potential runway incursion incidents. The scalability of sensors within the network, and methods and algorithms utilized for detection, classification, and tracking are virtually endless (MITRE, Leading Edge Articles, 2006). In addition with simulation environments such as the Research Evaluation and Experimentation Fabric (REEF), these aspects can be tested and evaluated a priori before the hardware demonstrations need to be performed – saving time and money. The benefit of RIMDAS is that each airport can customize the system to meet their unique needs, as well as test and optimize the system's parameters and configuration to address those unique needs – something which current large systems can not provide. Because of the scalability and customizability afforded by such a system and the limited space of the proposal, lower level technical details of the system will not be discussed in depth. To illustrate the functionality for how the RIMDAS system will operate, three different scenarios will be examined.

Scenario One: Plane A has recently landed and is taxiing to a gate; plane B is preparing for takeoff and is taxiing to a runway. Both aircraft are preparing the required operations and are very busy within the cockpit, and plane B does not notice that it has taxied onto the wrong lane, and is now heading for a potential runway incursion. Current operations would require controllers or pilots to identify the potential incursion, and notify the crew to perform corrective actions. These current procedures place a large burden on the controllers and pilots to perform these runway incursion detections. Under RIMDAS, however, this ground-based runway incursion incident could be prevented more easily (see Figure 13 for a graphic representation).

1. Acoustic sensors would be configured throughout the airport to detect the movement of planes and other items of interest. The acoustic sensors on the MOTES will be used to perform the initial detection. Planes could be differentiated from a spectral analysis of the acoustic signal, and a simple linear weighted classifier employed.
2. The probability of false alarms and misses in aircraft detection can be reduced when the sensors act collaboratively. When one sensor detects an aircraft, it would transmit that information to the other sensors nearby. When three sensors (or some optimized number for a set detection threshold) detected an aircraft within a short time window a detection event would be generated.
3. One sensor could then be selected as the "leader" and would forward the information to a centralized server to be analyzed.
4. Based on known positions of the sensors, the centralized severs can calculate the approximate speed and direction of the target. The speed and direction of all aircraft currently operating within the airport ground space would be known and reside within these centralized servers. From the known positions, speeds, and directions of the planes, the likelihood of a runway incursion could be determined.
5. Once a runway incursion event threshold had been reached, the centralized servers would wirelessly send a direct warning to alert the aircrafts of concern. The alert would parallel the warning approach used in RIPS, in which a generic alert sounds to gain the pilot's attention, and subsequently provide a brief form of verbal conflict resolution (i.e. "Stop aircraft"). The pilot would then immediately follow the instructions and avert the potential incursion.

This type of approach using acoustic sensors has been demonstrated with vehicle identification and classification (Glenn, Flanagan, & Otero, 2006) and could easily be employed for aircraft since the acoustic signatures of aircraft are known and easily distinguishable (Shi, Fante, Yoder, & Crawford, 2006).

Scenario Two: Plane A has been cleared by ATC to land. At the same time, however, plane B is attempting to make a landing and despite repeated attempts to communicate by ATC, is not responding. Again, current operations would require that controllers or pilots make an identification of the potential incursion, and notify the crew to perform corrective actions.

These current procedures place a large burden on the controllers and pilots to perform these runway incursion detections. In addition, because ATC may be actively trying to alert the other aircraft or performing other activities, they may fail to notify the aircraft cleared to land about the potential threat. Under RIMDAS, however, these air-based runway incursion incidents could be prevented more easily.

Detecting and tracking aircraft movement in the air is critical for helping prevent runway incursion incidents. To be able to perform these functions and directly alter pilots of potential threats the RIMDAS uses different sensor types to perform these functions. Working together, these MOTES can detect, track, and discriminate aircraft in the air (see Figure 14 for a graphic representation).

1. A radar fence consisting of multiple low-power radar units (whose range is typically about 4 kilometers) would be distributed across the airport grounds – See Figure 15. Each radar would operate with a different carrier frequency to avoid crosstalk between radars, and each has a beam width that is broad in both azimuths (so that the number of radars can be kept small) and elevation (to detect both high and low-flying targets). The radars measures target range and report these values to a central processing station.

2. When the radar has detected the presence of an aircraft, this signal is passed on to microphone arrays. The acoustic arrays would detect broadband emissions from approaching targets. These emissions can help determine the target's direction of arrival, mitigate false alarms, and supply a target identification and classification.
3. The microphone arrays and radar fence would work together to perform an initial aircraft classification (e.g. type, speed, and distance) based on the target's radar and acoustic signals. Similar to the ground based detection scheme, multiple sensors could be used to increase the reliability of the systems. Once detection was generated, this information would then be passed on to the centralized servers for further analysis.
4. Based on known positions of the sensors, the centralized sever can calculate the approximate speed and direction of the aircraft relative to other aircraft within the surrounding airspace. The speed and direction of all aircraft currently operating within the airport's air space would be known and reside within these centralized servers. From the known positions, speeds, and directions of the planes the likelihood of a runway incursion could be determined.
5. Once a runway incursion event threshold has been reached, the centralized servers would send a direct warning to alert the aircrafts of concern. The alert would again parallel the warning approach used in RIPS, in which a generic alert sounds to gain the pilot's attention, and subsequently provide a brief form of verbal conflict resolution (i.e. "Conflict – Go up"). The pilot would then immediately follow the instructions and avert the potential incursion.

This type of approach using a Multi-Modal Netted Sensor Fence approach has been demonstrated with light weight civilian aircraft such as a Cessna, Beech craft, and crop dusters (Shi, Fante, Yoder, & Crawford, 2006) – See Figure 16. The primary difference between this approach and the MITRE is that rather than performing visual target identification, aircraft tracks would be collected and analyzed for potential runway incursions.

Scenario Three: Plane A is currently on the runway preparing to take-off. At the same time however, plane B is attempting to make a landing. Again, current operations would require that controllers or pilots make an identification of the potential incursion, and notify the crew to perform corrective actions. A combination of the procedures used in scenario one and scenario two can utilized. The aircraft information obtained either from ground based sensor detectors or air based sensor detectors would be collected (as described previously) and then passed along to the centralized servers. Once the information is passed along that a runway incursion event threshold is exceeded, an alert would be sent to aircrafts of interest. The landing aircraft would be given one aversion command (i.e. "Conflict – go up") whereas the taxiing aircraft would given another (i.e. "Stop aircraft"), both of which would be relevant to resolving the situation. The pilot would then immediately follow the instructions and avert the threat (see Figure 17 for a graphic representation).

V. Interactions with Airport Operators and Industry Experts

Airport Experts

Peter Stassen, MITRE. Peter Stassen was interviewed in order to obtain a better understanding of pilot procedures. He currently works for MITRE and was a pilot for Independence Air from 1998-2006. Mr. Stassen shared information and manuals concerning pilot procedures from start to finish of flight. Additionally, he provided background information on pilot training and preliminary procedures conducted prior to flight. The information provided helped better understand some of the causes of runway incursions, as well as identify spaces within current procedures that could be used to implement our solution.

Vimal Patel, General Aviation Pilot. In order to determine the most appropriate times during take off and landing to implement our design, we created a hierarchical task analysis for each procedure. Since none of our group members are pilots, we used procedural manuals and various aviation papers to form the basis of our understanding of each procedure. The design team met with Vimal Patel, a general aviation pilot, to discuss and confirm the hierarchical task analyses of take-off and landing procedures for general aviation. Mr. Patel's input assisted in identifying the different sensory modalities used and cognitive load during flight procedures. Mr. Patel's input assisted the design team in further specifying the procedural analyses used to support further design decisions.

Matthew Hintze, Air Wisconsin. Matthew Hintze was interviewed to help identify preflight and landing procedures, along with insight into causal factors of runway incursions. He is currently a pilot for Air Wisconsin with over 5 years of line experience. Mr. Hintze shared additional information regarding piloting procedures, runway locations perceived as more probable to have runway incursions, and provided insight into cognitive and perceptual limitation of the pilot and first officer (both pre-flight and after landing). The information provided by Mr. Hintze assisted the design team to aid us in better identifying potential causes of runway incursions, as well as airfield areas where pilots could benefit from incursion warnings.

Industry Experts

Dr. Garry Jacyna, MITRE Fellow. The title of fellow is conferred on senior members of the company's technical staff who have made significant contributions to the state of the art in one or more technical disciplines. MITRE has appointed only 14 fellows since the position was created in 1962. Jacyna is the chief scientist for MITRE's program in netted sensors, where he is developing and directing research in distributed detection, classification, and tracking algorithms. Dr. Jacyna provided a greater understanding of MOTES technology, feedback on our design approach, and valuable materials on the Netted Sensor Project.

Denise Jones, Principal Investigator for the Runway Incursion Prevention System (RIPS), NASA Langley Research Center, Hampton, VA. Ms. Jones' expertise is in pilot situational awareness and cockpit displays. She provided valuable input regarding visual and auditory perceptual cues of pilots, aircraft landing scenarios, data-link technology, and how NASA Langley implements these concepts into their state-of-the-art RIPS system. We consulted her regarding how best to capture pilots' attention and verbally communicate conflict resolution, as well as future possibilities for MOTES to interact with head-up displays. Ms. Jones also stressed the importance of incursion prevention, rather than simply incursion detection. She noted the cost-effectiveness of our solution as particularly attractive, and pointed us toward an inexpensive data link called the "UAT data link" as a means for aircraft and airport vehicles to connect to the MOTES network. Overall, her expertise helped refine several critical aspects of our solution.

Dr. Kathleen McGarry, MITRE Human Factors Engineer. Dr. McGarry's expertise is in performing experimental human factors research in the assessment of runway safety. She provided valuable input regarding runway incursions, current runway safety systems and the initial discussion and feedback for our RIMDAS systems design. We consulted with her regarding the possibilities for the RIMDAS system as compared to current safety systems. This initial feedback was critical for ensuring the feasibility of our approach, and identifying current safety trends.

Christopher Yarbrough, Booz Allen. Christopher Yarbrough supplied the design team with a lot of helpful information specifically regarding runway incursion history, such as examples of real runway incursions along with class and accident report descriptions. In addition, Mr. Yarbrough provided an initial understanding of FAA goals and the ASDE-X system.

Academic Experts

Dr. Ericka Rovira, Assistant Professor in the Engineering Psychology Program of the Behavioral Sciences and Leadership Department at the United States Military Academy, West Point, NY. Dr. Rovira served as the technical liaison for research matters concerning air traffic controllers. She has published on future air traffic control concepts and regularly interacts with air traffic controllers. Dr. Rovira also provided much insight concerning how the design may impact the air traffic controllers.

Dr. Robert Simon and Dr. Sanjeev Setia, Associate Professors of Computer Science at George Mason University. Dr. Robert Simon's research specialization is in the field of distributed systems, networks, performance modeling, and simulation. Dr. Sanjeev Setia's research is in the area of sensor and ad-hoc networks, network security, especially secure multicast, peer-to-peer computing, and performance modeling of computer systems. Drs. Simon and Setia provided the initial comments on the feasibility of the wireless sensors concept for a real-time solution to runway incursions.

Lance Sherry, George Mason University. Lance Sherry is the Deputy-Director of the Center for Air Transportation Systems Research at George Mason University in the systems engineering department. Dr. Sherry was interviewed for his insight into our proposed direct warning system. He likened the concept to some aspects of TCAS, and suggested investigating TCAS literature for potential problems with detection and alarm rates. Dr. Sherry's suggestions assisted in guiding the team towards potential "problem spots" in the proposed design.

VI. Description of the Projected Impacts of RIMDAS

How RIMDAS Addresses FAA Runway Incursion Goals:

As a direct warning system, the Runway Incursion Monitoring System (RIMDAS) has the potential to address multiple FAA goals for runway incursions. The primary FAA objective for runway incursions is to reduce the severity, amount, and rate of incursions. RIMDAS provides a method to reduce the frequency of runway incursions by directly warning pilots of scenarios that lead to incursions. More importantly, RIMDAS' relatively low cost could allow airports with moderate traffic (who may not be able to justify the expense of a system such as ASDE-X) to benefit from a direct warning system. Increased situational awareness due to a direct warning system at regional airports may address the FAA's goal of reducing the rate of runway incursions. The implementation of RIMDAS also addresses some of the specific goals identified by the FAA in the 2002-2004 Runway Safety Blueprint (FAA, 2002). Five of the eight established Runway Safety Program Goals can be supported by the implementation of the RIMDAS system. Each goal and how RIMDAS could assist are listed below.

FAA Runway Safety Program Goals:

Expanding situational awareness of pilots and on the airfield

RIMDAS' "netted sensor" approach to detecting environmental changes creates a system that can capture and interpret a wide variety of signals indicative of the presence of aircraft, ground crew, or other agents on the runway. This design supports the goal of increasing pilot situational awareness by monitoring potential risks and sending out a warning directly to pilots if the potential for a runway incursion is detected. The FAA Runway Safety Report (2005b) notes that miscommunication or lack of situational awareness between pilot and ATC/ground control has been identified as a primary causal factor in many runway incursions. RIMDAS addresses this error by enabling pilots to be warned directly by the detecting system, reducing the possibility of incursions due to a lack to Type 1 SA.

Due to the wide variety of sensors available, RIMDAS could be attuned to detect the presence of objects that might not be considered in the original scenarios. Appropriate algorithms can be used to alter the warning system to fit any number of characteristics. For example: using speed, relative distance, and metallic properties of the detected objects, the

RIMDAS system can be used to warn two planes on the verge of collision, a pilot of runway debris, or even a baggage operator of an approaching plane preparing to land.

Give immediate warnings of probable collisions and/or incursions directly to flight crews in the cockpit

RIMDAS provides a unique style of warning system that can be altered to provide auditory warnings for any manner of incursions or collisions. The proposed design leverages algorithms to determine whether a problem or risk exists, the location and directional trend of the potential problem, and the approximate distance from other objects in the local space. Once RIMDAS has determined that conditions include the possibility of a runway incursion, the system can identify which aircrafts are involved, and issue the appropriate warning.

Identify and implement enhancements to improve surface communications

As previously mentioned, the RIMDAS system significantly reduces the workload on ground control to warn pilots of possible incursions. With the implementation of RIMDAS, pilots can be warned directly, thus improving surface communication by reducing the amount of information that must be communicated between ground control and pilot. This is especially important during periods of high workload for the ATC operator, who may not be able to attend to a rapidly developing incursion situation.

Support and deploy new technologies that reduce the potential for collisions

The design team envisioned RIMDAS being used in one of two roles; as either the sole technology for warning against potential collisions in airports that cannot justify a large incursion detection system, or as an addition to a large airport's existing technologies. This is one of the greatest strengths of RIMDAS; its solution could be integrated with other larger systems (such as ASDE-X or RIPS) in a support role or as a system redundancy for safety. However, RIMDAS could just as easily be applied alone to small-medium sized airports around the airports "hot spots" for runway incursions.

Implement site-specific runway safety solutions in coordination with local aviation communities

One of the many advantages of the RIMDAS system is that it can be executed in airports of any size or layout. A single MOTE covers an established area; this MOTE communicates with the other MOTES to create a networked infrastructure, which can be placed in any location and shape that can support the airport's specific needs. This unique aspect of its networked nature allows for a series of sensors to work together to send alert any receiving party of a possible incursion. This is especially important for smaller airports, as the FAA noted that local factors at particular airports may be just as important as high operation levels at determining the risk of an incursion (FAA, 2000).

Commercial Potential of RIMDAS

The commercial potential of RIMDAS can be evaluated both qualitatively and quantitatively. To address all possible opportunities, the design team evaluated RIMDAS using qualitative means (SWOT analysis) and quantitative means (Cost-Benefit Analysis). The results of both analyses are presented below.

SWOT Analysis

To assess the commercial potential of RIMDAS in the marketplace, the design team used a Strengths, Weaknesses, Opportunities, and Threats (SWOT). SWOT analyses are often used assist in the strategic planning of entering a particular marketplace. As such, a SWOT analysis clearly delineates the strengths and weaknesses of a particular solution or plan, as well as opportunities and threats to the solution's success in the open market. The results of the analysis are diagrammed in Table 4.

The SWOT analysis demonstrates that RIMDAS has several distinct strengths unique to the marketplace, such as the ability to be implemented quickly, cheaply, and configurable for any airport. The same strengths of RIMDAS translate into commercial opportunities when compared to competing systems. By being cheaper and easier to implement than any current system, RIMDAS fills a niche in the market that is not currently addressed by any incursion detection solution. Furthermore, future projections by industry experts in MOTES technology indicate that maintenance and upkeep costs may be much less than the projected maintenance costs of systems like ASDE-X.

The weaknesses of the current design center on the unknown quantities of MOTES, and are similar to the weaknesses observed among many innovative products. As more information disseminated regarding the costs of maintenance and the survivability over time, the realistic weaknesses of the system can be assessed. Due to the relatively novel nature of the proposal, current systems do not pose a large threat for the successful development of RIMDAS. Because the core market group is airports that can not justify investing in expensive, complex systems, RIMDAS occupies a market space of its own. Qualitatively, it seems the strengths of our design, and the opportunities it presents outweigh potential weaknesses and threats to its commercial viability.

Financial Analysis

Cost Benefit Analysis of RIMDAS

While a SWOT analysis allowed the design team to qualitatively evaluate RIMDAS against its peers, a cost benefit analysis provided some quantitative analysis of system value. To perform a cost-benefit analysis for RIMDAS, the design team looked to prior cost-benefit analyses that had been performed on systems with similar purposes. One system that received a comprehensive cost-benefit analysis was the ASDE-X system (FAA, 2000). To provide an estimate of the predicted values of a full cost-benefit analysis, the design team leveraged the ASDE-X life cycle benefit estimates for use with RIMDAS. More specifically, the team calculated the ratio of benefits and costs with RIMDAS, or the present monetary value (present value) of safety benefits (the money saved by preventing runway incursions) and the present value (PV) of system life cycle costs (FAA, 2000). The benefit to cost ratio is then used to determine the economic worth of a system. This ratio is determined by dividing the PV of safety benefits by the PV of system life cycle costs, or C/B = (PV_{sb} /PV_{sc}). If the ratio is greater than 1.0, then the benefits are greater than the costs, and the system is economically feasible for use.

Using the figures in the FAA (2000) investment analysis report, the design team held several financial assumptions. First, the Present Value of one system is estimated to be approximately 7.62 Million USD. This number was established by taking the expected benefit for 10 ASDE-X systems and dividing to the expected benefit for a single system. Second, the expected costs for RIMDAS are based on the following assumptions: with an average range of 100 feet, roughly 100 sensors would be needed to cover a runway of 10,000 feet (this assumes, of course, that the airport wanted to cover every area of the runway. Though this would be optimal for picking up trend information, it would not be completely necessary for smaller airports). If for these 100 sensors the airport chose to detect across 4 detection types (Acoustic, radar fence, infrared, or vibration), then the maximum needed would be 400. If each sensor costs between $400-500, we can estimate that we would need a minimum cost of ((100 Sensors x $500 Dollars) + (3,000 Development Kits X 100) = $50,000 + $300,000 = $350,000) $350,000, and a maximum cost of (500 Sensors x $500 Dollars) + (3,000 Development Kits X 100) = $250,000 + $300,000 = $550,000) $550,000, creating an average start-up cost of ((350,000 + 550,000)/2 = $450,000) $450,000. If maintenance costs are assumed to be a 10% replacement rate over a 5 year period (10-50 Motes at $500 = $5000-$25000) and a dedicated service technician for the server and sensor field (100,000 for salary + benefits cost), then maintenance costs should range from $105-125,000 per year. The start up and operational costs were compared to expected present value of the systems to determine the cost-benefit and net present value of RIMDAS.

The cost-benefit analysis indicates several strong points of the design; first, the cost of RIMDAS is minimal (Present Value Average of $623,592 compared to the potential benefit (Present Value Benefit of $76.2 Million) – see Table 5. On average, the cost/benefit ratio for the RIMDAS system is 122 times greater than the minimum required for justifying the system use. Even if the estimate of present value benefit of RIMDAS turned out to only be half of the estimated benefit of the ASDE-X system, the cost-benefit ratio would be still be almost 61 times what is necessary to justify system development.

Affordability & Utility of RIMDAS

The largest potential impact of a system like RIMDAS is its immediate utility. For a system to be useful, it must first be available. Current solutions (such as ASDE-X and RIPS) have great potential to reduce runway incursions, but are not readily available. In the case of ASDE-X, this is due to the high cost, which makes it difficult for many airports to afford its implementation. In the case of RIPS, it is due to the fact that the technology on which the system is built is still in testing. In contrast, RIMDAS can be used on a relatively short timeframe. The system's components are readily available, and with some testing, the system could readily be implemented in multiple airports.

RIMDAS is affordable. As the cost-benefit analysis indicated, the benefits of RIMDAS far out-weigh the costs of installation and maintenance. Furthermore, the cost of RIMDAS is a fraction of the amount currently proposed for other incursion detection solutions. Further increasing RIMDAS' overall affordability is the relative simplicity of the system. There are only a few pieces of technology needed to run the system, all of which are inexpensive compared to other detection technologies. This will undoubtedly keep maintenance costs low, as few parts are available and solutions to any issues that arise should be relatively straightforward to troubleshoot. Even more encouraging is the nature of the MOTES network itself. Not only will RIMDAS continue to perform if one or more sensors fail, but the sensors can simply be replaced rather than sinking costs into repairs. The simplicity of the system also minimizes training costs. Training for pilots, air traffic controllers, and other airport personnel would be fairly minimal, thus requiring less time and fewer materials to complete.

Process to Bring Design to Implementation-Ready State

That all components of RIMDAS are already commercially available means that bringing the design to implementation would focus on the integration of the system with the airport. However, the presence of the parts commercially on the market does not ensure that the system will operate perfectly once deployed. The development process used to bring RIMDAS to an implementation – ready state would likely mirror the design process used with Motes for the REEF system (Figure 18). REEF is a project carried out by MITRE as a venue for testing out MOTE's abilities and unifying netted sensor issues. REEF identified the following design process guidelines for readying a MOTE's system for deployment. Several issues were noted for research and development – namely that the initial purchaser should have the capability to model and simulate the netted sensor problems, and leverage test results to determine the appropriate solution or the potential of a proposed solution. The purchaser would also need the capability to rapidly prototype hardware proof-of-concept demonstrations prior to releasing the system for test at various airports.

Several components would also be required to support system use. This includes an operational information infrastructure that can provide facilities for managing data, applications, and services needed to conduct research and development, a simulation test bed that can be used to perform simulations of netted sensor components and system, and a hardware test bed that encompasses both laboratory hardware assets and the sensor field (MITRE, 2007).

Once RIMDAS' benefits have been empirically validated, it could be implemented on an airfield using an engineering firm or other specialized group responsible for the layout of the motes system and the programming of the server. After installing RIMDAS, aircraft would also need to install an inexpensive "squawk box" in each flight deck to receive wireless transmissions from the system. Once the following steps are completed, the system will be ready for use.

Concluding Summary

This proposal followed a multidisciplinary approach to preventing runway incursions, melding existing research and technology into one cohesive, innovative solution. The product, RIMDAS, was conceptualized with three general aspects in mind: utility, customizability, and affordability. The perspective expressed throughout this paper is that RIMDAS holds the potential to make a drastic real-world impact. While the design specifications (discussed in section IV) provide the groundwork for real-world implementation, this solution is not bound by conventional restrictions.

The customizability aspect is one of the most appealing qualities of RIMDAS. Because the system uses digital wireless transmissions, any number of people would be able to access the information flow provided by the sensor technology. For instance, ground vehicles (e.g. fuel trucks or baggage vehicles) would theoretically be able to receive warnings if their safety is threatened by a runway incursion. In addition, RIMDAS holds the potential to expand its capabilities by interacting with other, more elaborate, technology if desired. For example, RIMDAS could transmit information through a visual modality, such as RWSL or HUD, in addition to the auditory alert, or it could be integrated into RIPS or ASDE-X as a redundant safety system.

The affordability aspect of RIMDAS also has enormous future potential. This belief is based on a unique approach. Instead of focusing on the most advanced technology available, the design team developed a solution that can reach the most people, while still retaining several state-of-the-art qualities. Its cost-effectiveness would allow nearly any airport to benefit, regardless of size or budget. The widespread dispersion of RIMDAS, combined with its technical capabilities, holds a great deal of promise for boosting runway safety.

Appendix A
Contact Information

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Appendix B
Description of George Mason University

George Mason University began as the Northern Virginia branch of the University of Virginia in 1957. Eager to support the fledgling institution, the Town (now City) of Fairfax purchased 150 acres in 1958 and donated it to the University of Virginia for a permanent branch campus. In 1966, the General Assembly authorized the expansion of George Mason College into a four-year, degree-granting institution with the long-range mandate to expand into a major regional university.

In 1972, George Mason University became an independent member of the commonwealth's system of colleges and universities. Since then, the university's development has been marked by rapid growth and innovative planning. Employing the revolutionary concept of the "distributed" university, George Mason acquired the George Mason University School of Law and a campus in Arlington in 1979. The Prince William Campus was established in Prince William County in 1997. The 150 acres that once was the entire George Mason University campus has become the 677-acre Fairfax Campus. Mason began having classes in Loudoun in the fall of 2005. With 64 undergraduate, 94 graduate degree programs, and a combined enrollment of over 29,000 students, George Mason University has grown into an educational force and earned a reputation as an innovative, entrepreneurial institution.

Appendix C
Description of Non-University Partners Involved in Project

This project was not conducted with the assistance of any non-university partners.

Appendix E
Evaluation of Educational Experience

As graduate students, the opportunity to work on designing a solution to a real-world problem was an empowering experience. Through interaction with industry experts, aviation professionals, and aviation academics, the design team was exposed to not only a wealth of information, but a different viewpoint on where human factors principles can be applied – along with where others disciplines' expertise is required.

Though many human factors graduate students are involved in research projects, it is rare that students receive the opportunity to develop a design under their own accord. Over the course of two semesters, this project has provided a wealth of applied knowledge in solving a real-world challenge. This project gave the GMU design team a better understanding of the rigors that go into planning, developing, analyzing, and designing a warning system to be used in aviation.

The experience of leading a group also emphasized several lessons in the importance of project management and setting attainable design goals for the team. Each group member had a significant role in the design and development of RIMS, with many aspects being tied to set deliverables and dates. Team members learned the value of updating each other frequently, and holding each other accountable to stay on schedule in meeting goals. Several team members noted learning about the importance of delegation and time management, and the ability to collaborate on design aspects that were too large for a single designer or analyst.

Overall, developing a strong team, learning the technical aspects of aviation, and overcoming obstacles faced during the design process was the greatest experience; the best educational experience ended up being the experience of designing the system itself.

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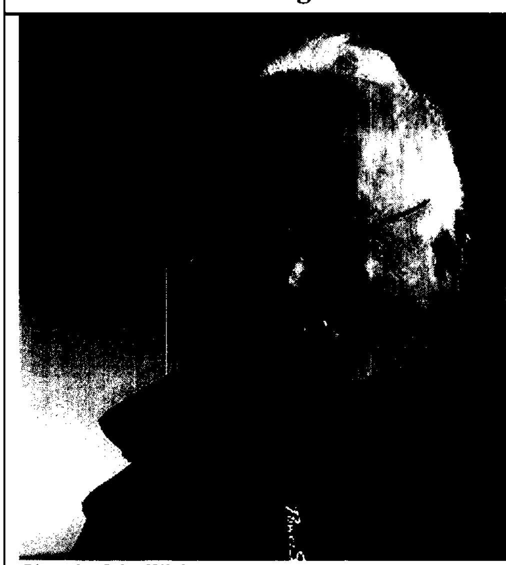
Appendix G
Supplementary Materials

Table 1. Examples of tasks generated through unstructured interview techniques.

Taxiing/Take Off	Landing
- Checking physical condition of plane - Filing a flight plan - Obtaining ATC clearance - Performing pre-takeoff checklists - Continuously monitoring outside environment - Repeating all ATC - Accelerating on runway - Monitoring instruments - Doing callouts to communicate between pilots	- Obtaining take-off clearance from ATC - Performing pre-landing checklists - Setting speed of aircraft - Setting pitch of aircraft - Manipulating aircraft controls - Monitoring instruments - Scanning outside aircraft - Touching down on runway - Doing ground roll - Taxiing to gate - Shutting down aircraft

Table 2. Examples of Aviation Personas

Persona 1 – Roger Valencia	Persona 2 – Frederick Simmons
 Photo by John Wigham. Roger Valencia is a 60 year-old pilot who has worked for American Airlines for the past 30 years, just six months shy of retirement. Due to his extensive experience, he almost always flies as the Captain. Roger believes in teaching younger pilots, and thus always delegates the checklist tasks and programming information into the onboard computer to	 Photo by Carl Collins. Frederick Simmons is a 29 year-old pilot for Air Wisconsin. He has only recently graduated from training and has only ever flown as the First Officer on a flight. Although Freddy is new to flight, he is well liked due to his thorough work when completing checklists and programming the onboard computer, and for keeping a vigilant watch outside the aircraft when

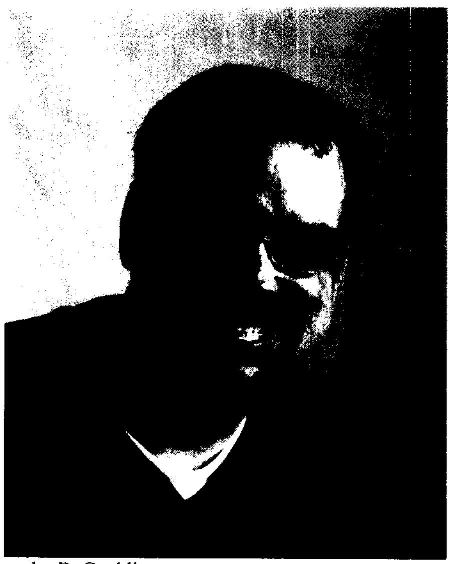
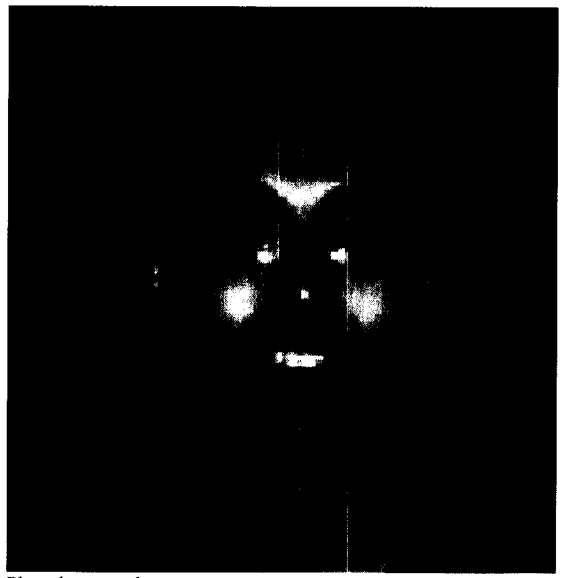
his First Officer. He always does a walk around of the plane prior to flight, and always checks the First Officer's work prior to calling for ATC clearance. His pre-flight briefings are well known for their thoroughness and good-humor, and he is a popular Captain to work with. Roger is generally comfortable multi-tasking in the aircraft, and is able to keep a calm head when things do go wrong.	taxiing. He has not yet had the opportunity to control the aircraft during take-off or landing, but is looking forward to his first opportunity. In the meantime, he carefully monitors the instruments and the outside environment as the Captain performs the necessary maneuvers.
Persona 3 – Douglas Hill	**Persona 4 – Jason Huang**
 Photo by D. Conklin. Douglas Hill is a 40 year-old ground crew worker at Dulles International Airport. He primarily works as a baggage handler, but sometimes drives pushback tugs. Although Doug has not personally had any close calls with aircraft, one of his close friends was killed when he got too close to an active jet engine during the an aircraft push back. Doug has been acutely aware of safety issues ever since.	 Photo by startrak.org Jason Huang is a 35 year-old air traffic controller at the main tower in San Francisco International Airport. He is fairly new to the job and mostly works on the night shift. His primary job is to provide clearance for pilots taking off and landing, and to ensure that proper separation is maintained at all times. Jason has had one incident where he allowed two incoming aircraft to breach the FAA mandated separation distance, but was very quick to correct the mistake. The incident was listed as a Category D incursion.

Table 3. *Examples of Scenario-based Use Cases generated by the design team*

Take-off Use Cases	Landing Use Cases
- Crossing an active runway - Attempting to take off on a runway while another aircraft attempts to land - Taxiing to runway when ground vehicle cuts in front of aircraft - Taxiing while checking pre-flight checklist - Waiting on taxiway for permission to prepare for takeoff	- Landing on a runway that is currently occupied by another plane - Landing on a runway that is occupied by ground vehicle - Landing as an aircraft descends for the same runway - Landing as an aircraft prepares to cross over the runway

Table 4. *SWOT analysis of MOTE solution's commercial potential.*

Strengths	Weaknesses
• Can be implemented quickly • Less time spent on programming the system and training personnel • Low cost • Fewer costs associated with programming the system and training personnel • Uses existing inexpensive technologies • Simple design • Caters to all types of airports • Attractive solution for small airports due to the affordability • Attractive solution for larger airports due to rapidity of implementation • Can be utilized as a primary system or as a back-up system	• Too many false alarms can greatly reduce the impact of our design – the sensitivity threshold would have to be carefully selected • Potential to overload pilots with further information • Could be distracting to pilots performing a difficult maneuver • Limited information is provided – pilots may have difficulty interpreting the meaning of the alert • MOTES are relatively new – the cost of long-term maintenance is unknown • Pilots can just turn the system off if they don't like it

Opportunities	**Threats**
• Can be rolled out more rapidly than other, current solutions • Less expensive than other systems currently on the market • Fewer maintenance costs than current systems • No development needed – system has already been well established in other applications • Will not interfere with currently implemented systems • Functions in all types of weather, unlike some current solutions	• Does not provide same level of detailed information that ASDE-X does • Does not use proven radar technology that current solutions are built on • Does not use FAA approved components, so system would need to obtain FAA approval before being implemented • Long-term maintenance and repair costs associated with the system are an unknown

Table 5. *Costs for Purchase of Ten RIMDAS Systems over five years**

RIMDAS Costs	**Most Likely Values (Avg)**	**Low Cost Estimate**	**High Cost Estimate**
FAA F&E Costs	$450,000	$350,000	$550,000
FAA O&M Costs	$515,000	$505,000	$525,000
Total Costs	$965,000	$855,000	$1,075,000
Present Total Value Costs			
	$623,592	**$552,509**	**$694,675**
RIMDAS Benefits	**Average**	**20% CV**	**80% CV**
Present Value Benefits	$76.2 Million	$41.2	$100.6
RIMDAS Benefit/Cost Ratio	**Average**	**Low Cost Estimate**	**High Cost Estimate**
Net Present Value	$75.58 Million	$40.44 Million	$99 Million
Benefit/Cost Ratio	122	74	145

*Note: Benefit numbers not adjusted from 2000 calculations. Mote estimates based off of individual system parts and does not include labor fees of initial setup.

*Benefit costs taken from 2000 assessment of ASDE-X system. Actual predicted benefit costs may be less.

Figure 1. "Recommended types and levels for future ATC systems, consistent with three evaluative criteria-human performance consequences, automation reliability, and costs of actions" (Parasuraman, Sheridan, & Wickens, 2000).

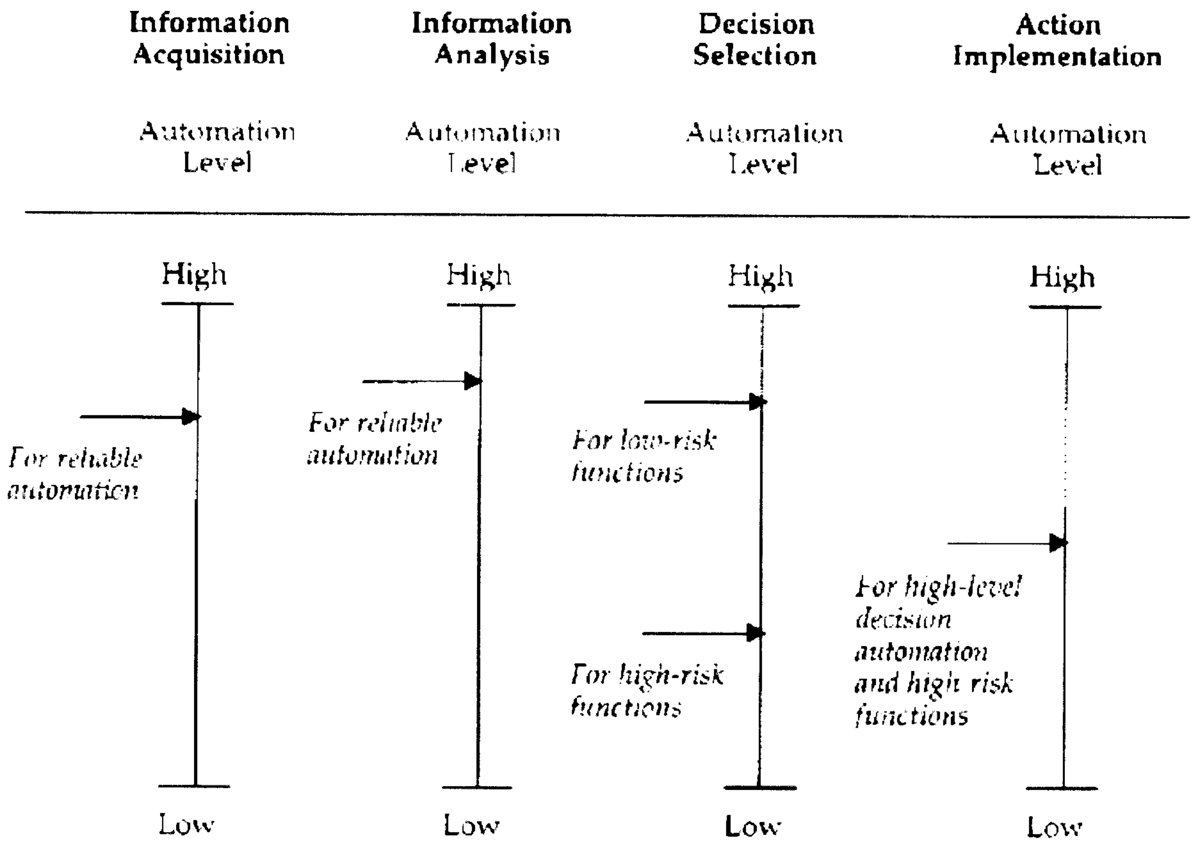


Figure 2. Receiver Operating Characteristic (ROC) curve for the GPWS system (Parasuraman, Hansman, and Bussolari, 2002). Probability of false alarms (x-axis) is compared to probability of correct detections (y-axis) to determine an optimal detection threshold.

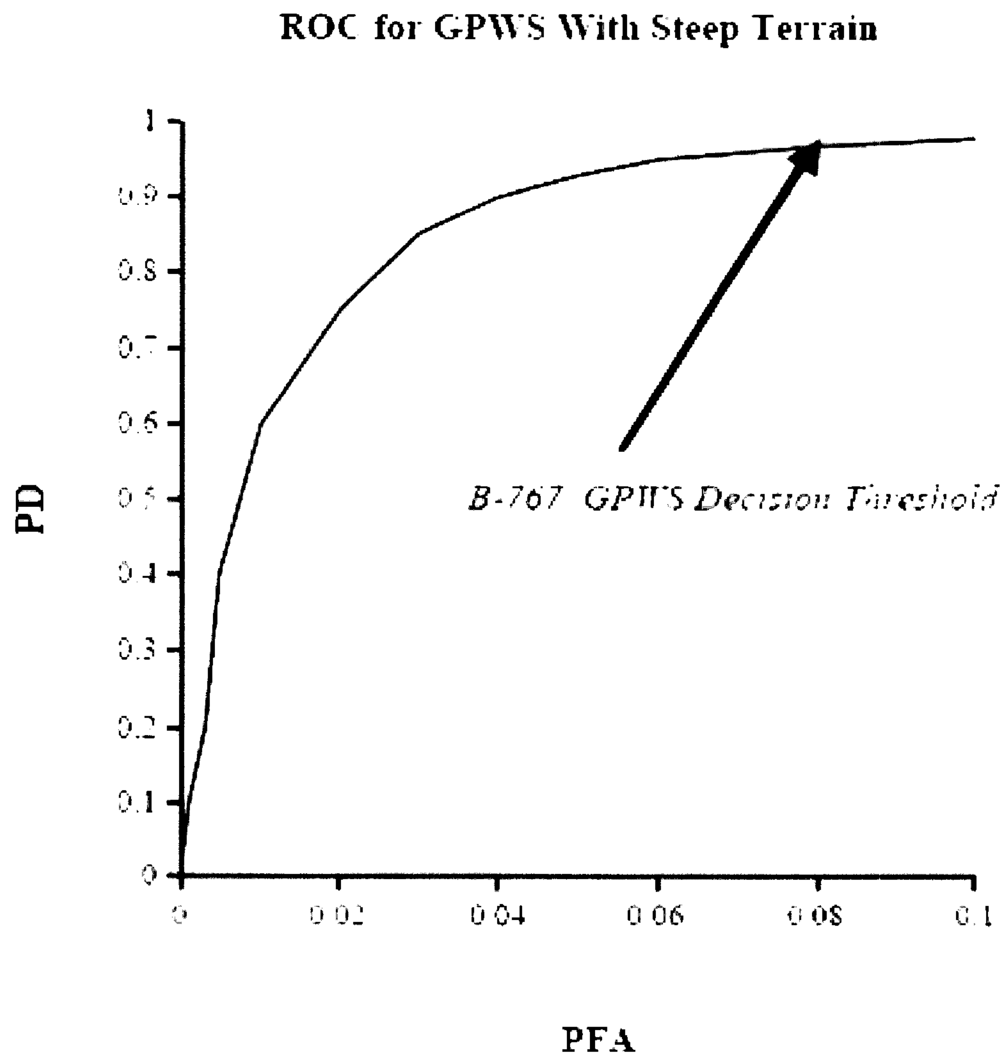


Figure 3. Hybrid design approach - Methodologies are listed below each concept. (Adapted from Smith, Prada, & Rahman, 2006)

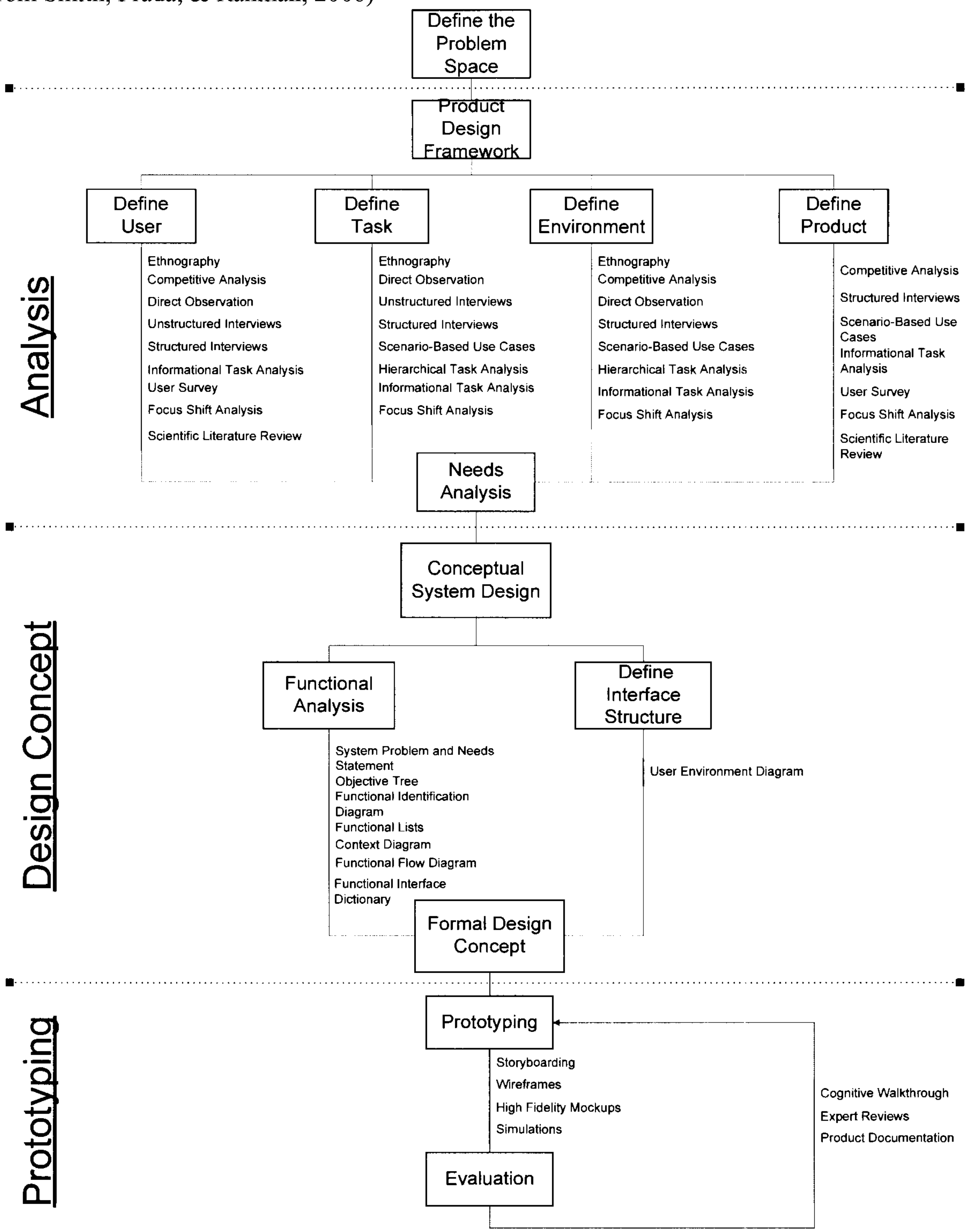


Figure 4. The cognitive triad, in which a user uses a product to perform a task in the context of a specific environment. (Adapted from Boehm-Davis, 2006)

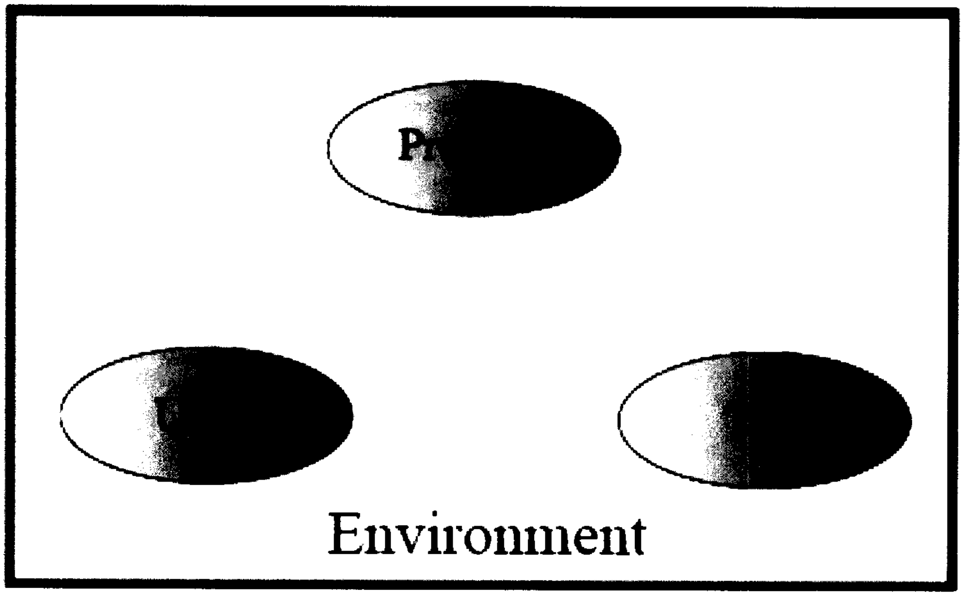


Figure 5. HTA of Piloting Tasks performed while Descending (Part 1)

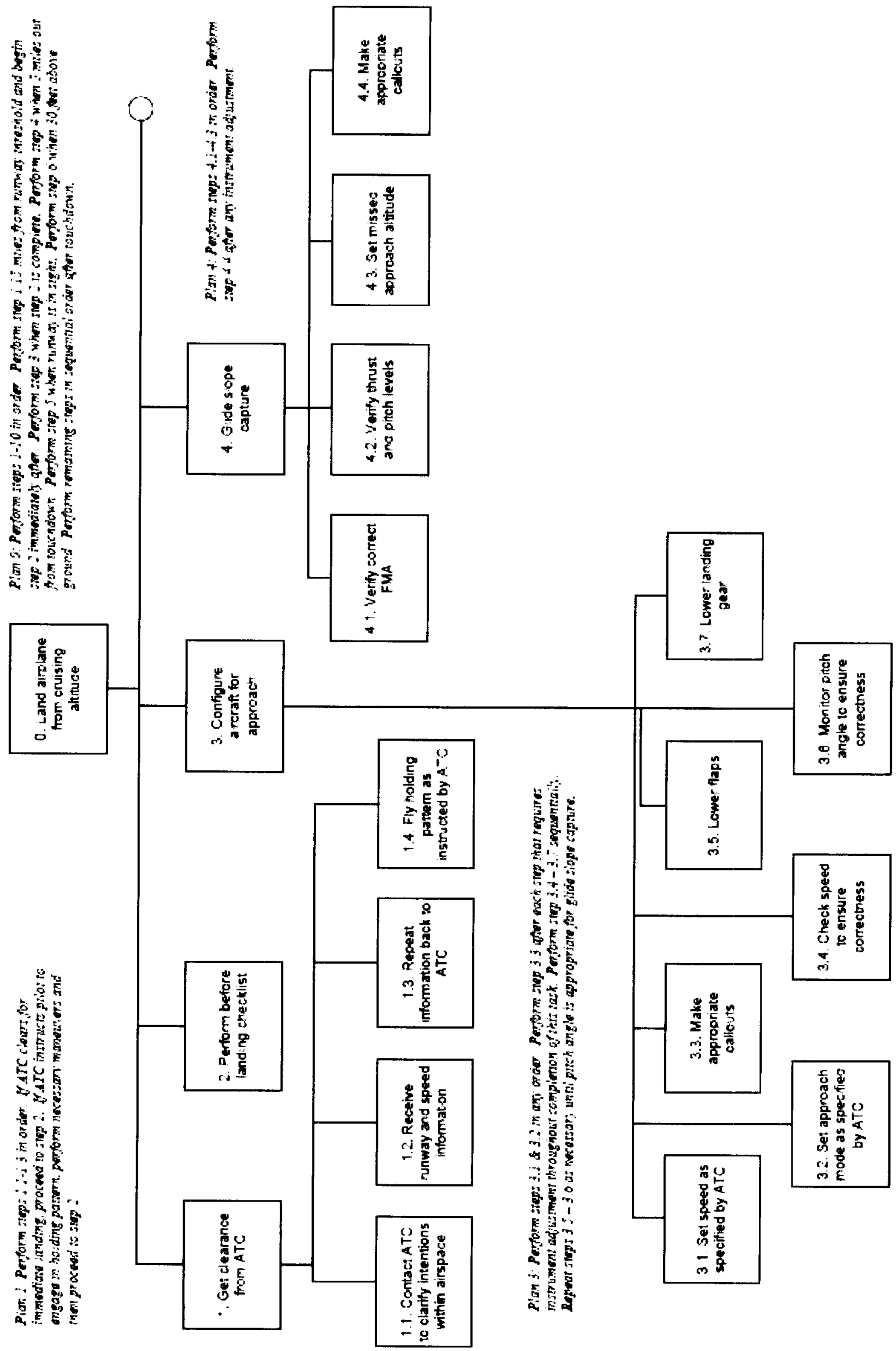


Figure 5. HTA of Piloting Tasks performed while Descending (Part 2)

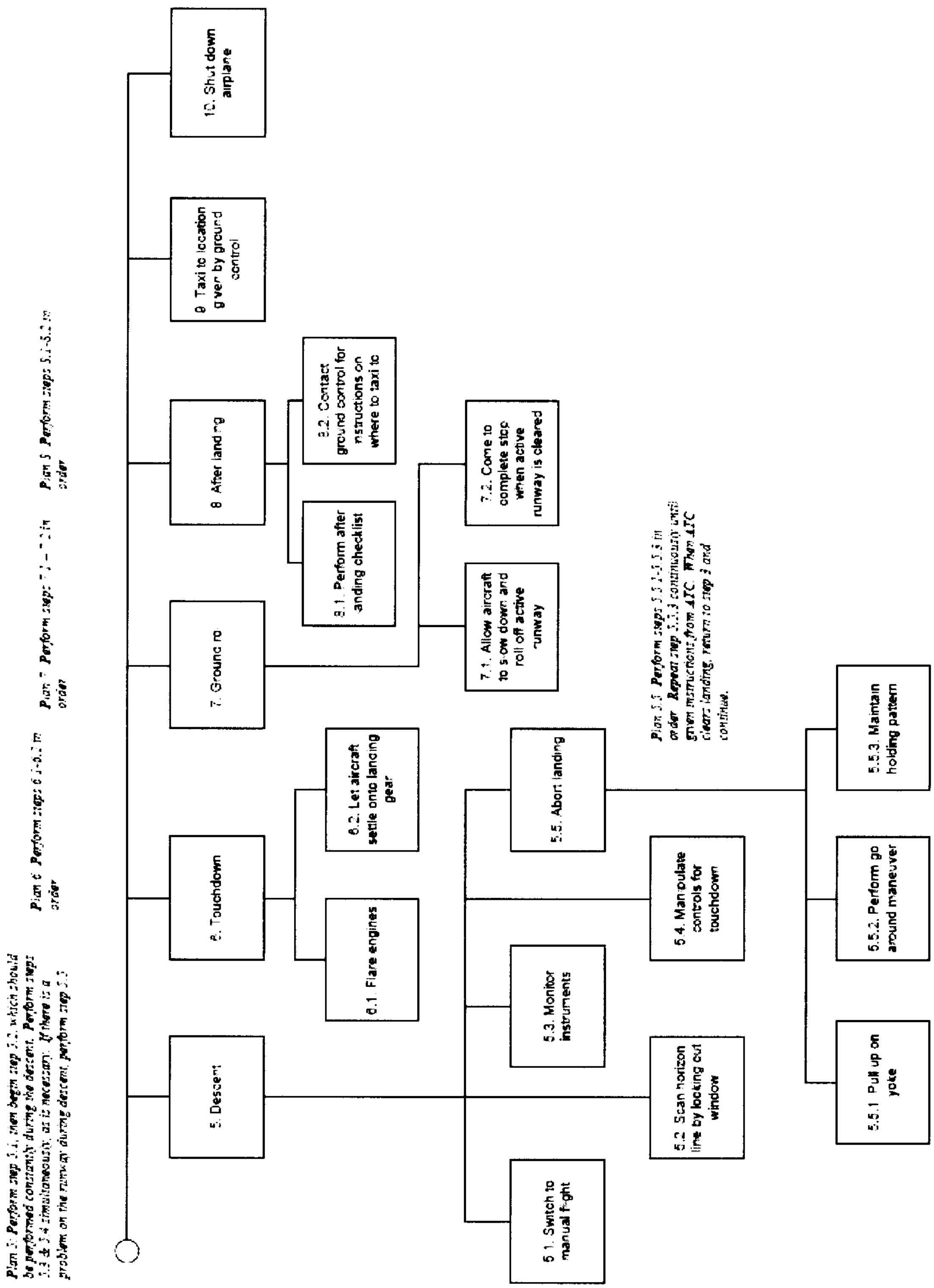


Figure 6. HTA of tasks performed during pre-flight and take-off

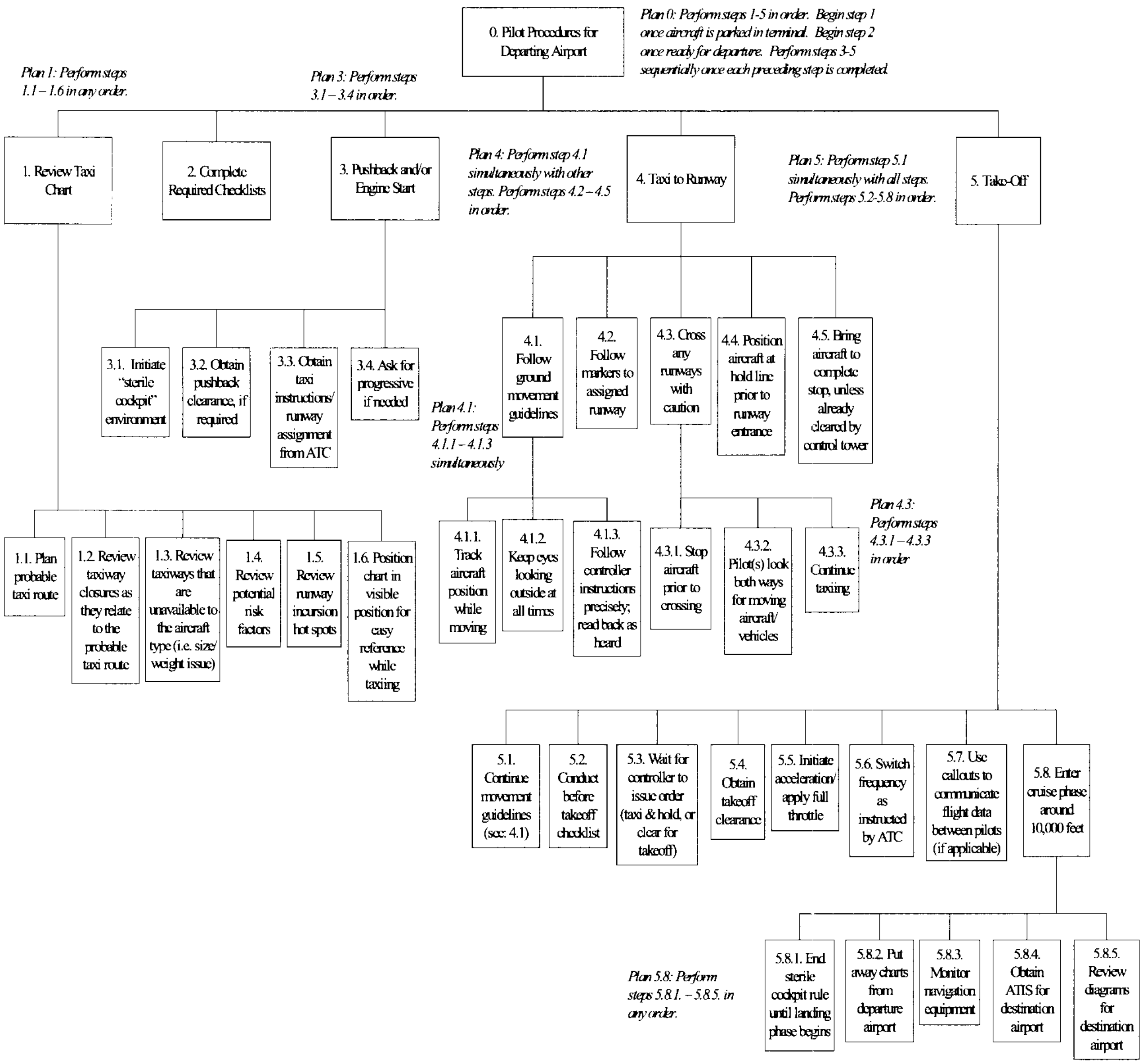
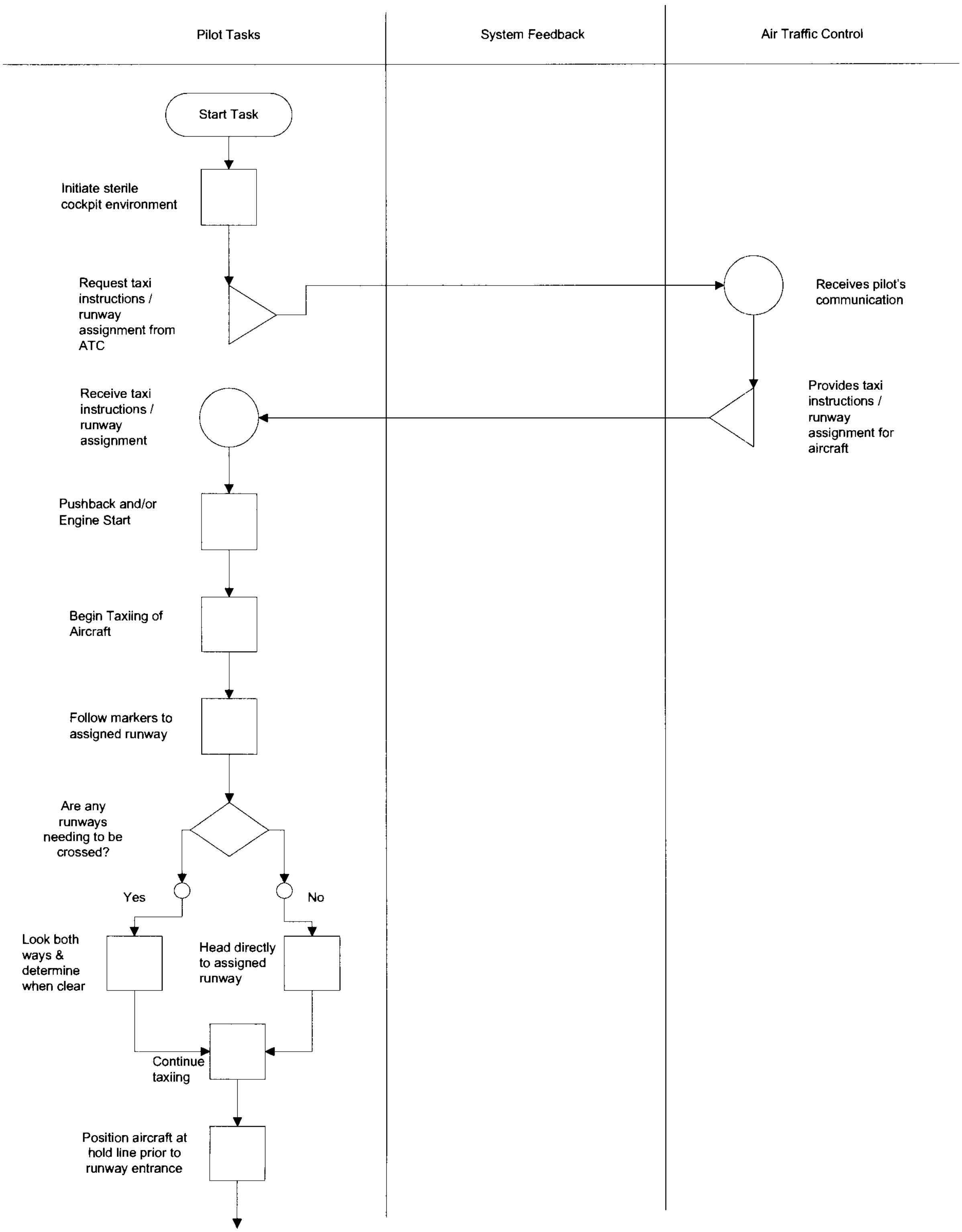


Figure 7. OSD of piloting tasks during take-off



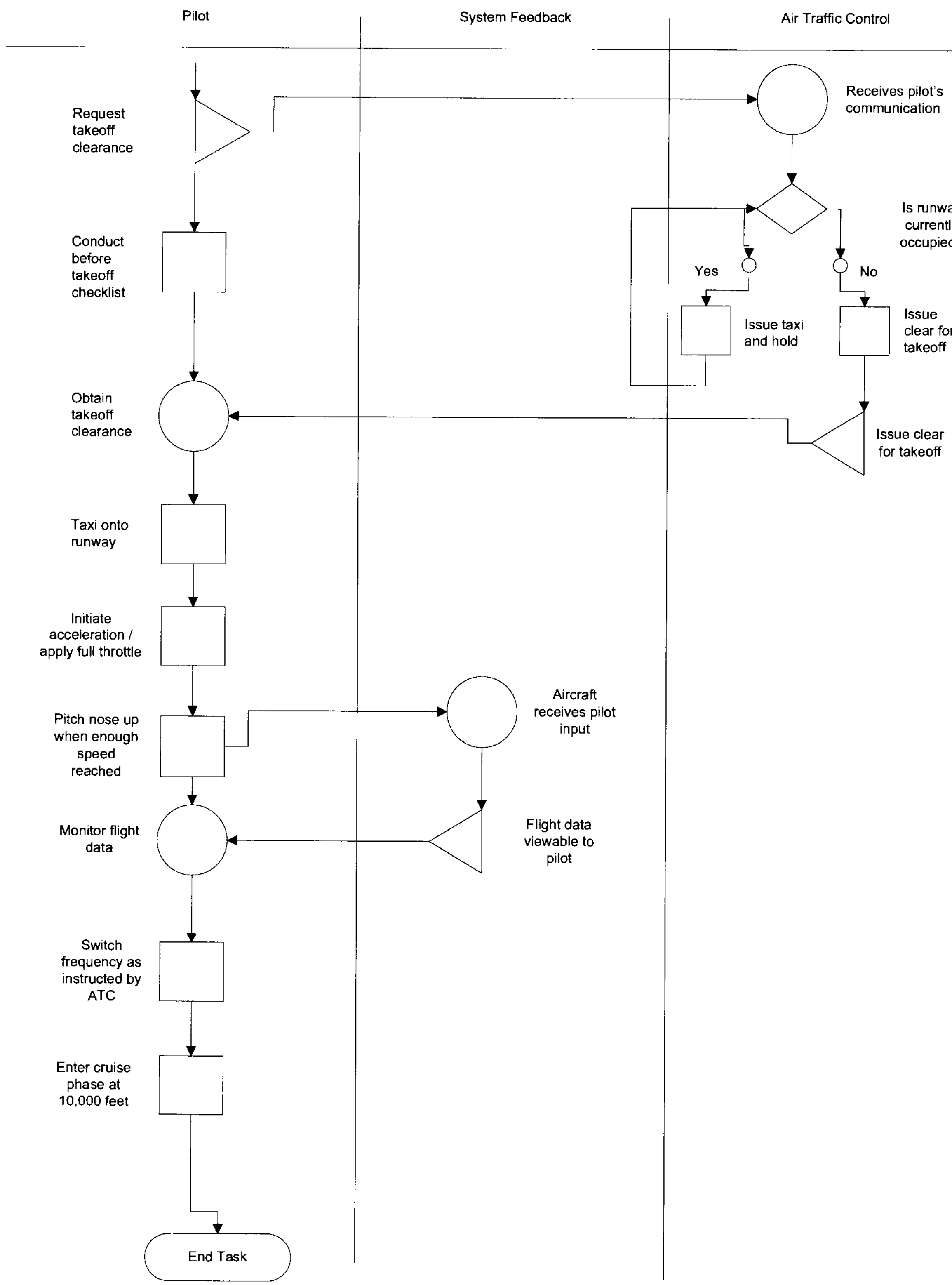
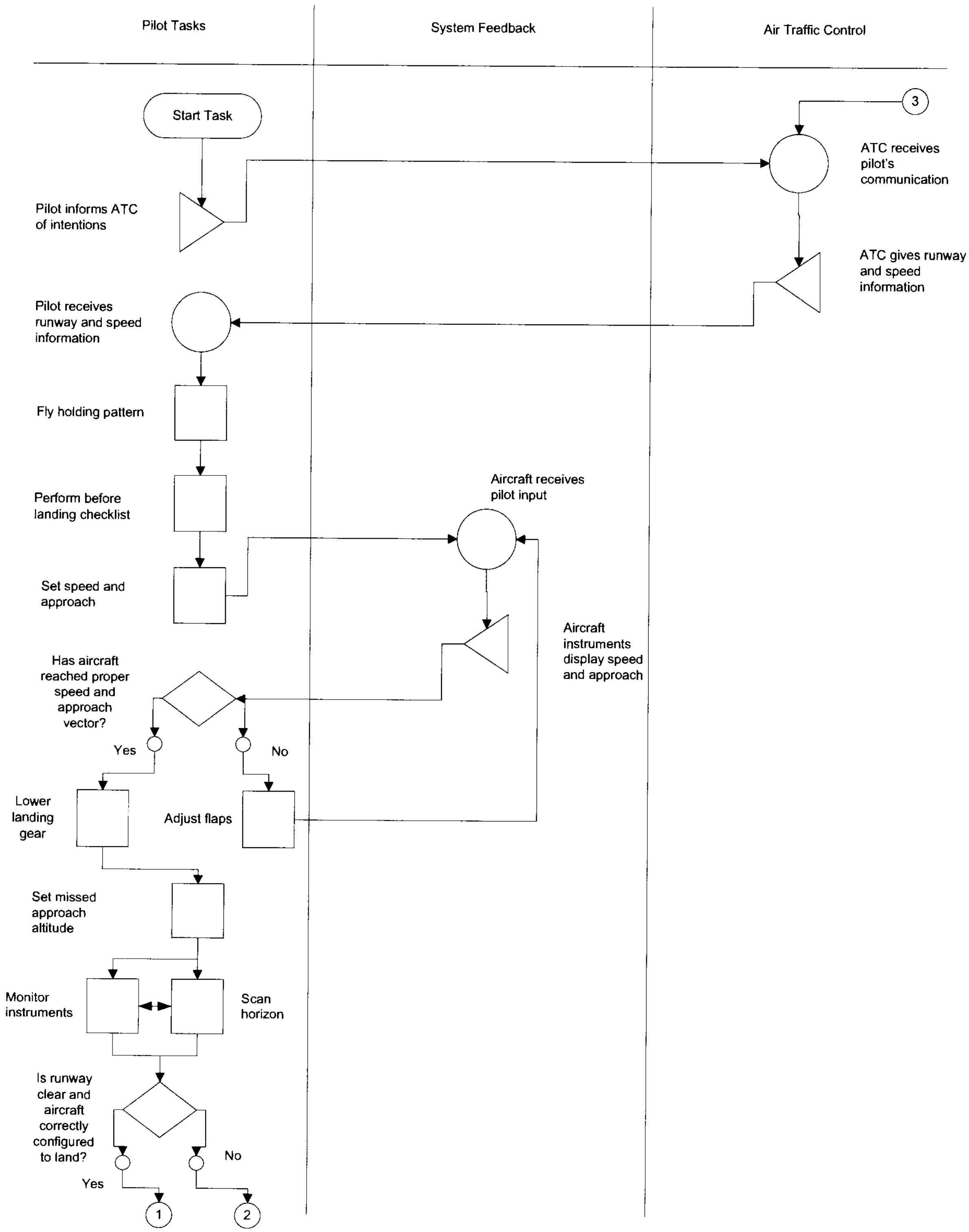
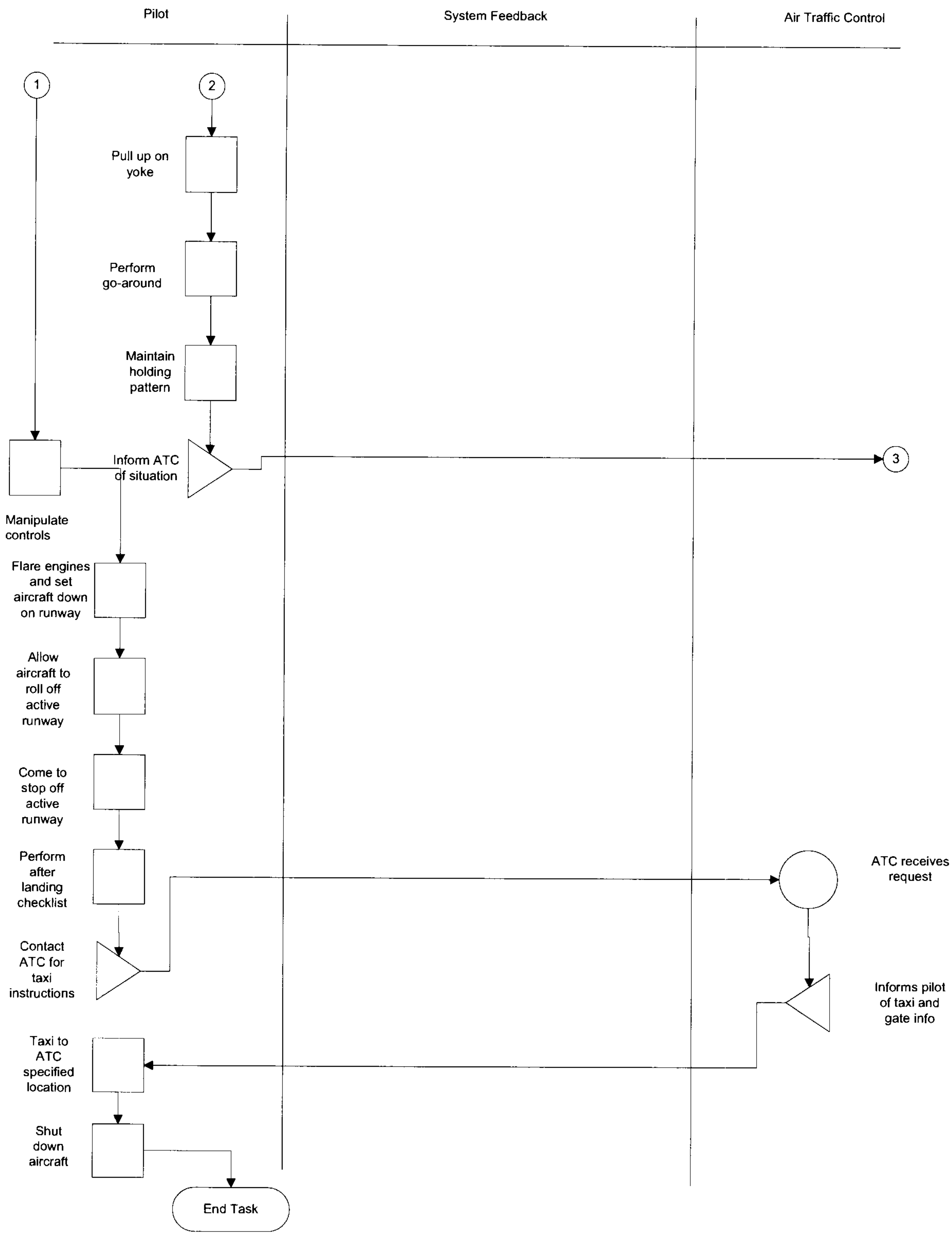

Pilot
System Feedback
Air Traffic Control
Request takeoff clearance
Receives pilot's communication
Is runway currently occupied?
Yes
No
Issue taxi and hold
Issue clear for takeoff
Conduct before takeoff checklist
Obtain takeoff clearance
Issue clear for takeoff
Taxi onto runway
Initiate acceleration / apply full throttle
Pitch nose up when enough speed reached
Aircraft receives pilot input
Monitor flight data
Flight data viewable to pilot
Switch frequency as instructed by ATC
Enter cruise phase at 10,000 feet
End Task

Figure 8. OSD of Pilot Tasks during landing.





Pilot
System Feedback
Air Traffic Control
1
2
Pull up on yoke
Perform go-around
Maintain holding pattern
Inform ATC of situation
3
Manipulate controls
Flare engines and set aircraft down on runway
Allow aircraft to roll off active runway
Come to stop off active runway
Perform after landing checklist
Contact ATC for taxi instructions
ATC receives request
Informs pilot of taxi and gate info
Taxi to ATC specified location
Shut down aircraft
End Task

Figure 9. MOTES and their many uses. (Image from Tromp, L.D & Jacyna, G: Netted Sensors Presentation http://www.ffrdc.com/news/events/tech04/briefings/1423.pdf)

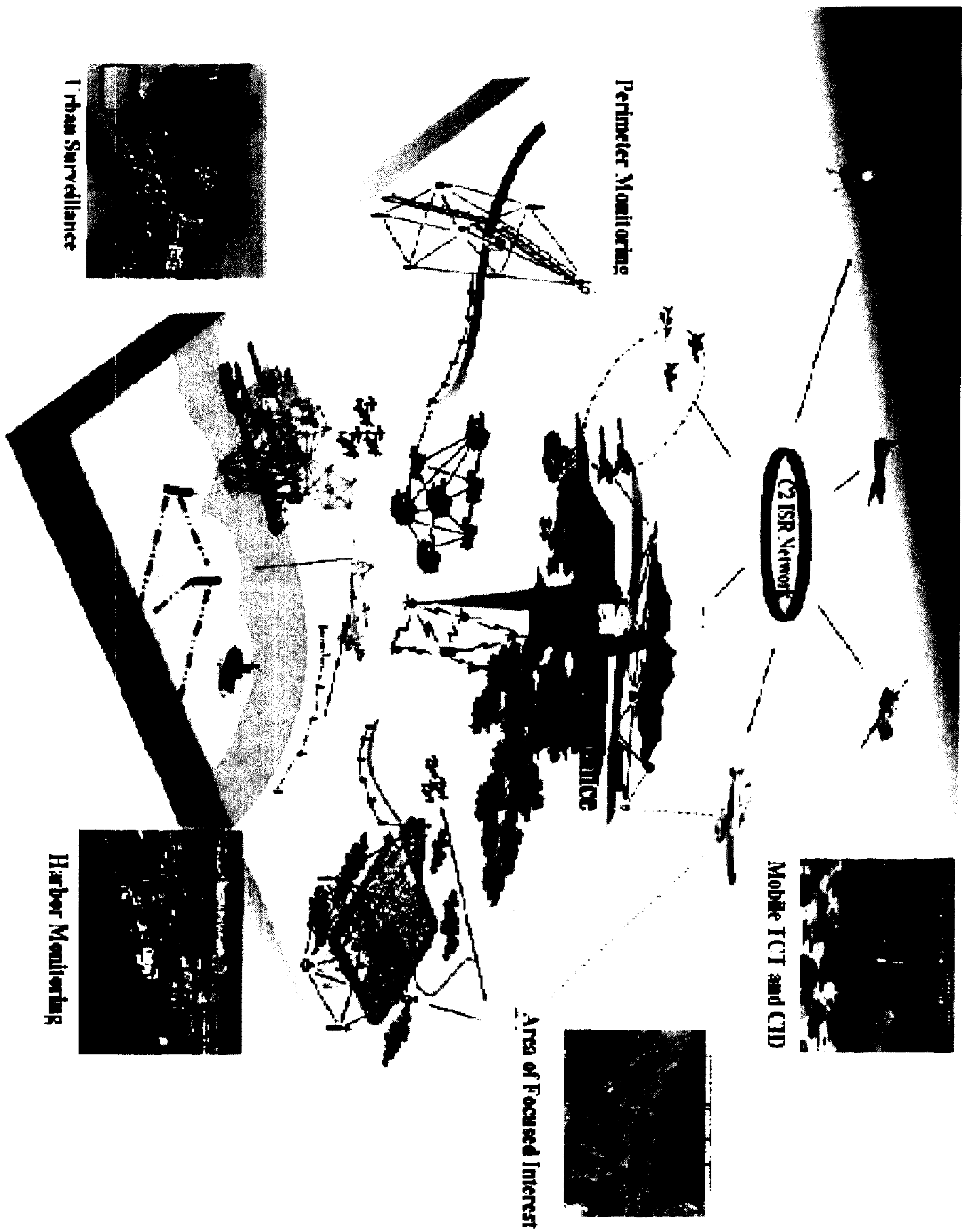


Figure 10. Diagram of a typical MOTE.

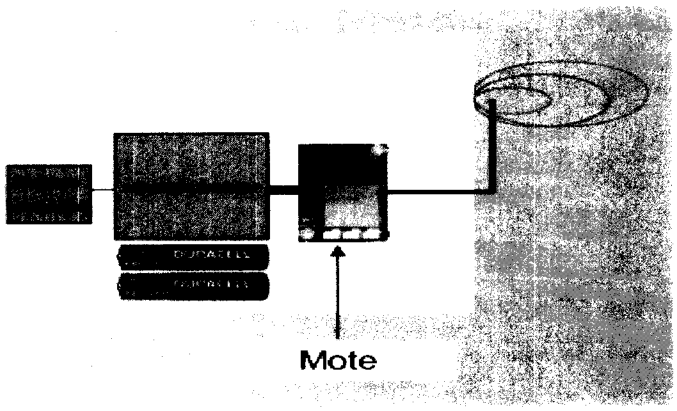


Figure 11. Example of how Wireless MOTES Network Operates
http://www.xbow.com/Products/Product_pdf_files/Wireless_pdf/MoteWorks_OEM_Edition.pdf

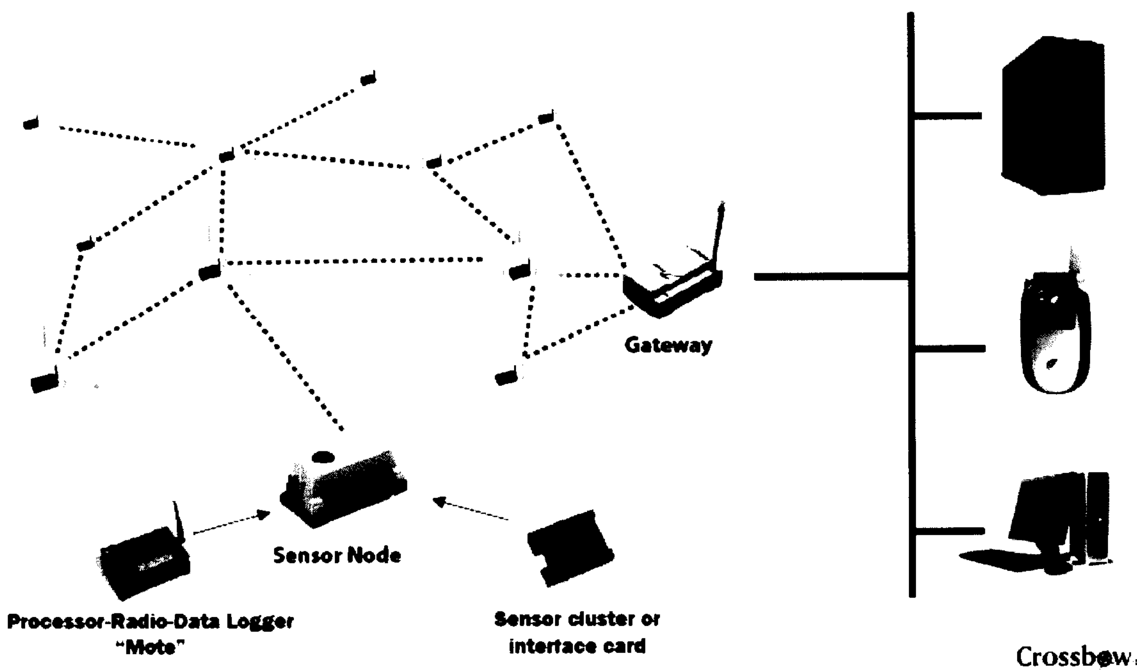


Figure 12. Increasing Sales of Wireless Sensor Networks, Crossbow Technology, E-Seminar on "How Wireless Sensors Work", https://event.on24.com/eventRegistration/EventLobbyServlet?target=registration.jsp&eventid=24933&sessionid=1&key=FAED9C287B8874A35B47D7100CB5B73B&referrer=&sourcepage=register

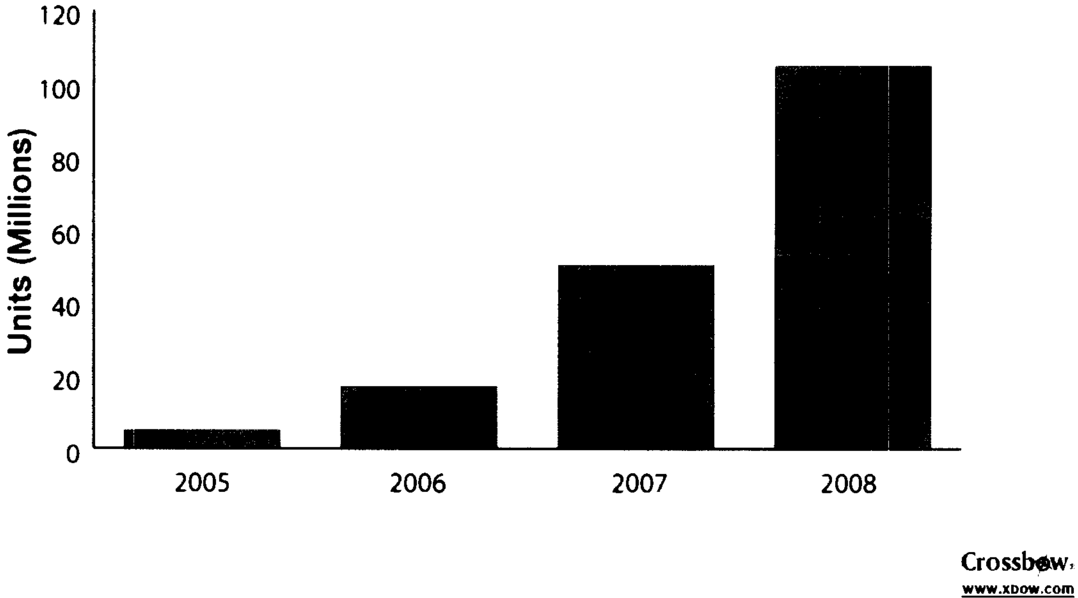


Figure 13. Graphical depiction of how RIMDAS could help prevent Scenario One. The sensors lining the runway detect the presence and rate of the aircraft on the runway and taxiway (1) and forward this information to the server (2) where an algorithm detects the potential for a runway incursion. The server then wirelessly broadcasts a signal to each plane (3), providing notification that there is potential for a runway incursion.

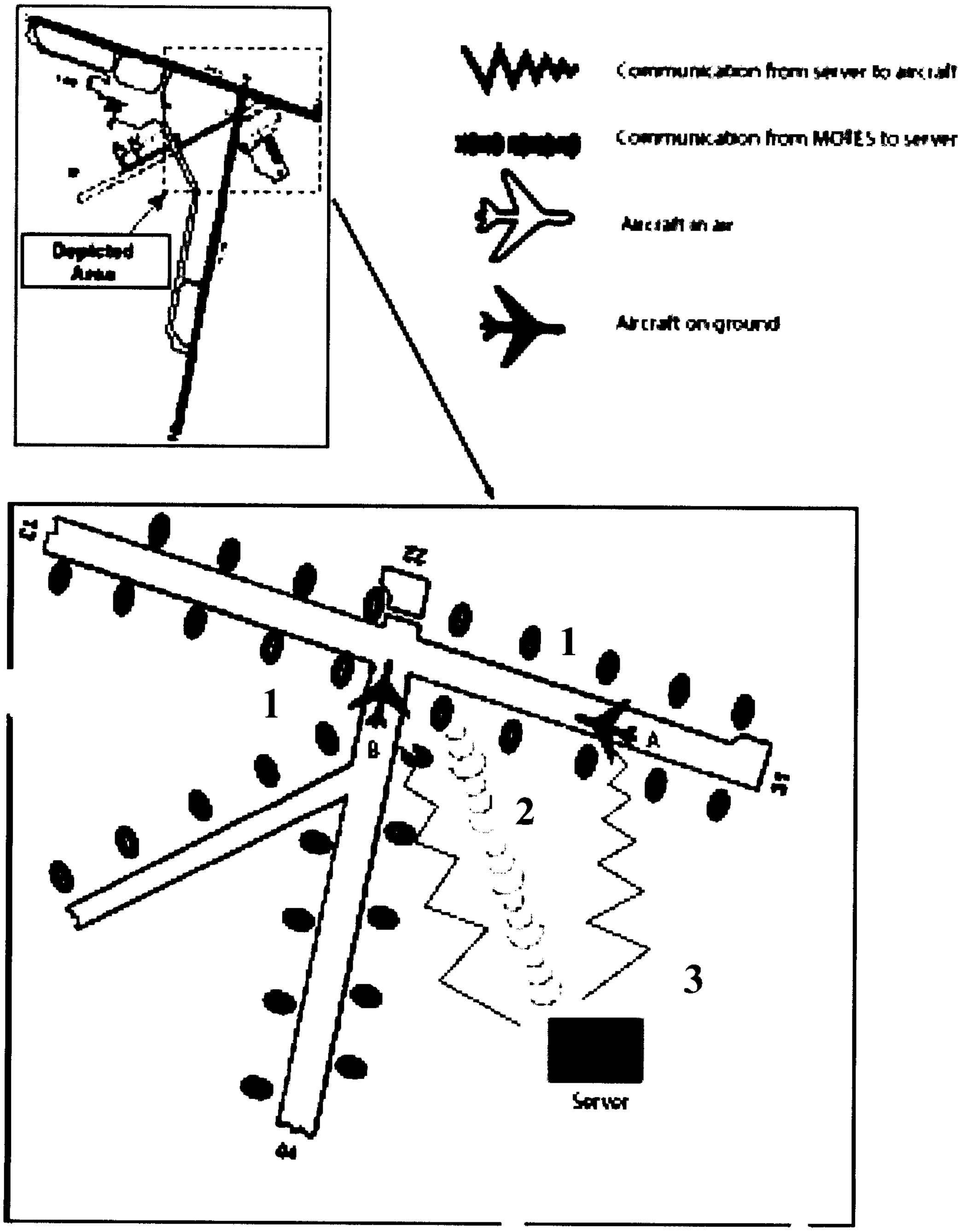


Figure 14. Graphical depiction of how RIMDAS could help prevent Scenario Two. The sensors lining the runway detect the presence aircraft over either end of the runway (1) and forward this information to the server (2) where an algorithm detects the potential for a runway incursion. The server then wirelessly broadcasts a signal to each plane while in the air(3), providing notification that there is potential for a runway incursion when landing.

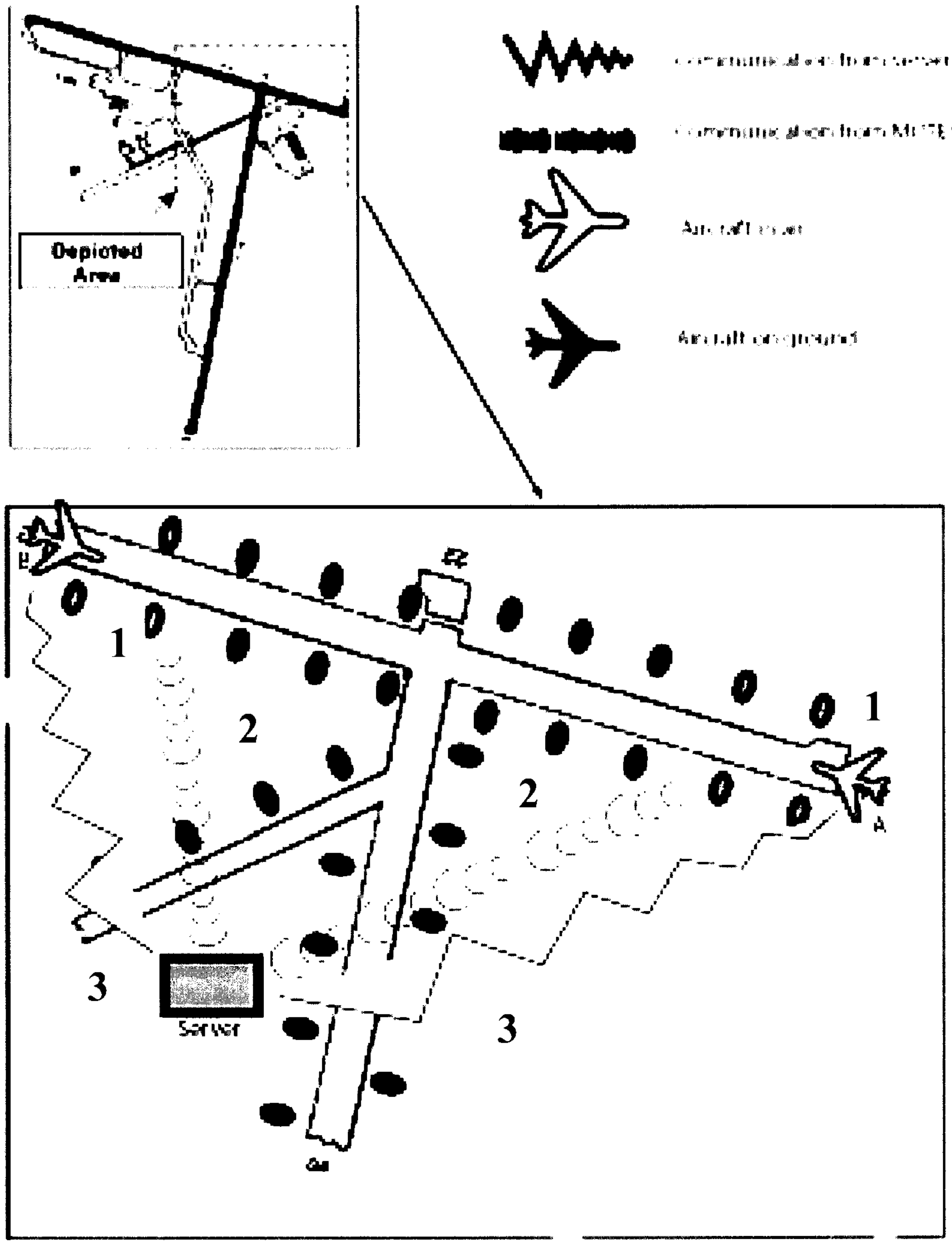


Figure 15. Mutli-Modal Netted Sensor Fence (Image from Shi, W. , Fante, R., Yoder, R., and Crawford, G., "Netted Sensor, 2006"; The Edge Journal http://www.mitre.org/news/the_edge/spring_06/shi.html)

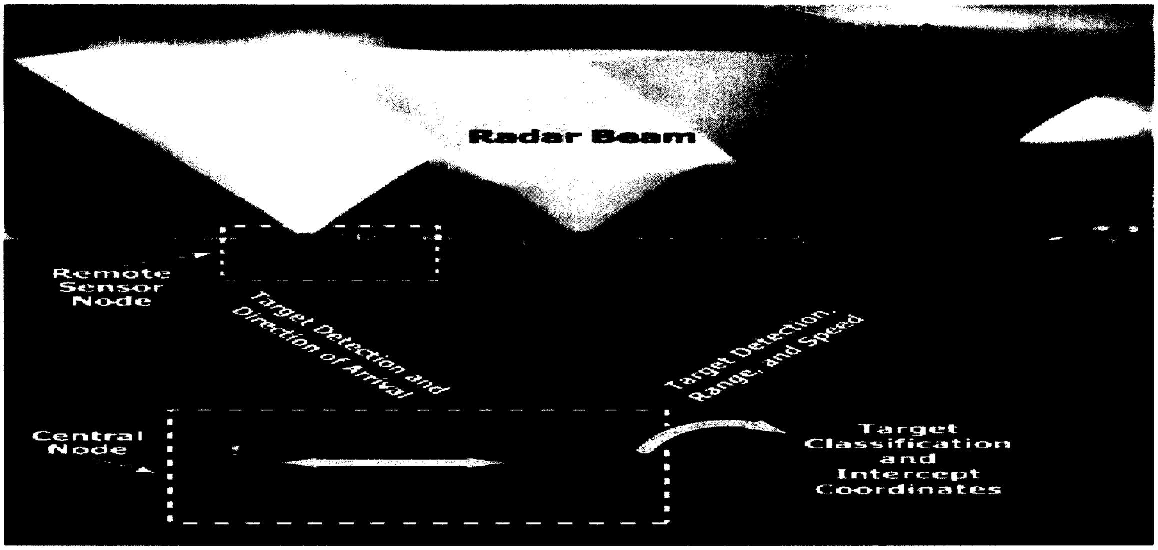


Figure 16. Implementation of hardware (acoustic sensor) for aircraft detection. (Image from MITRE Corporation Technical Briefs: http://www.mitre-corporation.com/news/events/tech06/briefings/1406.pdf

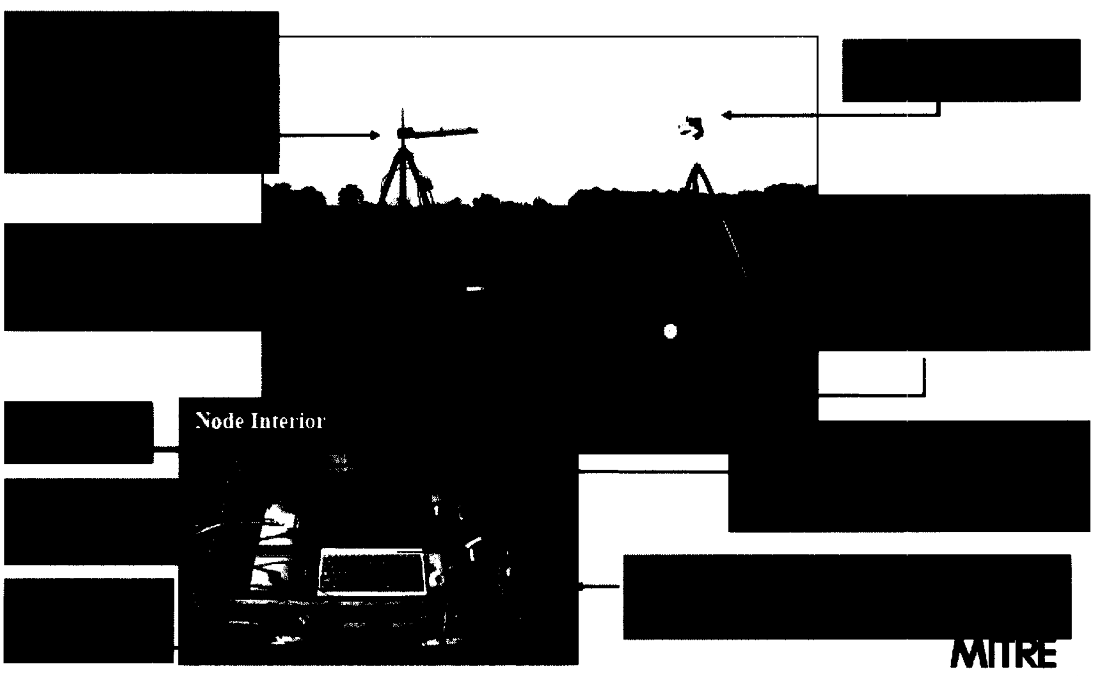


Figure 17. Graphical depiction of how RIMDAS could help prevent Scenario Three. The sensors lining the runway detect the presence and rate of the aircraft both on the runway and in the air(1). This information is forwarded to the server (2) where an algorithm detects the potential for a runway incursion. The server then wirelessly broadcasts a signal to each plane (3), providing notification to both parties that there is potential for a runway incursion.

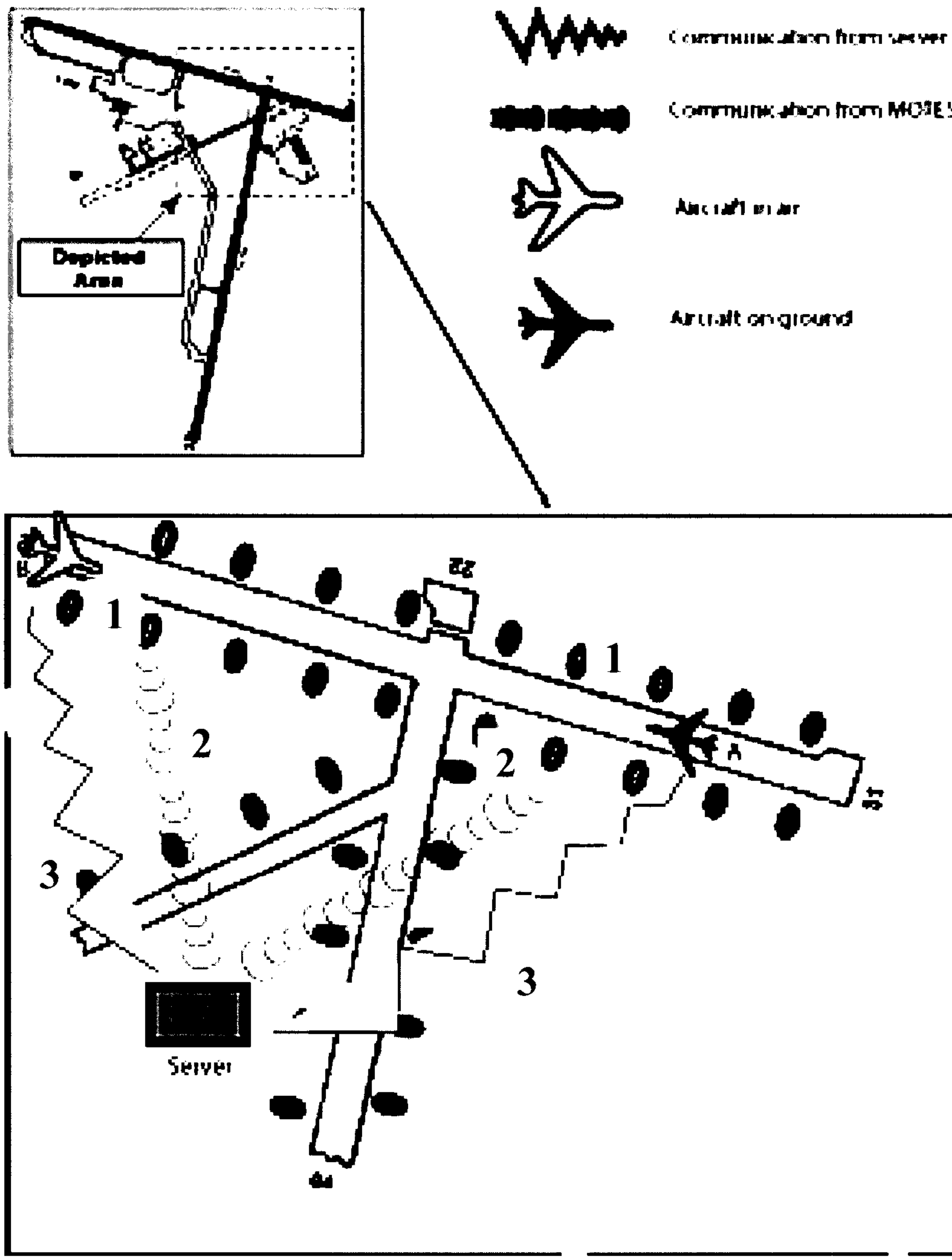


Figure 18. REEF Product Development Cycle (Image from Tromp, L.D & Jacyna, G: Netted Sensors Presentation http://www.ffrdc.com/news/events/tech04/briefings/1423.pdf)