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Redesigning Airport Diagrams with Principles of Cognitive Psychology

Jacob Miller
Embry-Riddle Aeronautical University - Daytona Beach

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REDESIGNING AIRPORT DIAGRAMS WITH PRINCIPLES OF COGNITIVE PSYCHOLOGY

by

Jacob Miller

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This thesis was prepared under the direction of the candidate's thesis committee chair, Elizabeth Blickensderfer, Ph.D., Department of Human Factors & Systems, and has been approved by the members of the thesis committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors & Systems.

THESIS COMMITTEE

Elizabeth Blickensderfer, Ph.D, Chair

Dr. Shawn Doherty, Ph.D., Member

Dr. James Pharmer, Ph.D, Member

MS HFS Program Coordinator

Department Chair, Department of Human Factors & Systems

Associate Vice President for Academics

Abstract

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The aviation community strives for air travel to be the safest form of transportation. The National Transportation Safety Board published a "Most Wanted" list to acknowledge the most threatening safety issues, and runway safety and runway incursions were at the top of their list. Furthermore, runway incursion statistics by the Federal Aviation Administration show that pilot deviations were the most common cause for runways incursions. Misunderstandings of airport diagrams may be one reason for pilot deviations. While navigating through airport taxiways, pilots refer to their airport diagrams as a map of the airport. Unfortunately, airport diagrams are not designed with the pilot in mind. This study attempted to redesign airport diagrams to incorporate principles of cognitive psychology. The redesigned airport diagrams included decreasing extra information, increasing overall size, and adding color. The study measured the participant's situational awareness and deviations throughout six simulated taxiing tasks. The results were not statistically significant. The results showed evidence of a ceiling effect which may indicate that the taxiing tasks were too easy to show performance differences. This research issue should not be abandoned. However, future studies should include increased workload within the experimental tasks to create a more realistic cockpit environment.

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Introduction

On July 11, 2007 at Ft. Lauderdale-Hollywood International Airport (FLL), two aircraft came within 100 feet of one another and were close to a disastrous accident. It was a nice day outside with 10 miles visibility and pilots were operating under visual flight rules (VFR). Delta Airlines (DAL) flight 1489 was inbound for landing on runway 9L. At the same time ground control instructed United Airlines (UAL) flight 1544 to taxi to runway 9L. Ground control told UAL1544 to take taxiways T7, D, and B. While traveling on taxiway D, UAL1544 did not turn on to taxiway B. Instead, it continued traveling directly towards runway 9L. The aircraft was traveling too fast and could not hold short of 9L. Ground control radioed UAL1544 to stop. The aircraft came to a halt 30 feet from the centerline of runway 9L. DAL1489 was cleared for landing on runway 9L. Local control (LC) instructed DAL1489 to go around. When UAL1544 finally stopped on 9L, it already had the main gear down and was ready to land. The crew of DAL1489 took to action immediately and flew by less than 100 feet over UAL1544. This was a serious runway incursion that put 307 passengers' lives at risk (National Transportation Safety Board, 2007).

Runway incursions may not make the network news and the odds of a passenger being involved getting hurt is very slim, but they are still a threat to aviation safety. Runway safety is number two on the National Transportation Safety Board's (NTSB) Most Wanted List. Additionally, NTSB concludes that response to runway safety is unacceptable (National Transportation Safety Board, 2009).

This project will examine a strategy to help avoid runway incursions, specifically redesigning airport diagrams to help alleviate pilot deviations during taxiing procedures. The newly designed airport diagrams will incorporate principles of cognitive psychology to better fit pilots' expectations. A review of relevant literature will be used to achieve a complete background of the project. This will include discussing runway incursions, pilot situation awareness, and principles of psychology used during navigational tasks. The results of this project may be used in future technologies (e.g. electronic flight bags).

Runway Incursions

The International Civil Aviation Organization (ICAO) (2007) defines runway incursions as any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the projected area of a surface designated for the landing and taking-off of aircraft. The Federal Aviation Administration (FAA) recently adopted the ICAO definition as well (Federal Aviation Administration, 2007). Four categories define the severity of a runway incursion. Category D, the least severe, is defined as little or no chance of collision, but still meets the basic ICAO definition of a runway incursion. Category C, the second least severe is the existence of decreased separation but ample time and distance to avoid a potential collision are also present. Category B, the second most severe, occurs when both a separation decrease and a significant potential for collision exists. Category A, the most severe occurs when decreased separation generates the necessity for participants to take extreme action to avoid a collision or the event did actually result in a collision (Federal Aviation Administration, 2008). The runway incursion on July 11, 2007 was categorized as Category A.

Three different types of runway incursions exist within the severity categories: pilot deviations, operational errors and deviations, and vehicle and pedestrian deviations. Pilot deviations include an action of a pilot that violates any Federal Aviation Regulations. The runway incursion illustrated at the beginning of this paper is an example of a pilot deviation. The crew did not follow the directions of the ground control and deviated from the route. In addition, operational errors and deviations are actions of an air traffic controller (ATC) that results in a loss of minimum separation between two or more aircraft, aircraft and other obstacles (e.g., vehicles, equipments, or personnel) or an aircraft landing or taking-off on a closed runway. Last, vehicle and pedestrian deviations occur when aircraft operations are interfered with by vehicles or pedestrians without authorization from ATC. It is important to note that any aircraft being pushed or towed for maintenance or gate re-positioning involved with a runway incursion would be considered a vehicle and pedestrian deviation (Federal Aviation Administration, 2008).

Runway incursion statistics. The FAA conducted a Runway Safety Report in 2008. It analyzed data gathered from fiscal year (FY) 2004 through FY 2007. During this time there were approximately 250 million operations and approximately 170,000 occurring daily. The analysis revealed that across the past four years, 5.5 runway incursions occurred per million operations or an average of one incursion every 183,621 operations. Total runway incursions in the FY 2007 were 370 and this was an increase from 330 incursions during FY 2006. Category D makes up 67% of all runway incursions. They occur about 3.6 times per million operations. Although, a decrease in serious runway incursions occurred in FY 2007, categories C and D actually increased. In the FY 2006, there were 24 category A runway incursions and in FY 2007 there were only 17 category A runway incursions, but this is still higher than FYs 2004 and 2005. Pilot deviations are the number one type of incursion, with occurrences about 3 times per million operations, and totaling 55% of all runway incursions.

The FAA has invested millions of dollars in researching interventions to improve runway safety. For example, *Flight Plan* (Federal Aviation Administration, 2009) is a strategic plan that proposes research within many areas of aviation safety. One of six objectives within the Safety Management System portion of the "Flight Plan" is to reduce the risk of runway incursions. The

FAA's goal is to limit Category A and B runway incursions to a rate of no more than 0.45 per million operations by FY 2010 and all the way through FY 2013. Furthermore, another goal is to reduce runway incursions an additional 10% from the FY 2008 baseline. The *Flight Plan* describes several planned initiatives to accomplish this goal. These include the evaluation of Electronic Flight Bags, moving map displays and aural alerting cockpit technology for the purpose of reducing runway incursions (Federal Aviation Administration, 2009). In addition to the FAA goals, the international aviation community also has to identify potential new technologies that may reduce the possibility of a runway incursion (International Civil Aviation Organization, 2007).

Contributing factors. Many different contributing factors to runway incursions exist. Analyzing and understanding the root cause for runway incursions can guide future research projects to discover new ways to improve safety. The FAA created a Runway Safety Council and Working Group to conduct a root cause analysis. They have found contributing factors to be confusing runway and taxiway patterns, airport layouts, ambiguous pilot-controller communication, and pilot awareness and attention (Federal Aviation Administration, 2008). While all of these factors are important, the focus of the current study is on airport layouts and runway and taxi patterns.

One of aviation's attractive aspects is the ability to travel around the world. This gives pilots and passengers the opportunity to see the world and experience the different cultures. In traveling the world, however, pilots will encounter new airports with a variety of runway layouts and varying degrees of complexity. Large airports, such as Boston-Logan International Airport (BOS), require many runways to handle the amount of traffic that comes in and out of the airport. BOS has twelve runways, 15R and 33L, 15L and 33R, 14 and 32, 4L and 22R, 4R and

22L, and 9 and 27. Additionally, there are 19 different taxiways (A, B, C, D, E, F, G, H, J, K, L, M, N, P, Q, R, X, Y, and Z). With this many runways, it is no surprise that the Runway Safety Council and Working Group lists confusing runways and taxi patterns as a top factor in runway incursions.

One reason that confusing runways and taxi patterns are problematic is that their complexity adds to pilot workload. The amount of workload in the cockpit is a contributing factor to pilot deviations, and pilot deviations make up the majority of runway incursion that occurs. Thus, a discussion of workload is warranted.

Workload

Pilots and ATC experience different levels of workload while performing their jobs. Workload, defined by Bowers, Braun, and Morgan (1997) is "the realization that task performance is a function of the cognitive resources dedicated to accomplishing a task" (p. 87). High workload demands more attention and cognitive resources of ATC and pilots than do low workload tasks. If a pilot encounters a situation with too much workload or too little workload, errors are likely. For example, a pilot in a situation with high workload will have less attentional resources for other tasks then a pilot in a low workload situation. This sets the pilot up for error because not enough attention resources are focused on all tasks and important information may not be acquired or may be forgotten or overlooked. Additionally, in the event of a limited amount of workload, complacency can occur. This means that pilots may not pay enough attention to their instruments, radios, or location on the airport taxiways to keep an accurate situational awareness and this would consequently allow pilots to commit errors. Research indicates that pilots need a steady amount of moderate workload in order to remain vigilant and not overloaded (Kantowitz & Campbell, 1996).

The aviation industry has developed several strategies to counteract the effects of high or low workload situations. The strategy for larger and complex aircraft is to use a flight crew rather than a single pilot. In periods of high workload, this allows tasks to be evenly distributed across the crew members. The crew works together to make sure they operate the aircraft successfully and safely, although communication between the flight crew members becomes very important. Automation is another strategy to reduce workload. Automation is the capability of a system within the cockpit to perform a function normally done by pilots. Technology such as "autopilot" can take over tasks to maintain a certain altitudes or headings to relieve the flight crew and allow them to perform other tasks (e.g., attend to the radio, run checklists, or check instruments) (Prichett, 2009).

Landing and taking-off sequences are some of the busiest times in the cockpit. Pilots must use all of their attentional resources to accomplish these tasks effectively. Chou, Madhavan, and Funk (1996) describe multi-tasking in the cockpit as Cockpit Task Management (CTM). Chou et al. (1996) define CTM as "the management level activity pilots perform as they initiate, monitor, prioritize, and terminate cockpit tasks" (p. 307). During landing and taking off sequences, pilots are performing concurrent tasks, such as completing checklists and communicating with ATC at the same time. Additionally, pilots usually have a limited amount of time to complete the tasks. This can put more pressure on pilots and give more opportunity for error. A significant concern for errors arises during these times of multi-tasking. The flight crew uses several strategies to balance this time of high workload. First, scripted flow checklists are used in the cockpit. This means that every time a crew is running pre-flight checklists or preparing for landing they are using the same checklists they have used many times before. Checklists help protect pilots from forgetting a step and missing an important step in procedures.

The majority of the pre-flight checklists are completed while taxiing. This means the crew must perform the checklist and continue to navigate through potentially complicated taxiways (Loukopoulos, Dismukes, & Barshi, 2003). One issue that can occur during heavy workload is loss of situation awareness.

Situational Awareness

Pilots must maintain situational awareness (SA) during all phases of flight. Endsley (1995) defines SA as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (p. 5). Furthermore, Endsley describes three hierarchal phases, or "levels" of SA. Level one is perception of the elements. This means a pilot will be gathering information from their cockpit, radio, and environment outside. Level two of SA is comprehension of the current situation. During this level, pilots will interpret all of the information from level one and establish the current status of the environment. Level three of SA is the projection of future status. Pilots will use their current interpretation of their environment and create a near future prediction (Endsley, 1995). Thus, to achieve SA, pilots must gather and interpret the information of their environment and then predict the near future.

SA in taxi phase of flight. One phase of flight is the taxi phase, and pilots must achieve and maintain SA during this phase to accurately navigate an airport. Amar, Hansman, Hannon, Vanheck, and Cauldhry (1994) defined airport situational awareness as, "a flight crew's awareness of their location with respect to airport surface features such as runways and taxiways" (p. 2). To achieve this SA, pilots use visual cues from the cockpit windows, talking to ATC, and consulting maps. Unfortunately, for pilots to rely on the view out of the cockpit there must be good visibility. Additionally, pilots can ask ATC for feedback to help establish an understanding of where the aircraft is on the runway, but this can difficult also. That is, navigating an aircraft in the air or on the ground requires proper communication of information between ATC and pilots and is vital to avoid critical mistakes. Communication between ATC and pilots is necessary to change altitude, heading, airspeed, altimeter settings, traffic avoidance, and overall situation awareness. Not only do pilots rely on ATC to guide them through sky highways, but they also rely on ATC to act as traffic coordinators while the aircraft is on the ground taxiing on the ramp or runway (European Organization for the Safety of Air Navigation, 2004). Pilots currently rely on paper airport diagrams or "charts" and their view out of the cockpit to navigate taxiways. Again, however, ATC can only help so much during poor visibility conditions.

Maps

All pilots use charts to taxi, take-off, and to land. The charts give pilots important information about the airport. For example, the pilots gather radio frequencies to specific control towers or runway widths and lengths by consulting the airport diagram. Currently, pilots primarily use Jeppesen charts, but some pilots use FAA charts. Jeppesen charts cost money, while FAA charts are offered free on their website. Military pilots are they only exception, as they use military charts. At Embry-Riddle Aeronautical University, students are taught to fly using FAA charts. Charts are usually provided by a pilot's employer, but a recreational pilot will have to purchase Jeppesen charts if that is what they prefer. Jeppesen charts can retail for several hundred dollars depending on how many are purchased. No matter what the preference, a pilot does not leave home without their charts. Pilots, especially corporate and commercial pilots can collect hundreds of charts; this is why electronic flight bags have become so popular.

Pilots carry a flight bag with them, inside are all their supplemental flight material (e.g., charts, checklists, etc.) (M. A. Miller, personal communication, September 12, 2009). Recently, people are discussing the concept of an "electronic flight bag" (EFB). The EFB is a tablet computer that contains all the flight material a pilot would need. The EFB has revolutionary implications and would allow pilots to not worry about lugging around a bag. Not only will this include all the information a pilot would need it could also change the presentation of the information (CaHill & McDonald, 2006). This electronic presentation could include more effective ways at presenting airport diagrams. The next section of this paper will discuss maps and how to design effective maps based on principles of cognitive psychology.

Research on maps. Robert Lloyd (1993) defines maps as "two-dimensional or three dimensional spatial structures that represent some part of the environment and communicate information about the environment" (p. 84). The airport diagrams used today are two-dimensional spatial structures that represent the airport layouts of taxiways and runways and communicate important information to pilots require to regarding airport navigation. The most basic form of map research design is the cartographic communication model. The model describes maps as channels that transmit information from a source to a map reader (Montello, 2002). The model involves four steps in developing a successful map; the real world, cartographer's conception, the map, and map user's conception. The real world is the environment the cartographer is trying to portray. In aviation, the "real world" would be any airport and its layout. The cartographer's conception is how the cartographer interprets the airport. The map is the cartographer's conception of the airport on a two-dimensional spatial structure. Finally, the map user's conception is how a map user understands the map. The goal of the cartographer's is to create their conception of the real world in the map user (Chrisman, 1987).

At this time, cartographic researchers do not fully understand every aspect of map reading. However, many aspects of map reading have been researched and several steps in the process have been identified. The first of these steps is symbol detection through search. Airport diagrams are covered in symbols (e.g., taxiway letters and numbers). Pilots must search the diagram to find their assigned navigational routes to their runways or terminals. The process pilots use to find taxiway letters or runway number is called visual search. Airport diagrams contain a lot of information, and pilots are constantly using their visual search abilities. For example, when a pilot is given their taxi route the pilot must visually search the map for each corresponding taxiway. This task can exhaust attentional resources, unless proper principles of cognitive psychology are applied to the map design. The performance of pilots may be improved by implementing visual search principles, as this will create a stronger understanding of the diagram to the pilot (Nelson, 1994).

Currently, airport diagrams are cluttered and involve information for three phases of flight; taxiing, take-off, and landing. The diagrams do not use different colors, size, and shape to improve visual search. Airport diagrams must include considerable information as the same diagram is used at several different phases of flight. This mass of information can be confusing and complicated for pilots to intercept. Fortunately, research exists in the cognitive literature that has generated principles applicable to map design. This will be described next.

Feature Integration Theory of Attention

The "feature integration theory" of attention is a well known theory of visual perception. Treisman and Gelade (1980) discussed feature integration theory and several experiments that supported the theory. Briefly, the feature integration theory describes how the human visual system integrates different features from visual a stimulus to develop an understanding of our visual world. This occurs in two stages. The first stage is processed in preattention. That is, in the beginning, the human visual system identifies several separable dimensions such as, color, brightness, spatial frequency or directions of motion. Dimensions are broken down into specific values, called "features", such as blue or any physical orientation. The separable features are coded independently and in parallel. The features from each dimension are used to create "feature maps". These feature maps are used to code locations of features compared to other nearby features. Additionally, features are grouped and segregated into clusters. The second stage of visual processing integrates the features and dimensions together to develop a perceptual understanding of the world. Feature clusters are integrated together to form conjunctions of features or "perceptual conjunctions" (Quinlan & Humphreys, 1987).

Attention is required to correctly interpret the perceptual conjunctions. Since attention is a limited resource however, humans also rely considerably on an automatic "top-down" processing. Top-down processing occurs when a human understand an overall picture before seeing the details. For example, when a human uses automatic top-down processing to identify a target (e.g., an airplane), he/she will see the target as a whole, before seeing the individual features (e.g., features that distinguish the airplane as a Boeing 747). If prior experiences exist for a specific conjunction of features it does not require focused attention. A good example of this, is perceiving the sky is blue and sun is yellow. Attentional resources are not used to perceive these features; instead we rely on past experiences (Treisman & Gelade, 1980).

Since all airports are unique, pilots will not be able to rely on past experiences of airports in general to find their way around an unfamiliar airport. Thus top down processing cannot be used in any situation where the pilot is unfamiliar with an airport, and pilots will need focused attention. This requires attentional resources and, depending on the workload in the cockpit, pilots may not have enough available attentional resources to correctly perceive the airport diagram. Some principles of visual search exist in the research literature. If applied to airport diagram design, these principles of visual search may improve airport diagrams by making them easier for humans to process and thus helping to ensure that pilots accurately perceive the information diagram.

Principles of visual search. Targets in a visual search task can be defined by a single feature (e.g, the color blue), multiple features (e.g., blue triangles among green circles distractors), or a conjunction feature (e.g, blue triangles among green triangles distractors). Treisman & Gelade (1980) experimented with visual search paradigms of feature integration theory of attention. In their research, they tested reaction time in visual search. They found that searching for conjunction features became more difficult when more than one conjunction stimuli is added as a distractor. The search process is slowed down because it is no longer parallel, it became a serial search. This means that every stimulus is scanned until the target is found. The reaction time had a positive linear relationship with more distractor stimuli present.

Lloyd (1997) researched visual search processes further and analyzed the three types of features. The participant had to search for a feature and answer as quickly and accurately as possible, as to whether the target was present or not. Single feature search tasks required participants to search for a target defined by color, shape, size, or orientation (e.g., look for the "blue" target or look for the "Δ"). The results showed that during a single feature search participants averaged 600 to 800 milliseconds to find a specific target and to decide if it was present or not. Additionally, the results also showed that the amount of distractors did not significantly effect reaction across trials with 6, 16, 26, 36, and 46 distractors. Multiple feature search task required participants to search for a target defined by two more features, but the distractors also differed by two or more factors (e.g., a blue triangle target among green squares distractors). The results indicated that the participants' reaction time of finding a target, if it were present, was slightly less than 600 milliseconds. The average reaction time of the participants to find that a target was not present was slightly higher than 600 milliseconds. Finally, the third task found reaction times dependent upon the features of the conjunction. Here, the author also found several differences in reaction times and accuracy. For example, searching for conjunction targets with color and shape (e.g., purple circle) was the most efficient. Additionally, Lloyd found there was a positive relationship between distractors and reaction time and distractors and inaccuracy. In other words, the more distractors within the search, the participant will have a slower reaction time.

Lloyd's research is important because it shows that how a target is defined can negatively and positively effect performance in different ways. Manipulating the features of a target can cause for slower or faster reactions times. Furthermore, accuracy can be influenced as well with particular conjunction combinations. Any extra information on an airport diagram that is not need can be considered a distractor. Eliminating unnecessary information may lead to higher chances for accuracy in a pilot's perception of the airport. In terms of runway incursions it may be important for airport diagrams used for taxiing to include only the information for the taxi phase of flight.

In terms of runway incursions, while reaction times for processing the information are important, even more important is the accuracy of the perceived information. If a pilot misperceives a taxiway or taxiway for another, it may cause a deviation and create a dangerous situation. For example if the pilot of UAL1544, in the situation discussed earlier had perceived the information on his airport diagram correctly, then he may not have rolled onto runway 9L. Hence, it is important to consider the features of targets and build the most efficient conjunctions, so that pilots can perceive the correct information and refrain from deviations.

Color in visual search. Research has shown that participants pick out symbols defined by color faster than any other characteristics. Processing speed varies by color. For example, red is processed faster than blue is. Color can also mitigate search time when there are copious amounts of distractor targets (Smith, Dunn, Kirsner, & Randell, 1995). Colors can be used on maps to help readers easily find information. Color can clarify information and can also define boundaries of targets. For example, a map of Europe may have one country in one color and neighboring countries in other colors. The contrasting colors help readers to distinguish the boundaries of the countries.

Additionally, color can be the single feature of a target on a map. For example, if a participant is searching for a red circle amongst distractors that are green circles, then the color red is a single feature. The red circle target in the task will create a "pop-out" effect, as the red circle seems to jump out at the participant. Using the pop out effect is a goal of cartographers. They can use colors, text, or any type of feature to create the effect (Brennan & Lloyd, 1993).

Parallel processing enables a reader to process all the elements of a map at the same time, basically the human assesses all the features simultaneously. The information processing is an automatic process and requires little attention, although if targets become more complicated more focused attention may be required. For example, targets with several features also share factors with distractors (e.g., a green triangle with a purple border amongst distractors with green triangles with black borders), this will require more focused attention because there are multiple features a human will have to search and process. It will be more difficult to find the target and require more attention.

Generally, airport diagrams and several other charts used in aviation do not use any color. One exception is the Molesworth and Wiggins (2004) study that redesigned en-route aeronautical charts and incorporated color. They used color to identify specific features on the chart and found that red, blue, and yellow provided the greatest degree of discrimination. Color also was used successfully to help define airspace boundaries. They found that two boundaries defined by a solid light blue diamond and solid blue disk had the highest performance rate. The participants that were in this condition committed the least amount of errors. Molesworth & Wiggins study showed that color can be used on aeronautical charts and that it can be successful.

The use of color can be task specific, however, in a study with multiple experiments, Smith et al.(1995) found that memory of previous target configurations is impaired when both color and shape are used. This means that a map reader is more likely to remember target configurations if shape is the only defining characteristic. That is, although reaction time of the visual search process decreases with color, the presence of color may actually decrease the memory retention.

Additionally, Smith et al. (1995) researched the effect of color on participant performance. They found that when a target was not completely whole, (e.g., if the target is half a circle or square), color actually decreased the accuracy of the participants' detection. In groups with color turned off, participants were more accurate in selecting the proper target, than when color was used.

Thus, it is important to include color for the right reasons. Color should not be used if improved memory retention is desired. Additionally, it should not be used if targets are not whole. Color should be used to harness the parallel processing in visual search to create the fastest pop out effect. Thus, color seems to have the potential to improve airport diagrams. It is the most efficient feature in the Feature Integration Theory of Attention. Yellow, Blue, and Red are the best color combination to use according to Molesworth and Wiggins (2004).

Size in visual search. Targets or symbol size is another issue in visual search. A study by Quinlan and Humphreys (1987) compared different sizes of a target during visual search tasks. The experiment compared basic features of color, shape, and size. The shapes were the letters A, H, and C. The colors used were blue, green, and orange. The experiment was conducted on a computer monitor, so the size was defined by a matrix of pixels: small (12pt font), medium (0.6 cm wide x 1.2 cm high), and large (1 cm wide x 2.2 cm high). Performance was measured by reaction time and accuracy of a search. The authors found that using size as a single feature can be efficient and create quicker and more accurate search times, but size was not as efficient as color. However, a combination of size and color showed to be more efficient when compared to combinations of shape and color and shape and size. The reaction times in visual search tasks with conjunctions of size and color were not affected by number of distractors in a set. This means that as the number of distractors increased, the reaction time to find the target did not increase as well.

The study by Quinlan and Humphreys shows that size can positively affect visual search process. This may help redesign airport diagrams in several ways, target or symbol size can also be manipulated on an airport diagram. First, this study showed that size as a single feature is efficient. Thus, increasing the size of the airport diagram may increase efficiency. Additionally, Quinlan and Humphreys' study showed the combination of color and size is efficient, therefore, it maybe useful to indicate color on the enlarged runways. The increase of the runway size and the use of colors may help maximize efficiency.

Shapes in visual search. Target shape in also important to consider for visual search tasks. While color is the most efficient feature for visual search tasks, it is limited to the eight basic colors of the rainbow. Shape, on the other hand, may be limited only by our imagination. Shapes in visual search have been criticized in the research and often described as not a key feature. For example, the most popular theory of visual search, Treisman's Feature Integration Theory, argued that shapes cannot be perceived in the preattentive stage (Treisman & Souther, 1985). Therefore, shape is not considered a feature. However, shapes create a lot more possibilities for cartographers, so it is important to discuss the use of shapes.

An experiment by Michaelidou, Filippakopoulou, Nakos, and Petropoulou (2003) found that manipulating shapes can make them more efficient during visual search tasks. The authors created several different target symbols and tested the reaction time of participants. As shown in figure 1, targets consisted of six abstract symbols and eight pictorial symbols.

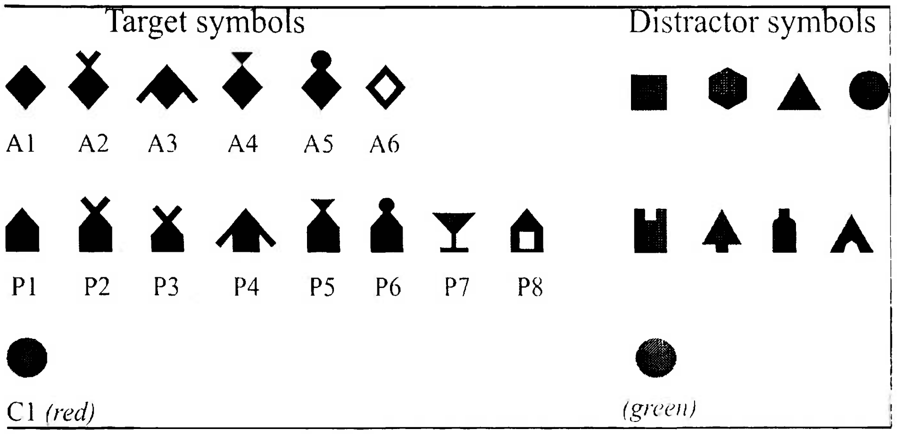

Figure 1. The abstract symbols are labeled A1 through A6 and the pictorial symbols are labeled P1 through P8.

The results indicated that the features that make the symbol more unique decreased the participants' reaction times. For abstract targets, target A1 was shown to be the most *inefficient.* Target A6 was found to be the most *efficient* target of all abstract symbols. The results of the pictorial symbols revealed similar results. Target P8 was found to be significantly more efficient then any other pictorial symbol. The second most efficient targets found were any targets with a unique feature on top of the target, such as A2 or P2. The hole in both targets A1 and P8 provided the most unique feature, which decreased the similarity between the target and distractor. Therefore, the searches were significantly quicker and more efficient.

Unfortunately, the symbols on airport diagrams cannot be changed because they must coordinate with markings on the taxiways themselves. It is not until symbols used on taxiways are change, that they can also be changed on the airport diagram. That has potential for a future research project. However, the Michaelidou et al. study still has important implications to redesigning an airport diagram because the most inefficient targets were the ones that looked most like the distractors. Airport diagrams use number and letters for symbols to identify taxiways and runways. Additionally, airport diagrams incorporate a lot of information not needed for taxiing phase of flight. This creates a large amount of distractor symbols that are very similar to one another. Michaelidou et al. found that symbols that were similar to the distractors were inefficient because participants relied on serial search. They were focusing on every target, one by one, until they found the target they were looking for. This increases reaction time and creates a high chance of selecting the wrong target if more and more distractors are added. It is important to use this information on the redesigned airport diagram.

Purpose of the Study

Runway incursions are a serious threat to the safety of the aviation world. Pilot deviations are the most common reason for runway incursions. Pilots face high workload during the taxiing phase of flight, and high workload can negatively affect a pilot's performance which will increase the chances for pilot deviations. Airport diagrams may not help make the pilot's job any easier during these times of high workload, as the diagrams are typically small and cluttered with information. However, airport diagrams may help pilots if they are correctly redesigned using principles of cognitive psychology. Specifically, the removal of unnecessary information, increasing the airport diagram size, and using color should improve pilot performance.

The purpose of this study is to examine pilot SA and performance (deviations) using two redesigned airport diagrams. After reviewing the literature, two cognitive psychology principles will be used to redesign an airport diagram for the taxiing phase of flight. The first issue is the size and the amount of distractors on the airport diagram. This is a combined issue as the size and numbers of distractors are interrelated. That is, the size of the airport diagram cannot be increased unless the number of distractors is decreased. The second issue is the color of the runways.

The study is a between groups experimental design (Refer to Table 1). The three types of airport diagrams are the FAA original, "half" redesign, and "full" redesign. Pilot performance and S.A. during taxiing scenarios will be assessed.

Table 1

Experiment Conditions

FAA Original Airport Diagram
Half Redesign Airport Diagram
Fully Redesigned Airport Diagrams

Hypotheses. It is expected, that increasing the size and decreasing distractors will improve pilot performance, pilot situational awareness, and decrease the perceived workload of the pilots compared to that of pilots using the original FAA charts. It is expected that adding color to the airport diagram in addition to a larger size and a smaller number of distractors will enable pilots to have the overall best performance. This means the fully redesigned airport diagram will be most effective. The following hypotheses are proposed:

H1a: *Pilots using the airport diagrams with increased size and decreased clutter will have fewer deviations than those pilots using the original FAA airport diagrams.*

H1b: *Pilots using the airport diagrams with increased size, decreased clutter, and color coded runways will have fewer deviations than those pilots using the original FAA airport diagrams.*

H1c: *Pilots using the airport diagrams with increased size, decreased clutter, and color coded runways will have fewer deviations than those pilots using the airport diagrams with increased size and decreased clutter.*

H2a: *Pilots using the airport diagrams with increased size and decreased clutter will exhibit higher SA scores then the pilots using the original FAA airport diagrams.*

H2b: *Pilots using the airport diagrams with increased size, decreased clutter, and color coded runways will exhibit higher SA scores then the pilots using the original FAA airport diagrams.*

H2c: *Pilots using the airport diagrams with increased size, decreased clutter, and color coded runways will exhibit higher SA scores then the pilots using the airport diagrams with increased size and decreased clutter.*

H3a: *Pilots using the airport diagrams with increased size and decreased clutter will exhibit lower workload then the pilots using the original FAA airport diagrams.*

H3b: *Pilots using the airport diagrams with increased size, decreased clutter, and color coded runways will exhibit lower workload than pilots using the original FAA airport diagrams.*

H3c: *Pilots using the airport diagrams with increased size, decreased clutter, and color coded runways will exhibit lower workload than pilots using the airport diagrams with increased size and decreased clutter.*

Method

Participants

A total of forty-five participants (42 males and 3 females) completed the study. Forty-one participants were students at a southeastern university and the four other participants were recent graduates. The ages ranged from 18 to 29 and the average age was 20.64 years (*SD* = 2.63). The average flight hours were 178.89 and they ranged from 15 hours to 1,330 (*SD* = 278.52).

Apparatus

This experiment used Microsoft Flight Simulator ™ with a standard 19" LCD screen. The participants controlled the aircraft with a yoke and throttle controls.

Materials

Airport diagrams. This study included two redesigned airport diagrams of Newark International Airport (EWR). The control airport diagram was the FAA airport diagram that is available for free online (Refer to Appendix A). The first experimental condition used an airport diagram of EWR in which distracting information was reduced and the size of the airport diagram was increased (Refer to Appendix B). The diagram in the second experimental condition was the same as condition one, with the addition of colored runways (Refer to appendix C). Thus, the diagram for experimental condition two had reduced distracting information, increased size, and colored runways. Color was only used on the runway and runway symbols to emphasize the importance of correctly using the assigned runway. The current airport diagrams used are on regular 8.5" x 11" paper. If the number of distractors was not decreased and the size was increased, then the size of the paper would be larger than the normal 8.5" x 11". It was not feasible for pilots to use an airport diagram on a larger piece of paper because the cockpit has a limited space.

EWR has three runways; Runway 11 & 29, Runway 22R & 4L, and Runway 22L & 4R. The colors used were yellow, blue, and red on the three runways at Newark Airport. The color red is the most efficient according to Smith et al. (1995), therefore it was assigned to Runway 11 & 29. Runway 11 & 29 crosses the other two runways, so there was more of an opportunity to cause a runway incursion. Runway 22L & 4R and 22R & 4L was assigned blue and yellow. Additionally, these colors were also used on the symbols identifying the runways. The symbols were the same color as their corresponding runway.

Taxiing scenarios. Six taxing scenarios were used. In all conditions the participants performed the same six tasks. Each task began at different terminals or taxiways and all the routes are unique. For example, task one started at taxiway A and ended at runway 4R. The taxi route to runway 4R was via Alpha, November, Delta, Victor, cross Runway 4L/22R, and Alpha Alpha. Table 2 describes the starting gate, ending runway, and taxi route of all the tasks.

Table 2

ATC Scripts, Starting Positions, and Ending Runways for Scenarios One Through Six

Scenario	**Starting Position**	**Route Script**	**Runway**
#1	Taxiway A	Echo Romeo 123 travel to runway 4 Right via Alpha, November, Delta, Victor, clear to cross runway 4L/22R, Alpha Alpha	4R
#2	45	Echo Romeo 123 travel to runway 11 via Echo, Bravo, Sierra, clear to cross runway 11/29, Zulu.	11
#3	115	Echo Romeo 123 travel to runway 22 Left via Romeo-Kilo, Bravo, Uniform, Whiskey, Romeo, clear to cross runway 11/29, Zulu, clear to cross runway 4L/22R, Zulu-Bravo.	22L
#4	62	Echo Romeo 123 travel to runway 11 via Golf, Bravo, Romeo, Whiskey, Zulu.	11
#5	14	Echo Romeo 123 travel runway 4 Left via Romeo-Alpha, Alpha, Romeo-Bravo, Papa-Alpha, Papa-Delta.	4L
#6	99	Echo Romeo 123 travel to 22 Left via Romeo-Hotel, Bravo, Uniform, Yankee, clear to cross runway 22R/4L, Papa, clear to cross runway 11/29, Zulu-Bravo.	22L

The taxing scenarios one, two, and three are grouped into a practice group. Refer to appendix D through F to see the correct routes for each practice scenario and the designated probe areas. The taxing scenarios four, five, and six are grouped into a performance group. Refer to appendix G through I to see the correct routes for each scenario and the designated probe areas.

Measures

SA measure. The SA measure and deviation measure were recorded on the same worksheets (Refer to Appendix J through O). The measurement tool to assess the participants' airport situational awareness is based on the Situation Awareness Global Assessment Technique (SAGAT) developed by Endsley (2000). At designated intervals, the scenario was stopped and the participant was questioned about his/her current environment and future states. During the probe, the experimenter hit the "Esc" button on their keyboard and this caused every instrument or indicator about the current environment to no longer be visible or accessible to the participant. This allowed the experimenter to assess the SA at that given moment. The experimenter recorded the answers on the SA worksheets specifically made for all the taxiing scenarios.

SA score included the probe answers from the participants. The results of the SA measure were analyzed by summing up scores for each scenario probe. The probes for each scenario that were successfully completed were totaled and percentage of correct was calculated. Then the scenarios in each task group were combined to create an overall SA score for the practice scenarios and performance scenarios, although only performance scenarios were used in the analysis.

Deviation measure. Pilot deviations were assessed via trained observers with flight training experience. The observers watched the participants perform. The rating form included specific events throughout the task. The observers noted whether deviations occurred on each event. The deviation scores were totaled to create a score for each scenario. The deviation scores were then combined to create an overall score for practice and performance scores.

NASA TLX. The NASA TLX is a survey measurement created to reveal task load (Hart & Staveland, 1988). This measurement was administered after the second scenario in each task group. The participant rated the mental demand, physical demand, temporal demand, performance, effort, and frustration that occurred in the previous task (Refer to Appendix P). A workload composite score was created for practice and performance scenarios. The composite was calculated by coding each sliding scale into a numerical value depending upon which box the participant checked. Then the numerical values were summed up and divided by six (six sliding scales on the NASA TLX). The composite value was rounded to the nearest half a score. For example, if the composite score was 4.65, the score would be rounded down to 4.5. The regression weights, or paired comparison procedure of the NASA TLX was not included in this study. A review of workload measurement tools by Nygren (1991) discusses the NASA TLX and the weighting procedure. The review validates the NASA TLX with or without the paired comparison. The review cites an empirical study (Byers, Bittner, & Hill, 1989) that found the traditional NASA TLX procedure and the NASA TLX with equal weights was found to be perfectly correlated, with *rs* ranging from 0.96 to 0.98. This supports that the NASA TLX scores recorded in this study would likely be the same if the paired comparison was included in the procedure.

Demographics questionnaire. Participants completed a demographics questionnaire (Refer to Appendix Q). The questionnaire asked for their name, age, academic year, gender, and contact information. Additionally, it recorded the participants' pilot qualifications, such as total flight hours and all current ratings.

Familiarity questionnaire. The participants were asked to find five important landmarks (i.e., runways, control towers, and airport identifier) on a current FAA airport diagram and answer two survey questions to assess their experiences with FAA airport diagrams. This was to ensure all participants could effectively use FAA airport diagrams. Every participant answered the questionnaire successfully and showed enough expertise to complete the study.

Reaction & Eye Focus survey. After performing training and performance scenario the participants completed a reaction and eye focus survey (Refer to Appendix S). The scale used on the survey was one through seven, one defined as "Disagree very strongly" and seven defined as "Agree very strongly". The responses to the reaction were coded to create two composite scores; reaction and eye focus. The reaction survey was to capture what the participants thought about the airport diagram used during the experiment. Only responses to questions 2 and 10 were used for the eye focus score. The eye survey questions used the same rating scale in the reaction survey and asked questions to find out how often the participant looked at the airport diagram. All responses to negative questions were reverse coded. Two separate reliability analysis for the reaction survey and eye focus survey was completed. The reaction survey had a coefficient alpha 0.72 and the eye focus survey also had a coefficient alpha 0.72. The coefficient alphas were high enough to indicate moderate reliability.

Procedure

Before the experiment began, the participant completed an informed consent form (Refer to Appendix S) and filled out the background questionnaire. The participants were then handed the FAA airport diagram for Tampa International Airport. This was to be used during the familiarity questionnaire. The experimenters verbally administered the five questions on the questionnaire before the participants were allowed to answer the additional questions about FAA airport diagram experience. All of the participants passed the familiarity questionnaire. Next, the participants completed a five minute equipment training session after the questionnaire. The training session gave the participant the chance to interact with Microsoft Flight Simulator tm and the yoke. During the five minutes, the participant practiced freely taxiing around Daytona International Airport. The participant was not given any airport diagram. Additionally, participants were free to ask questions about the equipment they were using. This gave enough time for the participant to get acclimated to the simulation equipment.

Next, each participant was randomly assigned to one of three conditions; the current FAA airport diagram, half redesign (increased size and decreased clutter), or completely redesign (increased size, decreased clutter, and color on runways). The participant was also given the assigned airport diagram and a pad of paper to act as a knee pad. The participant was allowed to use the knee pad to write down ATC instructions. While the experimenter loaded the first scenario, the participant was allowed to familiarize themselves with the assigned airport diagram. The experimenter read the ATC script giving the assigned route to the ending runway. The participant was allowed to write down the ATC commands if they wished. The scenario began after the experimenter confirmed a correct read back from the participant.

Throughout the task the assigned map was in the participant's possession. The participant was instructed to use their airport diagram freely throughout all of the scenarios and there was plenty of room on the desk to put the airport diagram when the participant did not want to hold it. During each scenario they were probed five times with the S.A. measure. When a designated probe area was reached the experimenter turned the simulator screen off by pressing the "Esc" button on the keyboard. The participant was instructed to make eye contact with the experimenter immediately and to not look at the airport diagram. Then the participant was asked the S.A. question. The procedure for each scenario was the same. After the sixth scenario, each participant completed the reaction survey and was debriefed. The scenarios were completed in the same order for every participant.

Results

The data were analyzed using SPSS statistical software. The data was first analyzed for descriptive statistics and then a normality test, and next analyzed with a multivariate analysis of variance (MANOVA). Normality is an assumption of a MANOVA, so the data was tested for normality with a Kolmogorov-Smirnov (KS) test (Tabachnick & Fidell, 2001). The KS test found that practice deviations, $D(45) = 0.211$, $p < 0.00$, performance deviations, $D(45) = 0.358$, $p < 0.00$, reaction survey, $D(45) = 0.173$, $p < 0.019$, and eye focus survey, $D(45) = 0.173$, $p < 0.002$, were found significantly normal. However, the KS test found that practice SA, $D(45) = 0.123$, $p < 0.085$, performance SA, $D(45) = 0.124$, $p < 0.081$, practice workload, $D(45) = 0.128$, $p < 0.064$, and performance workload, $D(45) = 0.123$, $p < 0.085$, were not significantly normal. The S.A. measures and workload violate the assumption of the MANOVA because they are not normally distrusted. Tabachnick and Fidell (2001) suggest that if data are not normal it should be transformed to normality. However, they also warn that transforming non-normal data may limit the interpretability of results. Therefore, the analysis of the data will use a MANOVA and violate the assumption of normality.

Additionally, the skewness of the data was tested. The test revealed positive skewedness in the practice deviations (1.229) and performance deviations (1.226). The practice S.A. (-0.064) and performance (0.004) showed the lowest amount of skewedness. The workload measures were both skewed negatively (Practice, -0.165 and Performance, -0.351). The skewness test shows evidence of ceiling effects in deviation measures and workload measures.

A bivariate correlation was run to see if any dependent variables were significantly correlated with one another. Table 3 shows the intercorrelation matrix of the dependent variables. The matrix shows that the relationships between practice deviations and practice workload (0 433) and practice workload and performance workload (0 757) were both highly significant at a $p < 0\ 01$ level However, the performance deviations, performance SA, and performance workload measurements were not significantly correlated This means that each performance measure was independent from one another

Table 3

Intercorrelations Between Dependent Variables

Dependent Variables	Performance Deviations	Practice SA	Performance SA	Practice NASA TLX	Performance NASA TLX	Reaction Survey
Practice Deviations	362*	213	330*	433**	363*	041
Performance Deviations		277	166	357*	191	116
Practice SA			343*	161	- 187	035
Performance SA				- 080	132	- 009
Practice NASA TLX					757**	209
Performance NASA TLX						295*

* Correlation is significant at the 0 05 level (2-tailed)
** Correlation is significant at the 0 01 level (2-tailed)

Hypotheses 1 3

The first three hypotheses were tested with a between groups MANOVA The first hypothesis predicted that participants using the fully redesigned airport diagram would have fewer deviations then those in the half redesigned airport diagram and original FAA airport diagram Additionally, it predicted that the participants using the half redesigned airport diagram would have fewer deviations then participants using the original FAA airport diagram The means, standard deviations, and sample size are shown in Table 4 of the performance deviation measure The MANOVA overall F value indicated that no significant differences appeared, Wilk's Lambda, $F(6,80) = 0\ 502, p = 0\ 805$ Each follow up univariate F also indicated no significant difference between conditions. First, performance deviations were not significantly different between airport diagrams, $F(2,45) = 0.284, p = 0.754$. This means that hypothesis one was not supported.

Table 4

Mean Numbers of Performance Deviations

	Mean deviations	Standard deviation	Sample size
Original	.80	1.14	15
Half	.67	.72	15
Full	.53	.99	15

The second hypothesis predicted that participants using the fully redesigned airport diagram would have higher S.A. scores then participants using the half redesigned and original FAA airport diagrams. Additionally, the second hypothesis predicted that participants using the half redesigned airport diagrams would have higher S.A. scores then participants using the original FAA airport diagram. The means, standard deviations, and sample size of the performance S.A. scores are shown in Table 5. As reported above, the MANOVA overall F was not significant. The follow-up univariate F also indicated that S.A. scores were not significantly different between airport diagrams, $F(2,45) = 0.805, p = 0.454$. This means the second hypothesis was not supported.

Table 5

Mean Numbers of Performance Situational Awareness Scores

	Mean S.A.	Standard deviation	Sample size
Original	67.99	13.61	15
Half	74.21	17.24	15
Full	72.88	10.82	15

The third hypothesis predicted that the participants using the fully redesigned airport diagram would exhibit lower workload then participants using the half redesigned and original

FAA airport diagrams. Additionally, the hypothesis predicted that participants using the half redesigned airport diagram would exhibit lower workload then participants using the original FAA airport diagram. The means, standard deviations, and sample sizes of the performance NASA TLX workload scores are shown in Table 6. As mention previously, the overall MANOVA was not significant. The follow-up univariate F-test also found that workload scores were not significantly different between airport diagrams, $F(2,45) = .814, p = .450$. This means the third hypothesis was not supported.

Table 6

Mean Numbers of Performance NASA TLX Workload

	Mean workload	Standard deviation	Sample size
Original	4.26	1.48	15
Half	3.76	1.78	15
Full	3.35	1.54	15

Reactions and Eye Focus

The results of the reactions survey and eye focus survey were not hypothesized. The mean, standard deviations, and sample sizes of the reaction survey are shown in Table 7 and the mean, standard deviations, and sample sizes of the eye focus survey are shown in Table 8. The MANOVA overall F found no significant difference, Wilk's Lambda, $F(4,82) = 1.092, p = 0.366$. The follow-up univariate F test also found that the reaction survey, $F(2,45) = 1.348, p = 0.271$, and eye focus survey, $F(2,45) = 1.188, p = 0.271$, were not significantly different between airport diagram conditions.

Table 7

Mean Numbers of Composite Reaction Survey Scores

	Mean reaction score	Standard deviation	Sample size
Original	4.37	.542	15
Half	4.51	.888	15
Full	4.84	.918	15

Table 8

Mean Numbers of Composite Eye Focus Survey Scores

	Mean eye focus score	Standard deviation	Sample size
Original	5.73	.942	15
Half	5.73	1.34	15
Full	5.20	.941	15

Additional Analysis

Additional analyses were run to examine whether scenario and condition had a combined effect on deviations and S.A. (i.e., to see if deviations significantly decreased over the course of the practice and performance scenarios). Two separate two-way mixed (between and within) ANOVAs were run.

Beginning with performance deviations, the average deviations by conditions across the scenarios are displayed in Figure 2. The participants using the original FAA airport diagram averaged the most deviations during task three, task four, and task five. The participants using the fully redesigned airport diagrams had the lowest or shared the lowest average deviations in every task, except the second practice task. The ANOVA (using Wilk's Lambda) indicated that deviations were significant for scenario, $F(5,38) = 7.924, p < 0.01$. The ANOVA indicated that between subject effects (Airport Diagrams) was found to be insignificant, $F(2,42) = 0.594, p =$

0.557 and the interaction between scenario and condition was insignificant, *F*(10,76) = 0.722; *p* = 0.701.

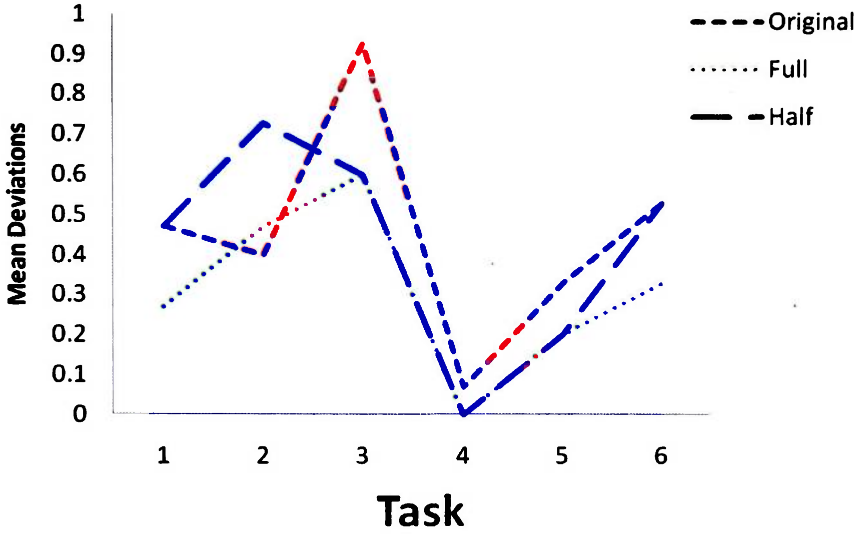

Figure 2. Mean deviations of practice and performance scenarios.

Next a similar ANOVA was used to examine S.A. scores across scenarios. In Figure 3, the means of the S.A. score across scenario by condition are shown. The S.A. scores of the participants using the original airport diagram were consistently the lowest across all tasks. The participants using half redesigned airport diagram showed the highest S.A. scores in all the tasks, except task one and six. The mixed ANOVA found that S.A. scores did differ significantly on the scenarios, *F*(5,38) = 31.786, $p < 0.01$. The between subject effects (Airport Diagrams) was found insignificant, *F*(2,42) = 2.708, $p < 0.078$. However, the interaction between scenario and condition was not significant, *F*(10,76) = 0.379, $p = 0.952$.

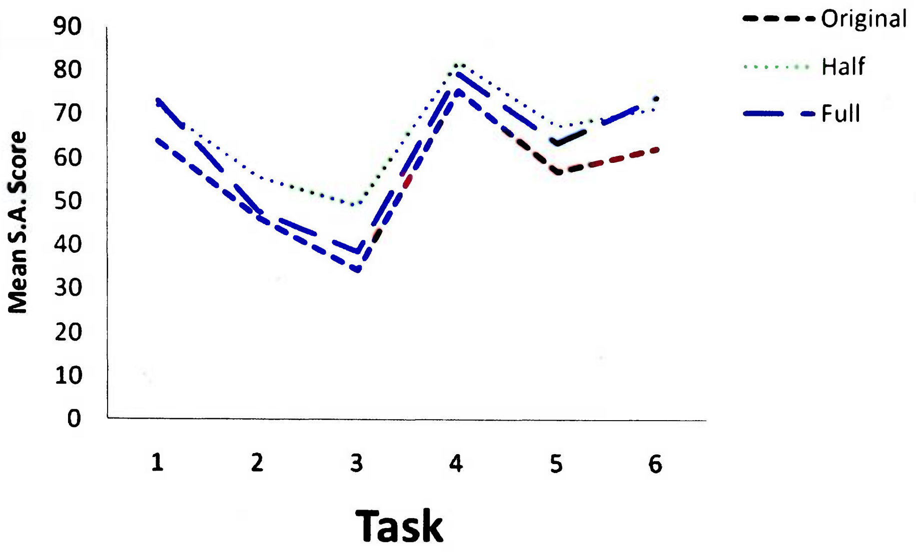

Figure 3. Mean S.A. scores of practice and performance scenarios.

It may be possible that several S.A. probe questions did not accurately measure the participants S.A. Therefore, the S.A. probes in the performance scenarios have been re-analyzed. The performance scenarios contained a total of fifteen S.A. probes across the experiment. The S.A. probes that were deemed inaccurate measures of S.A. were removed from the performance score. Five S.A. questions were removed and ten questions were used to create a percentage score for performance S.A. Table 9 shows the S.A. probes that were included and the S.A. probes removed. The new percentage scores were analysed with a one-way ANOVA

Table 9

Revised S.A. Probe Questions

Included in Percentage Score	*Removed from Percentage Score*
What taxiway are you on? Identify the fork in the taxiway What is your heading? What is next? (Asked a total of three times) What was the last taxiway you crossed? What taxiways are intersecting at your position? What is the next taxiway you will cross? What taxiway are you on?	What is the closest parallel runway? What is the closest terminal? Identify all the runways What was you beginning position? Identify the runways you crossed

to discover if the inaccurate S.A. probes were hiding a significant S.A. difference between airport diagrams. The results revealed an insignificant difference for the new S.A. scores between the airport diagram conditions, $F(2,44) = 0.04, p = 0.96$. Table 10 shows the means, standard deviations, and sample size across the airport diagrams for the new S.A. scores. The mean scores for the half and full airport diagrams are relatively similar to the scores in the original analysis (all 15 probes). However, the new mean S.A. scores for the original airport diagram increased approximately 5 percentage points from 68% to 73%.

Table 10

Mean Number for the New S.A. Score

	Mean new S.A. score	Standard deviation	Sample size
Original	73.33	12.91	15
Half	73.33	19.88	15
Full	74.66	11.87	15

Power Analysis

A *post-hoc* power analysis was completed to make sure the insignificant results were not highly susceptible to a Type II error. This study had forty-five participants, a significance criterion of 0.05, and an assumed medium effect size (0.30). The *post-hoc* power analysis discovered the power to be 95%. This means that the insignificant results only have a 5% chance of being caused by chance. The power of this study achieved the minimum requirement described by Cohen (1992) as a minimum of 80% power. The statistical power was calculated by a free online statistical power calculator.

Discussion

In the aviation industry, safety is a top priority. Currently, the safety of aviation is being threatened by runway incursions. The NTSB has put runway incursions on their "most wanted" and reported that current steps to decrease runway incursions are not satisfactory. An investigative study completed by the FAA analyzing runway incursion statistics during FY 2004 through 2007 found that pilot deviations are responsible for over half of runway incursions. Pilots are performing several concurrent tasks while taxiing to and from the airport. For example, a pilot may be communicating with ATC, running checklists, and referencing their airport diagrams all at the same time. This can overload the pilot easily.

The airport diagrams include large amounts of information for taxiing, taking off, and landing phases of flight. Additionally, the diagrams are small and include no color. The purpose of this study was to introduce a redesigned airport diagram that would cater to the needs of the pilot during taxiing. This study introduced two redesigned airport diagrams: fully redesigned and half redesigned. The fully redesigned included increase size, decreased clutter, and color coded runways. The half redesigned airport diagram included every aspect of the fully redesigned airport diagram minus the color coded runways.

Performance Deviations

The performance deviation hypotheses predicted that deviations during the scenarios would be significantly lower in the fully redesigned airport diagram than the half redesigned and original FAA airport diagram. If true, this hypothesis would mean that pilots using the fully redesigned airport diagram would be less likely to deviate off course and cause a runway incursion. However, the results showed that deviations were not significantly different between airport diagrams, and this hypothesis was not supported. A number of reasons exist why the hypothesis was not supported.

The skewedness of the data shows that a ceiling effect may have occurred, and this may have been the reason that the groups did not differ significantly on deviations. That is, the deviation scores were positively skewed, which means that all participants averaged a minimal amount of deviations throughout the performance deviations, and the scenarios may have been too easy to show variance among the participants. The workload scores were also positively skewed with the majority of the participants indicating that the performance scenarios were low in workload. This particular experiment eliminated all other traffic, checklists, and majority of communication with ATC. The only communication participants had with ATC was at the beginning of each task to get route directions. The low workload participants encountered in the experiment could have caused scenarios to be too easy to show an effect of the diagrams as the majority of participants performed well. It is possible that if all tasks (i.e., communicating with ATC, running checklists, and looking for other traffic) were eliminated in the taxiing phase of flight during actual operations then the chances of pilot deviations may decrease.

At the same time, however, runway incursions only happen about once every 183,621 operations (Federal Aviation Administration, 2008). Thus, a "ceiling effect" occurs in the actual operational environment. During the experiment, the participants only completed three performance taxiing tasks. Thus, it is not surprising that few deviations occurred in the experiment.

Internal validity is any sort of interference or extraneous variables within an experimental study that may influence the results of the study. The internal validity of a study can be threatened by many factors such as confounding variables, participant history, or selection bias to name a few. In this particular study, the instrumentation used to measure deviations may have threatened the internal validity. Specifically, the literature review that guided the airport diagram redesigns analyzed performance during visual search. In the studies reviewed, performance was defined by speed and accuracy. In this study performance has been defined by deviation. This poses a threat to internal validity because deviations measures accuracy but not speed. The trained experimenters recorded a deviation after a participant had made a complete deviation from the assigned taxiing route. The deviation measure is not the same as the background literature describes. Additionally, the deviations were recorded by observation of trained experimenters, and this could have affected the measurement. While unlikely, an experimenter could have misjudged a movement by the participant as a deviation or possibly missed a deviation all together. The experimenters were given proper and sufficient training, however, it is still possible a mistake was made and incorrect results were reported. The threats to internal validity from the deviation measure may be another reason why the hypothesis was not supported.

Situational Awareness

The S.A. hypotheses predicted that participants using the fully redesigned airport diagrams would score higher on the S.A. probes than the half redesigned and original airport diagrams. If supported, this would have meant that pilots using the fully redesigned airport diagrams would have had higher S.A. and therefore may have been less likely to deviate off course. However, the results found that S.A. scores were not significantly different between airport diagrams. This could be due to the low workload and possible inaccurate measurement of S.A.

In terms of workload, the participants may have responded differently to the S.A. probes if workload had been more realistic to real world cockpits because their attentional resources would be limited. If the attentional resources are more limited then the participant may not be able to attend and encode all the information on the airport diagram. This would most likely lead to lower S.A. scores and perhaps resemble more realistic scores.

Additionally, it is possible that the SA measurement was not effective. In particular, some of the S.A. probes may not have accurately measured the participant's S.A. In attempts to avoid participants becoming too familiar with the SA probes, the experiment used a variety of S.A. probes (refer to table 9 in results). Some of which were less central to navigating the airport (i.e., "How many terminals are at this airport?" or "What was your beginning position?"). It was important to not repeat question frequently in order to prevent participants from learning the S.A. questions. However, the alternate questions may not have measured S.A. effectively. Therefore, a separate *post-hoc* analysis was conducted to discover if the additional questions were hiding a S.A. effect. The questions were re-examined to include only the questions applicable to airport S.A. After eliminating the non-relevant questions, the S.A. scores were analyzed. The results did not find any significant difference between airport diagrams, however the S.A. scores in the original airport diagram condition improved and are similar to S.A. scores reported in the half and full redesigned airport diagrams.

Additionally, as with the deviation measure, the study required a trained experimenter to observe and record the participants' responses to the S.A. probes. The experimenters were thoroughly trained and several pilot experiments were completed to ensure that they were observing accurately. Additionally, when the experimenters began running subjects they were checked for accuracy. The experimenters proved they could be consistently accurate.

Additionally, worksheets were developed to make recording observations as objective as possible. All the S.A. probes had "yes", "no", or "I don't know" answers. The training and objective worksheets limited the observer threat to internal validity as much as possible, however, it is possible that human error may have occurred, and inaccuracies in the data may have led to the lack of support for the hypothesis.

Workload

The workload hypotheses predicted that participants using the fully redesigned airport diagram would report lower workload than participants using the half redesigned airport diagrams and the original FAA airport diagrams. The results indicated that workload was not significant between the airport diagram conditions. This is most likely due to the fact that the participants experienced low workload throughout the experiment, regardless of airport diagram. That is, had workload been higher an effect of the redesigned airport diagram may have occurred. The workload issue is likely tied to the low-fidelity aspect of the scenarios. That is the taxiing scenarios were not completed in an environment that would simulate a real-world cockpit. Therefore, the environment the participants completed the scenarios in did not replicate a real-world cockpit environment. This impacted the difficulty of the scenarios, and the workload experience.

Power of the Study

The *post-hoc* power analysis found that the study had enough statistical power that a Type II error most likely did not occur and that the insignificant results were not found by chance. The power is not a weakness of the study and is most likely not a possible reason for the insignificant results. However, if the assumed effect size is lower than a medium effect size the statistical power could be a reason for insignificant results. If the effect size is decreased to a small effect size (0.10) then the statistical power is only 41%. This would put the results at high risk of a Type II error. This can be corrected in future research by increasing the amount of participants.

Future Research

Redesigning airport diagrams is a unique way of solving a deadly problem within the aviation industry, and this research problem should be further investigated. A number of changes should occur in future research on this topic. First, additional measures and improvements of the current deviations measure is needed. The studies included in the literature review define performance by speed and accuracy. Therefore, because the current deviations measure may not have incorporated speed and accuracy, future studies should include speed and accuracy measurements. For example, possibly measuring the speed at which participants can find their current location on the airport diagram could show a difference between the airport diagrams. Additionally, further background literature and interviews with subject matter experts could reveal specific behaviors that occur in pilots before a deviation occurs. These yet unrevealed deviation behaviors could be the key to predicting when pilot deviations occur. In addition, a possible future measurement of deviation behavior is eye tracking. It is possible, that where the pilot's eyes are looking could hold the key to predicting deviation behavior. If an eye tracker is used in a follow-up study, the experimenter should compare where the eyes of a pilot are before they deviate off course to the eyes of a pilot that continues on the assigned route. Additionally, an eye tracking measure could also reveal the amount of time each pilot spent looking at the diagram.

Second, the S.A. measurement could be improved as well. The current technique developed by Endsley has been show to work well to measure S.A. However, not all the S.A.

questions used accurately measured the participant's airport situational awareness. Therefore, this measurement must be further developed. The S.A. questions should only assess the airport S.A. A current pilot should be involved in developing future S.A. questions because they will know what the pilot should be aware of while taxing. Additionally, strategically choosing probe locations throughout a scenario is important because they are supposed to keep the participant on their "toes". The probes locations should seem random to the participant so they are not prepared for them, but at the same time chosen at important sections of the scenario.

Third, future research should include scenarios that better simulate a real-world environment. In the current experimental design, scenarios did not simulate a real world cockpit environment and this may have caused the ceiling effect. The future scenarios should include everything a pilot would encounter in a real-world situation. For example, including consistent pilot to ATC communication, hold shorts, checklists, and other traffic on the taxiways would benefit the validity of the results. The results would be more generalizable to the aviation community if the experiment incorporated real-world scenarios.

Including real-world scenarios would increase the cognitive fidelity to properly simulate the task and workload seen in a cockpit during the taxiing phases of flight. If the task is more difficult and workload is increased then redesigned airport diagrams may show a significant effect on performance. This would increase the validity of the scenarios and would better support any significant findings because they would represent a real-world pilot behavior.

Conclusion

The FAA continues to acknowledge runway incursions as a "most wanted" issue threatening aviation safety. The FAA runway incursion statistics revealed that pilot deviations were responsible for more than half of runway incursions. Currently, pilots rely on airport diagrams that are cluttered with excess information and are small in size. This study attempted to introduce a redesigned airport diagram by eliminating excess information, increasing the overall size, and adding color to runways. While the study showed insignificant results, this unique idea should not be abandoned.

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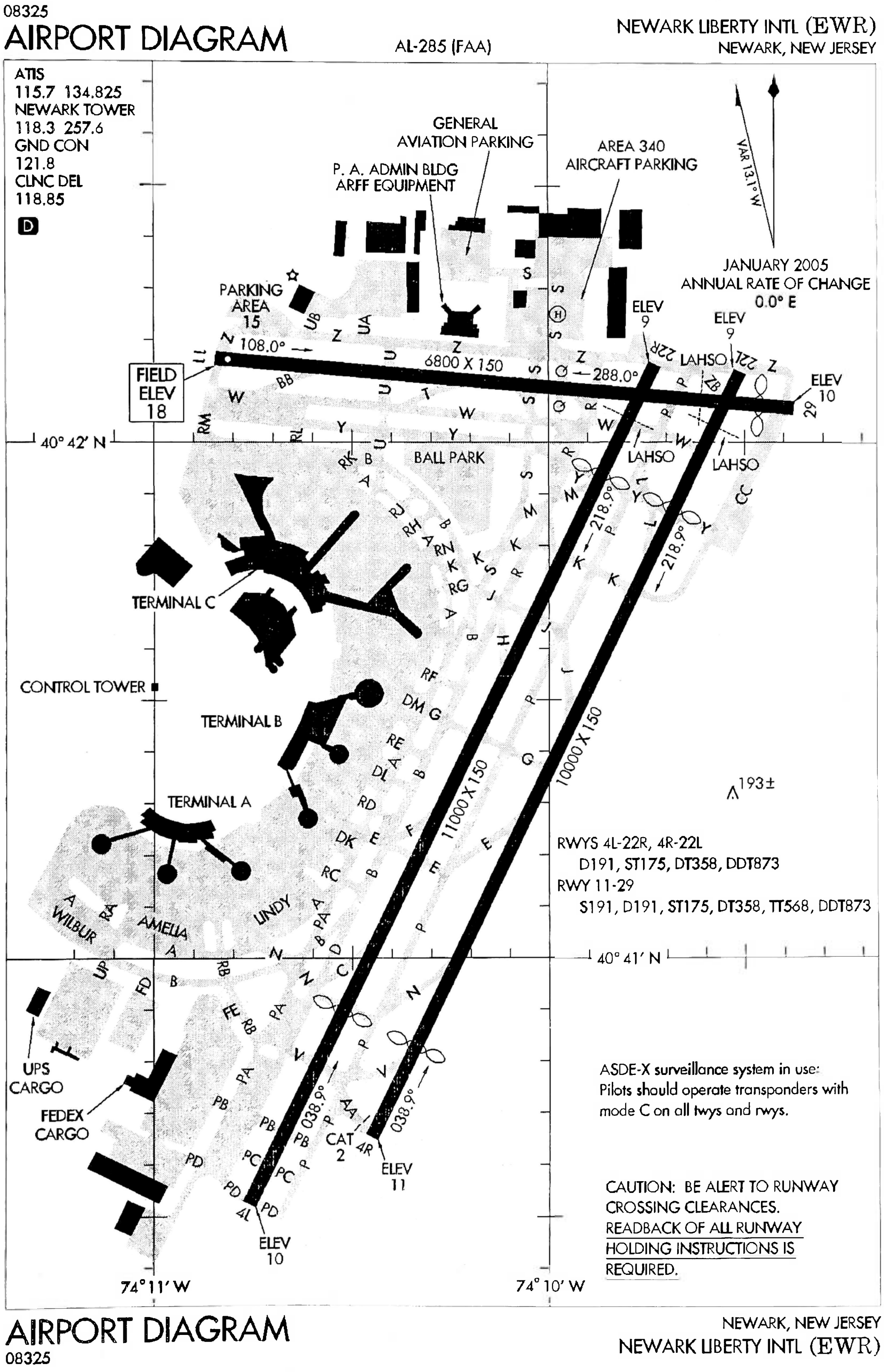
Appendix A

Federal Aviation Administration Newark Liberty International Airport Diagram



08325
AIRPORT DIAGRAM
AL-285 (FAA)
NEWARK LIBERTY INTL (EWR)
NEWARK, NEW JERSEY

ATIS
115.7 134.825
NEWARK TOWER
118.3 257.6
GND CON
121.8
CLNC DEL
118.85

JANUARY 2005
ANNUAL RATE OF CHANGE
0.0° E

RWYS 4L-22R, 4R-22L
D191, ST175, DT358, DDT873
RWY 11-29
S191, D191, ST175, DT358, TT568, DDT873

ASDE-X surveillance system in use: Pilots should operate transponders with mode C on all twys and rwys.

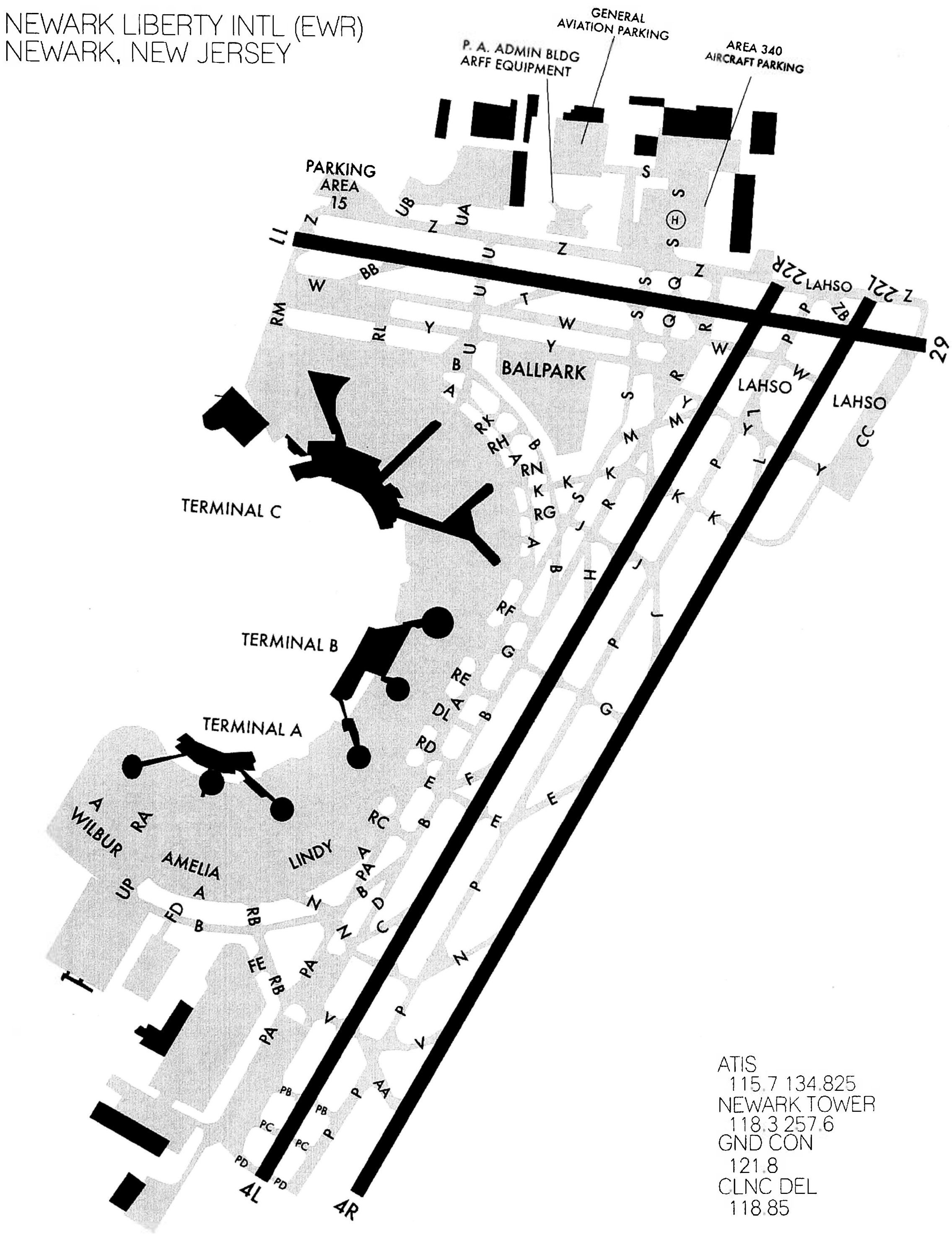
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.

NE-2, 19 NOV 2009 to 17 DEC 2009

AIRPORT DIAGRAM
08325
NEWARK, NEW JERSEY
NEWARK LIBERTY INTL (EWR)

Appendix B

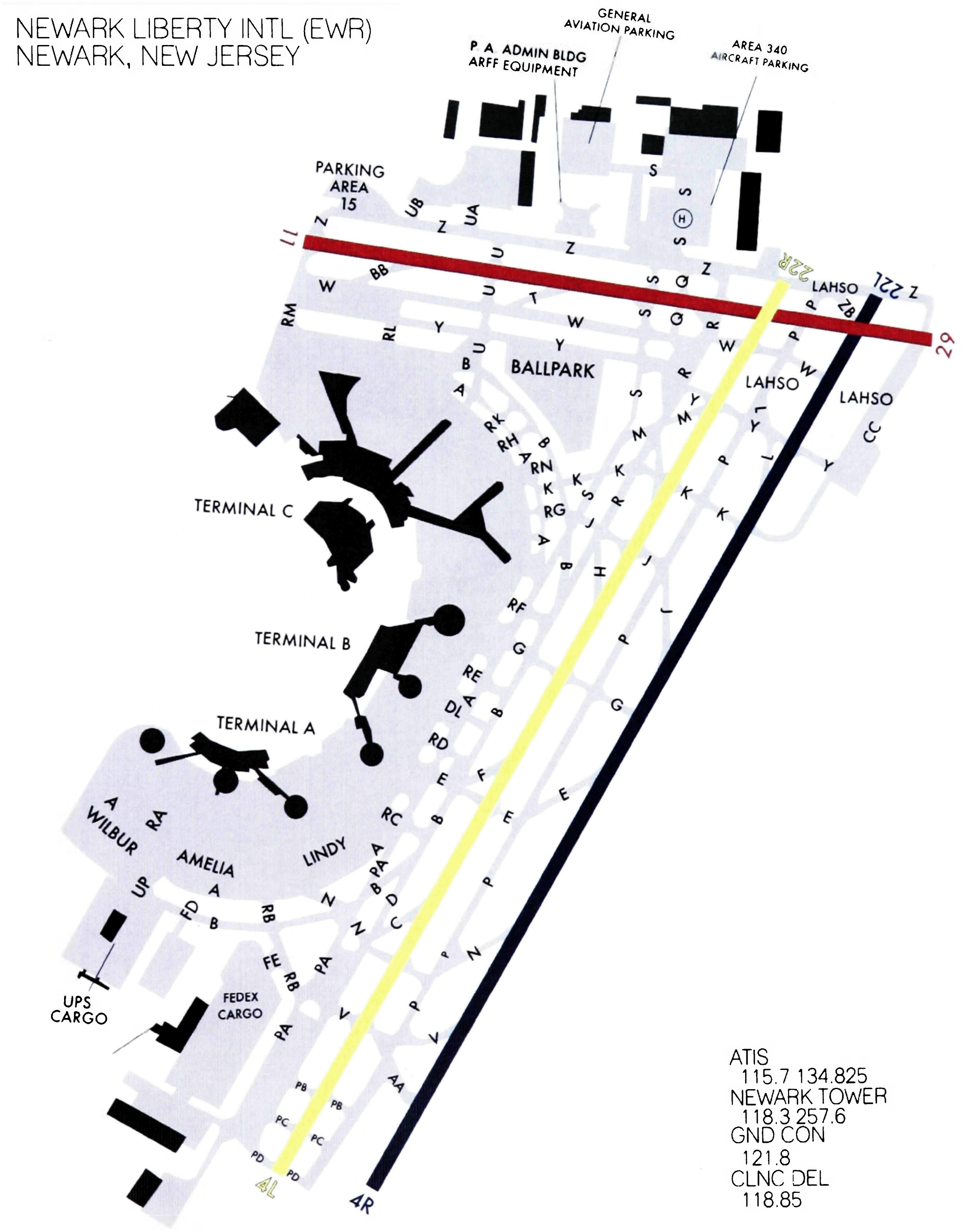
The Half Redesigned Condition



Appendix C

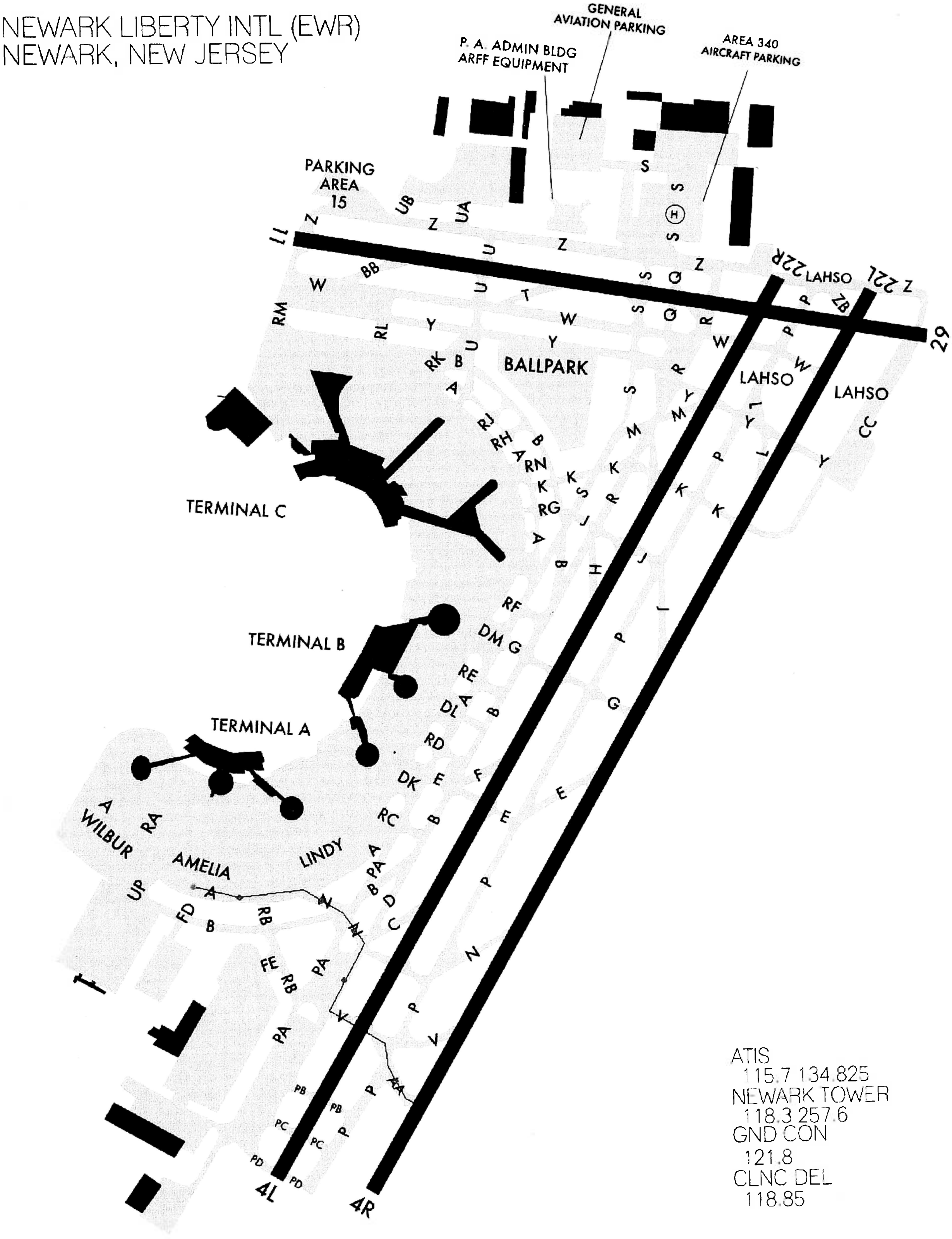
The Fully Redesigned

Condition



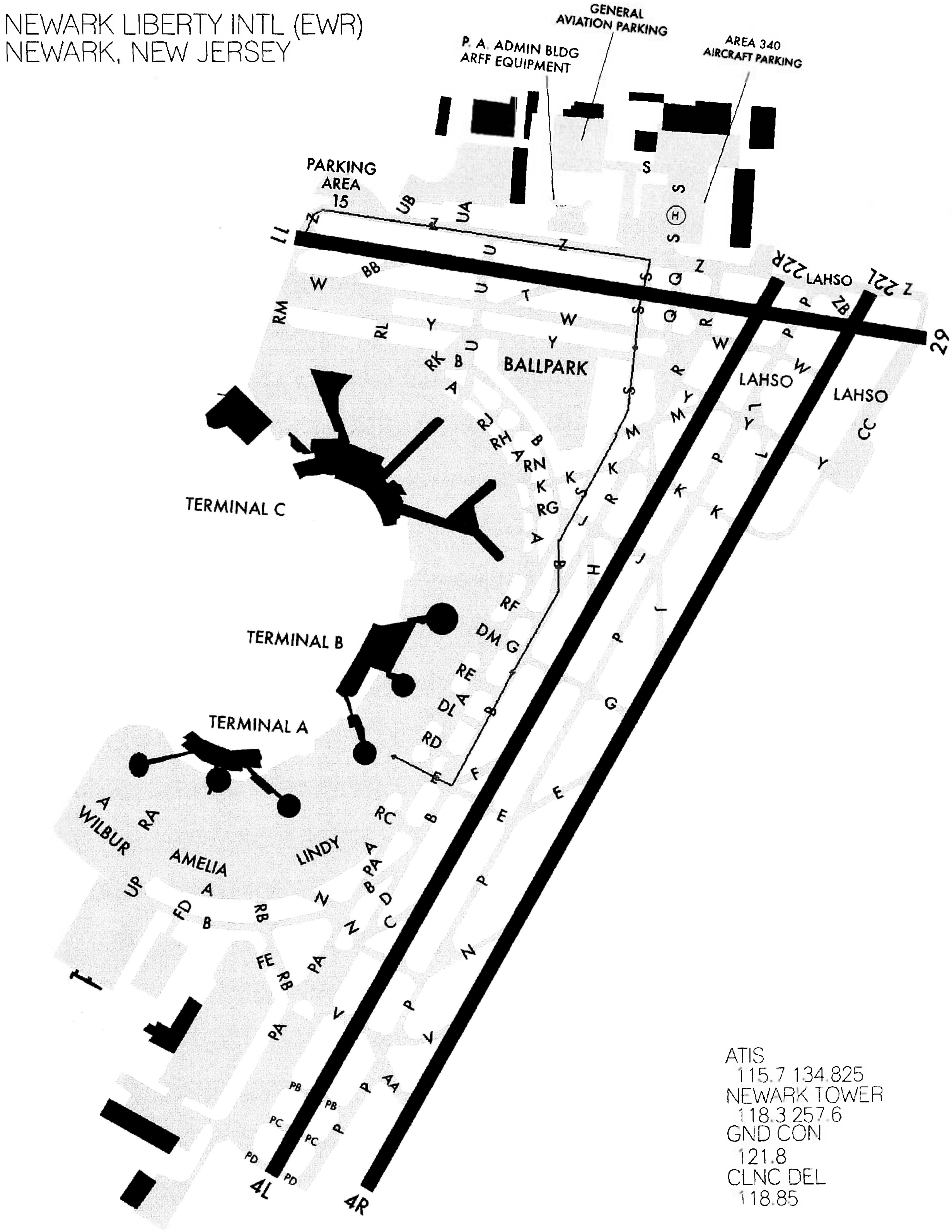
Appendix D

Taxi Route and Designated Probe Areas for Scenario #1



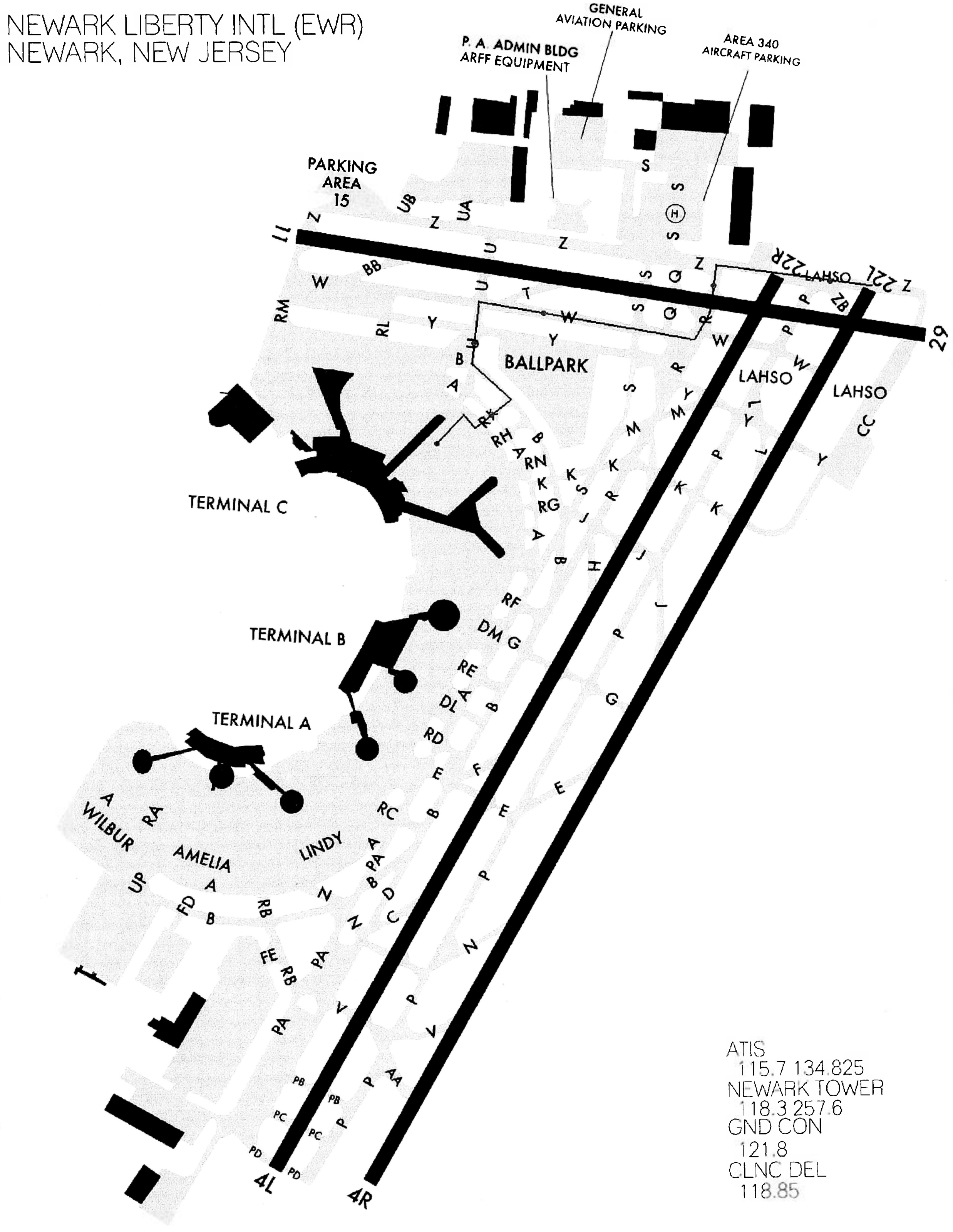
Appendix E

Taxi Route and Probe Areas for Scenario #2



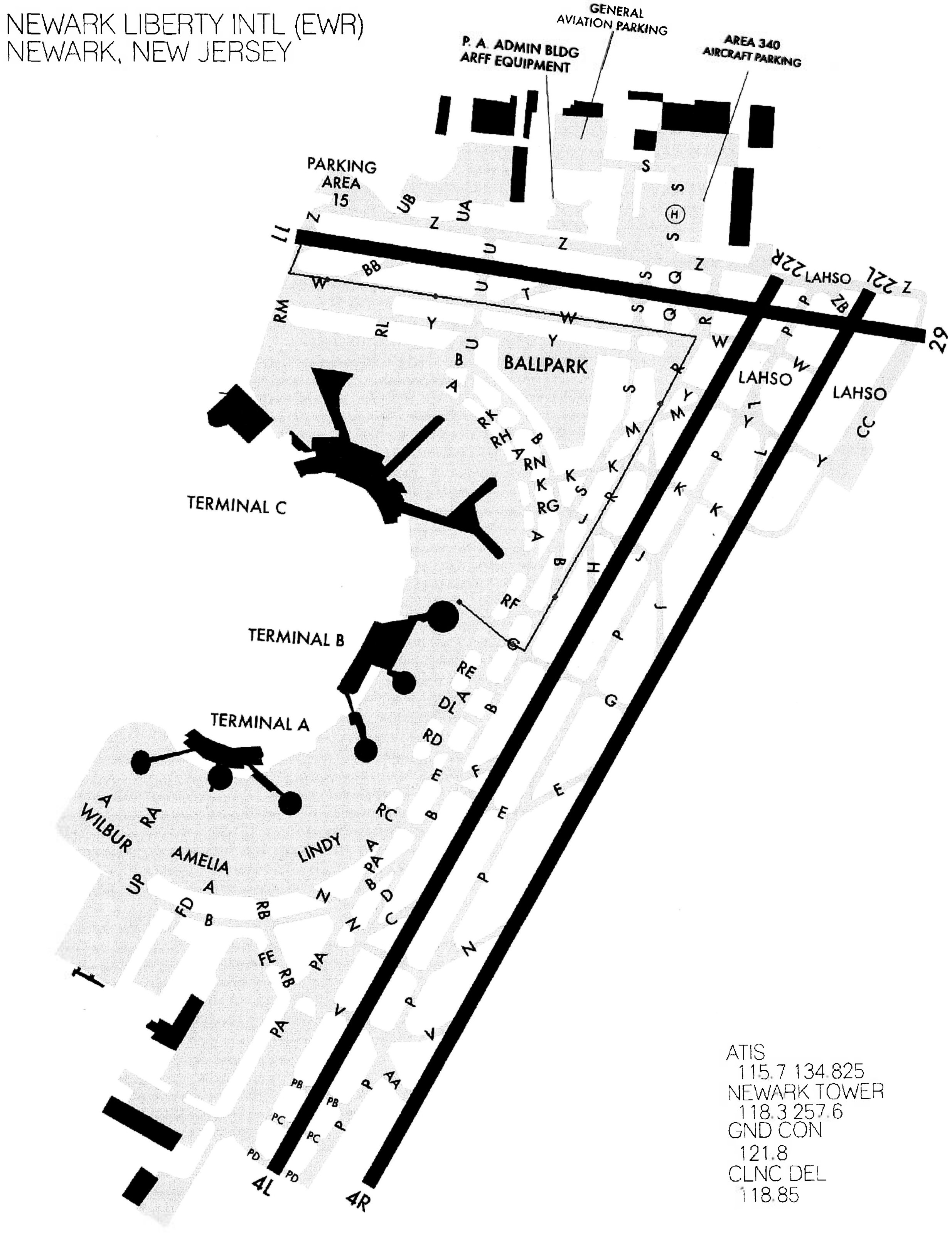
Appendix F

Taxi Route and Probe Areas for Scenario #3



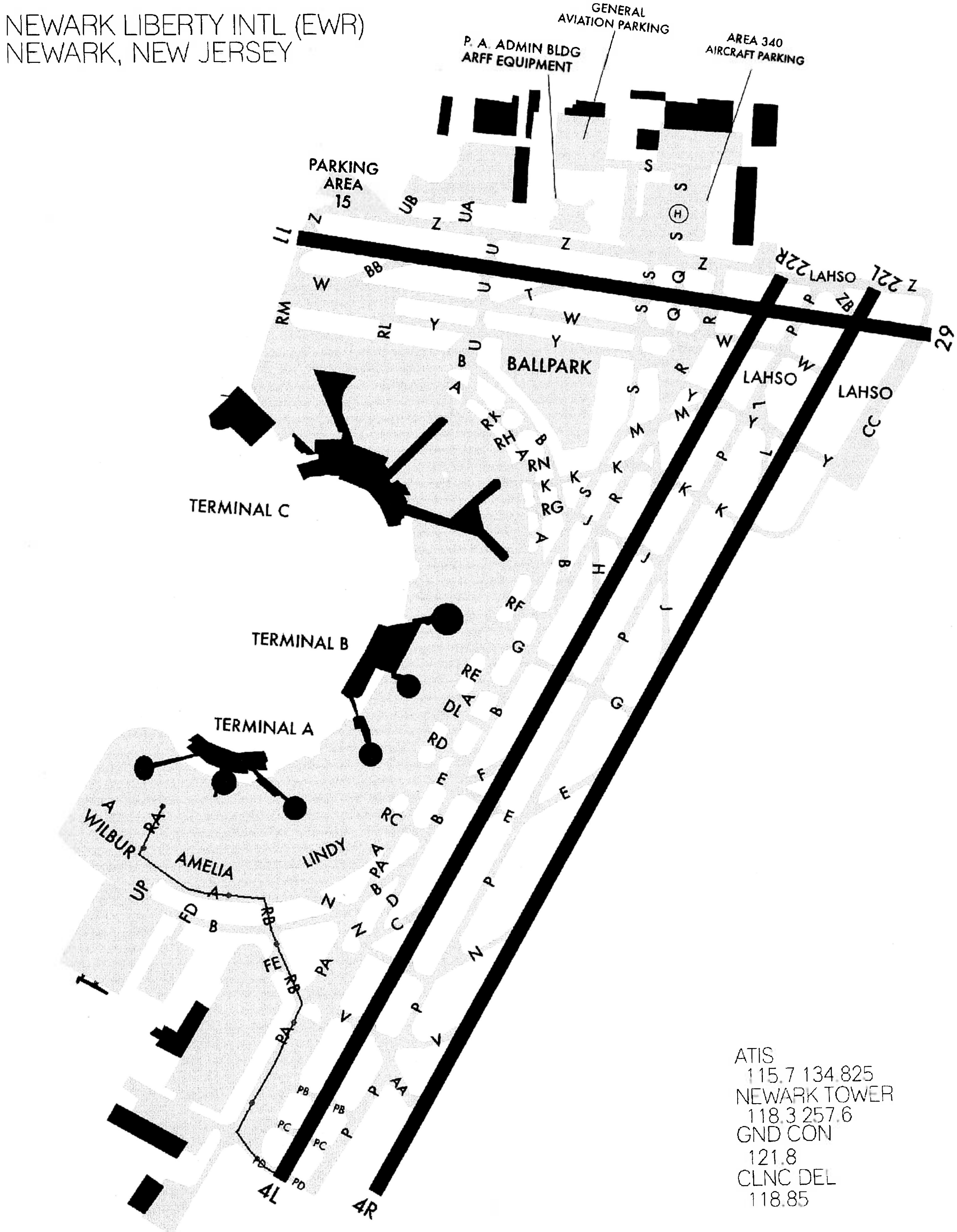
Appendix G

Taxi Route and Probe Ares for Scenario #4



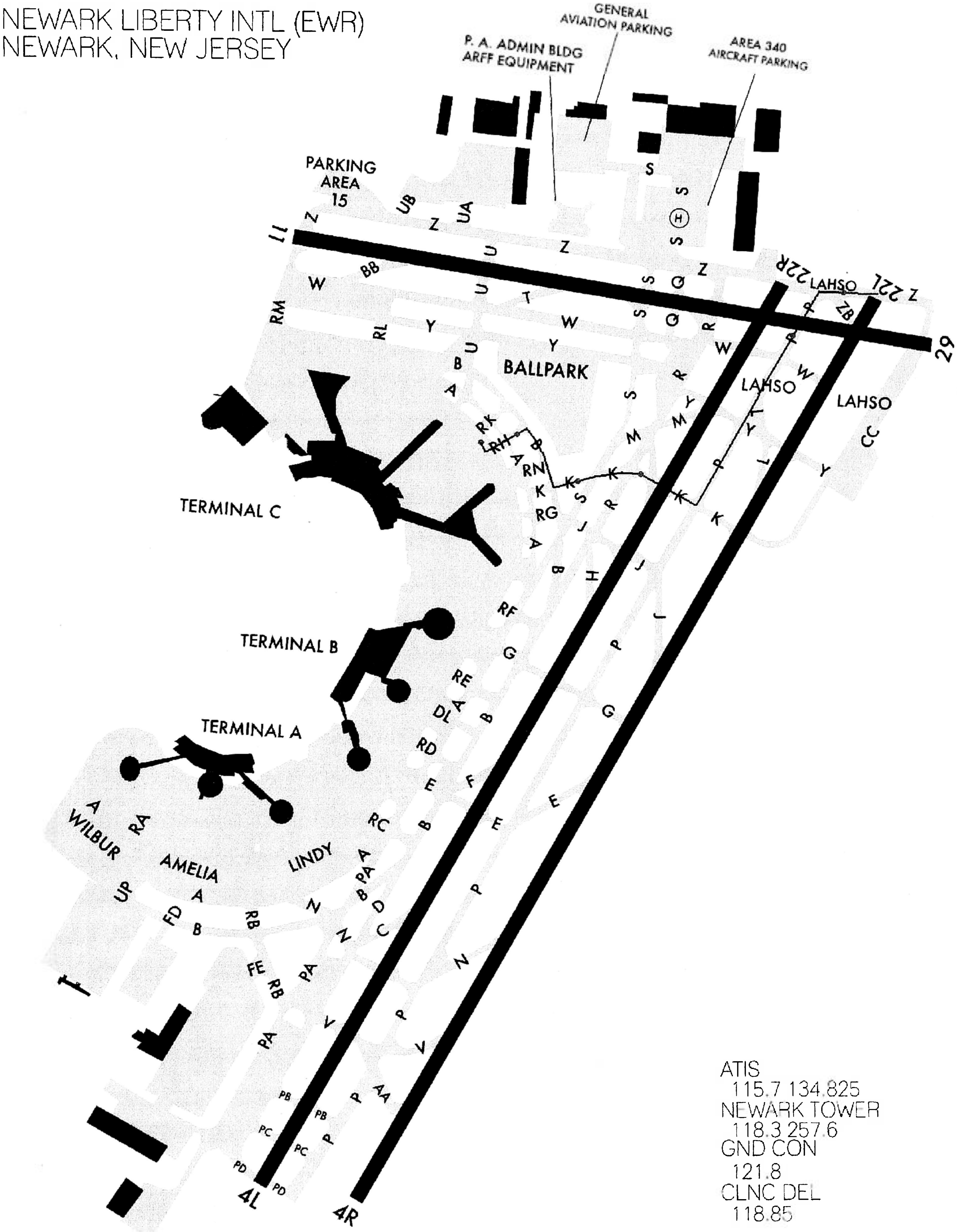
Appendix H

Taxi Route and Probe Areas for Scenario #5



Appendix I

Taxi Route and Probe Areas for Scenario #6



Appendix J

SA and Deviation Worksheet for Task #1

Task #1 Participant # ______________ Condition: Original / Half / Full

Interruption	Did the pilot deviate off course?	If the pilot deviated off course, Describe the deviation	Question (Only ask of pilot correctly navigated to probe)	Correct Answer	Did the participant answer it correctly?
Probe #1	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other ____________________ ______________________________	How many terminals are at this airport?	Three	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #2	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other ____________________ ______________________________	What Taxiway are you on?	Taxiway N	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #3	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ______________________________	What is your current speed?	Answer ___ Actual ___ (Must be within 2)	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #4	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ______________________________	How many runways have you crossed?	Zero	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #5	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ______________________________	What was your beginning position?	Taxiway A	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____

Did the pilot complete the task? Yes / No

Total Deviations: Backwards ____ Circling ____ Wrong Turns ____ Lost ____ Other ____ Total ____

Total Answers: Yes ____ No ____ Participant didn't know ____ N/A (Reset) ____ N/A (Other) ____

Appendix K

SA and Deviation Worksheet for Task #2

Task #2 Participant # ______________ Condition: Original / Half / Full

Interruption	Did the pilot deviate off course?	If the pilot deviated off course, Describe the deviation	Question (Only ask of pilot correctly navigated to probe)	Correct Answer	Did the participant answer it correctly?
Probe #1	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ____	What airport are you at?	Newark Liberty International	Yes ___ No ___ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #2	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ____	What was the last taxiway crossed?	Taxiway RE	Yes ___ No ____ Participant didn't know ___ N/A (reset) ____ N/A (other) ____
Probe #3	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ____	What is your direction?	North	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #4	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ____	What is ground control radio?	121.8	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #5	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ____	Is there a taxi named Romeo 1?	No	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____

Did the pilot complete the task? Yes / No

Total Deviations: Backwards ____ Circling ____ Wrong Turns ____ Lost ____ Other ____ Total ____

Total Answers: Yes ____ No ____ Participant didn't know ____ N/A (Reset) ____ N/A (Other) ____

Appendix L

SA and Deviation Worksheet for Task #3

Task #3 Participant # ______________ Condition: Original / Half / Full

Interruption	Did the pilot deviate off course?	If the pilot deviated off course, Describe the deviation	Question (Only ask of pilot correctly navigated to probe)	Correct Answer	Did the participant answer it correctly?
Probe #1	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ______________________________	What is the closest parallel runway?	22R/4L	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #2	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ______________________________	What is your current speed?	Answer ___ Actual ___ (Must be within 2)	Yes ____ No ____ Participant didn't know N/A (reset) ____ N/A (other) ____
Probe #3	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ______________________________	What is the airport identifier?	EWR	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #4	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ______________________________	Which is closest Ballpark or Wilbur?	Ballpark	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #5	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ______________________________	What was the last taxiway crossed?	Taxiway P	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____

Did the pilot complete the task? Yes / No

Total Deviations: Backwards ____ Circling ____ Wrong Turns ____ Lost ____ Other ____ Total ____

Total Answers: Yes ____ No ____ Participant didn't know ____ N/A (Reset) ____ N/A (Other) ____

Appendix M

SA and Deviation Worksheet for Task #4

Task #4 Participant # ____________ Condition: Original / Half / Full

Interruption	Did the pilot deviate off course?	If the pilot deviated off course, Describe the deviation	Question (Only ask of pilot correctly navigated to probe)	Correct Answer	Did the participant answer it correctly?
Probe #1	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________	What Taxiway are you on?	Taxiway G	Yes ____ No ____ Participant didn't know ___ N/A (reset) ____ N/A (other) ____
Probe #2	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other ____________________	Identify the fork in the taxiway	Taxiway B & R	Yes ____ No ____ Participant didn't know ___ N/A (reset) ____ N/A (other) ____
Probe #3	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________	What is the closest parallel runway?	22R/4L	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #4	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________	What is your heading?	Answer ___ Actual ___ (Must be within 2 degrees)	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #5	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________	What is next?	Turn right on Taxiway Z	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____

Did the pilot complete the task? Yes / No

Total Deviations: Backwards ____ Circling ____ Wrong Turns ____ Lost ____ Other ____ Total ____

Total Answers: Yes ____ No ____ Participant didn't know ____ N/A (Reset) ____ N/A (Other) ____

Appendix N

SA and Deviation Worksheet for Task #5

Task #5 Participant # ______________ Condition: Original / Half / Full

Interruption	Did the pilot deviate off course?	If the pilot deviated off course, Describe the deviation	Question (Only ask of pilot correctly navigated to probe)	Correct Answer	Did the participant answer it correctly?
Probe #1	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other______________________ ______________________________________	What is the closest terminal?	Terminal A	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #2	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other______________________ ______________________________________	Identify all the runways	11/29, 22R/4L, & 22L/4R	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #3	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other______________________ ______________________________________	What was the last taxiway crossed?	Taxiway B	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #4	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other______________________ ______________________________________	What is next?	Turn Left on taxiway PD	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #5	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other______________________ ______________________________________	What was your beginning position?	Taxiway RA	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____

Did the pilot complete the task? Yes / No

Total Deviations: Backwards ____ Circling ____ Wrong Turns ____ Lost ____ Other ____ Total ____

Total Answers: Yes ____ No ____ Participant didn't know ____ N/A (Reset) ____ N/A (Other) ____

Appendix O

SA and Deviation Worksheet for Task #6

Task #6 Participant # _______________ Condition: Original / Half / Full

Interruption	Did the pilot deviate off course?	If the pilot deviated off course, Describe the deviation	Question (Only ask of pilot correctly navigated to probe)	Correct Answer	Did the participant answer it correctly?
Probe #1	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ____	What taxiways are intersecting at your position?	Taxiway A	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #2	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ____	What is the next taxiway you will cross?	Taxiway K	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #3	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ____	What taxiway are you on?	Turn left on Taxiway P	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #4	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ____	What is next?	Taxiway W	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____
Probe #5	Yes ___ No ___ Reset ___	Backwards / Circling / Wrong Turn Right/ Wrong Turn Left / Lost Aware / Lost Unaware / Other____________________ ____	Identify the runways you crossed	Taxiway Z	Yes ____ No ____ Participant didn't know ____ N/A (reset) ____ N/A (other) ____

Did the pilot complete the task? Yes / No

Total Deviations: Backwards ____ Circling ____ Wrong Turns ____ Lost ____ Other ____ Total ____

Total Answers: Yes ____ No ____ Participant didn't know ____ N/A (Reset) ____ N/A (Other) ____

Appendix P

NASA TLX

Participant # ________ **Task #**

Mental Demand How mentally demanding was the task?

Very Low Very High

Physical Demand How physically demanding was the task?

Very Low Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low Very High

Performance How successful were you in accomplishing what you were asked to do?

Perfect Failure

Effort How hard did you have to work to accomplish your level of performance?

Very Low Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low Very High

Appendix Q

Demographics Questionnaire

Demographics Questionnaire Participant #____________

Name: ____________________

Phone Number (___) - ___ ___

Age: _______

Sex: MALE FEMALE

Year: FR SO JR SR

Pilot Experience

Total Hours: _________

List all current ratings: ____

____

____

____

____

____

____

Have you ever piloted an aircraft at Newark International Airport? _________

How often do you use Microsoft Flight Simulator?

_____	__________	_____	__________	__________	_____
Never	Very Rarely	Rarely	Occasionally	Very Frequently	Always

Appendix R

Familiarity Questionnaire

Familiarity Questionnaire Participant # ____________

Question	Correct Answer	Participant's Answer
Identify the runways	18R/36L, 18L/36R, & 9/27	Yes __ No __ Participant didn't know __
What the Tampa tower radio?	119.5 & 269.4	Yes __ No __ Participant didn't know __
Where is the control tower?	Participant must point out where the control tower is located	Yes __ No __ Participant didn't know __
Identify the airport	Tampa International Airport	Yes __ No __ Participant didn't know __

Would you consider yourself familiar with FAA airport diagrams?

Agree Very Strongly ☐
Agree Strongly ☐
Agree ☐
Disagree ☐
Disagree Strongly ☐
Disagree Very Strongly ☐

How often do you use FAA airport diagrams?

____ Never ____ Very Rarely ____ Rarely ____ Occasionally ____ Very Frequently ____ Always

During your flight training, how often did you use FAA airport diagrams?

____ Never ____ Very Rarely ____ Rarely ____ Occasionally ____ Very Frequently ____ Always

Appendix S

Reaction Survey

Reaction Survey Participant #___________

Condition: Original / Half / Full

7 = Agree Very Strongly

6 = Agree Strongly

5 = Agree

4 = Undecided

3 = Disagree

2 = Disagree Strongly

1 = Disagree Very Strongly

1. The general appearance of the airport diagram is clear _____
2. I did not look at the airport diagram often _____
3. The information on the airport diagram was clear _____
4. The airport diagram is cluttered _____
5. The color of the runways were helpful _____
6. The airport diagram was easily understood _____
7. The airport diagram was not large enough to clearly understand _____
8. The colors of the runways were not helpful _____
9. The size of the airport diagram made it difficult to understand _____
10. I had to look at the airport diagram frequently _____
11. The size of the taxiways were helpful _____

Appendix T

Informed Consent Form

CONSENT FORM

I consent to participate in the research project entitled:

Redesigning Airport Diagrams with Principles of Cognitive Psychology

The principle investigator of the study is:

Jacob Miller
Masters of Human Factors and Systems
Embry-Riddle Aeronautical University

Purpose of this research: Runway incursions are on the National Transportation Safety Board's most wanted list for safety improvements. Pilots consistently encounter unfamiliar airports throughout their careers and this can cause poor situational awareness and pilot deviations. Currently, airport diagrams are not designed for the human or taxiing phase of flight. This attempts to redesign airport diagrams to include principles of cognitive psychology.

Study Procedure: Participants will participate in six simulated taxiing tasks. The purpose of the study is to discover if airport diagrams can be improved to help pilots from deviating off course. The study will include several written measures throughout the simulation.

Confidentiality: Participant information will be confidential. The information amassed from the experiment will be provided to the sponsor. However, names and other identifying information will not be used in any reports generated by this project.

Consent: I demonstrate my consent for participating in this study by voluntarily signing the bottom of this page. Because my participation in this research is voluntary, I am aware that I can withdraw at anytime without penalty. If I have any questions, I may contact the researcher listed above.

Print Name ______________________________

Signature______________________________