ABSTRACT

PANKOK, JR., CARL JOHN. Mitigating Biases in Time-To-Contact Judgments with General Aviation Cockpit Displays of Traffic Information. (Under the direction of Dr. David B. Kaber.)

As the United States upgrades its current, radar-based air traffic system to a higher fidelity system based on Global Positioning System technology, many in-cockpit technologies are being developed to increase pilot situational awareness and decrease workload associated aircraft operation. Such technologies may be particularly beneficial to the general aviation community with frequent flights without the assistance of air traffic control. One tool that is currently available and expected to become more commonplace in general aviation aircraft is the cockpit display of traffic information (CDTI). Such displays present intruders in proximity to a pilot’s ownship. This information can be used to maneuver an aircraft to avoid conflicts with proximate intruders. Recent literature has revealed that, despite CDTI displays in the cockpit, pilots have difficulty accurately assigning risk to surrounding intruders. Pilots tend to place too much emphasis on the distance between ownship and intruders rather than using a combination of distance and velocity information; this is referred to as the distance bias. The present research investigates the effect of added CDTI features on mitigating the effect of distance bias in pilot time-to-contact (TTC) judgments.

Fourteen general aviation pilots participated in an experiment to assess six prototype CDTI formats. The added features were applied to intruder icons presented on the display and included a full crossing of three levels of perceptual cue type (blinking, color-change or baseline/no added cue) and two levels of a velocity data tag (absent or present). The experiment was performed with a PC-based flight simulator. Participants were asked to fly a
simulated aircraft on a straight and level path while making relative TTC judgments using the prototype CDTI presented on a touch screen display. Each pilot performed 16 trials under each of six test conditions. Objective responses measures included time to judgment, accuracy in risk prioritization of intruders, and frequency of pilot gaze to the CDTI. Subjective responses included pilot perceived workload and level of confidence in judgment, among others.

Results revealed the addition of the perceptual cue to be effective for mitigating the effect of the distance bias in terms of high-risk intruder selection accuracy and response time. The addition of the velocity data tag was effective for decreasing the response time. Furthermore, there was evidence that the addition of the perceptual cues reduced the proportion of pilot attention required by the cockpit display. Displays featuring the perceptual cues and the velocity data tags also yielded higher subjective ratings of preference than the baseline displays. In assessing the blinking cue compared with the color-change cue, there was no evidence among the performance measures nor the subjective ratings that one cue was more effective or favorable than the other.

These findings suggest that increases in pilot performance with the prototype CDTI and subjective ratings were primarily driven by perceptual cue type. The presence of velocity data tags only appeared to benefit pilots when presented in conjunction with the perceptual cues. It was concluded that addition of perceptual cues and/or the velocity data tags was effective for increasing the accuracy of pilot TTC judgments, as influenced by the distance bias. The findings of this research may serve as an applicable guide for future CDTI designs to support general aviation aircraft pilots in making more accurate risk assessments of intruders in the surrounding airspace.
Mitigating Biases in Time-To-Contact Judgments with General Aviation Cockpit Displays of Traffic Information

by
Carl J. Pankok, Jr.

A thesis submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the degree of Master of Science in Industrial Engineering

Raleigh, North Carolina

2013

APPROVED BY:

__________________________________________________________
David Kaber, PhD
Committee Chair

Нancy Currie, PhD  David Dickey, PhD
DEDICATION

To my parents, who worked so hard their entire lives to ensure that my siblings and I were given a strong foundation with which to succeed. They were always willing to make sacrifices so that I could pursue all my interests throughout my childhood and adolescence (including never complaining about taking me to my 5:00am hockey games on the weekends). I will probably never understand the pressures they faced to make certain I was given everything I needed to succeed, but they instilled in me a sense of work ethic and humility that I will continue to pour into every endeavor I encounter in life. I will forever be indebted to everything they have done for me.
BIOGRAPHY

Carl John Pankok, Jr. was born on February 9, 1987 in Bridgeport, NJ to parents Carl Pankok, Sr. and Jeanette Vollmer. After graduating from Kingsway Regional High School in 2005, Carl enrolled at Rutgers University and graduated Magna Cum Laude with a Bachelor of Science in Industrial and Systems Engineering in 2009. Upon graduating from Rutgers, Carl worked as a research analyst at the Federal Aviation Administration’s William J. Hughes Technical Center in Atlantic City, NJ, researching system-wide effects of novel air traffic concepts. In 2011, Carl resigned from his position to pursue a Master of Science degree in Industrial and Systems Engineering at North Carolina State University. In his second semester, he was awarded a fellowship through the National Institute of Occupational Safety and Health for graduate education and research. Upon completion of his degree, he plans on continuing his studies as part of the Doctoral program in Industrial and Systems Engineering at North Carolina State University.
ACKNOWLEDGMENTS

This research could not have been completed without many people who have helped me in one way or another. First and foremost, I have to thank my advisor Dr. David Kaber, who was always willing to take time out of his busy schedule to provide guidance and extremely constructive feedback on all of my work and ideas. If not for Dr. Kaber, my journey towards getting a masters degree would not have been nearly as rewarding or as positive an experience as it was. I would also like to thank Dr. Nancy Currie, who was also instrumental in my research, specifically in the early stages of the research and thanks to Dr. Dave Dickey for his valuable input on the statistics performed in the research. I’d also like to acknowledge all of the researchers who work in the North Carolina State University Ergonomics Laboratory, who were there to help me when I had hardware issues, were available when I was doing preliminary pilot testing, and were always more than willing to answer my questions or share their insights. In particular, I’d like to thank Carter Keough for her work in analyzing the videos of the pilots and recording which screen they were looking at. Finally, this research would not have been possible without funding from the National Institute for Occupational Safety and Health through a training grant (No. 2 T42 OH008673-06) to the North Carolina State University Ergonomics Laboratory.
# TABLE OF CONTENTS

LIST OF TABLES ........................................................................................................................................... viii

LIST OF FIGURES ............................................................................................................................................. ix

LIST OF ABBREVIATIONS ............................................................................................................................... xi

1 Introduction ......................................................................................................................................................... 1

1.1 Background .................................................................................................................................................. 1

1.2 Biases in Time-to-Contact Judgments ................................................................................................. 3

1.3 Information Acquisition and Analysis Automation in Cockpit Displays ................................................. 7

1.3.1 Perceptual Cues to Encode Information ............................................................................................ 7

1.3.2 Perceptual Cues to Capture Pilot Attention ....................................................................................... 12

1.3.3 Traffic Alert and Collision Avoidance System (TCAS) ..................................................................... 13

1.3.4 Variables and Thresholds for Cue Changes ....................................................................................... 15

1.4 Attention Allocation in Display Use ......................................................................................................... 16

1.5 Motivation .................................................................................................................................................. 17

1.6 Objectives ................................................................................................................................................ 20

2 Method .......................................................................................................................................................... 21

2.1 Participants ................................................................................................................................................ 21

2.2 Independent Variables ............................................................................................................................. 22

2.3 Experiment Design .................................................................................................................................. 23

2.4 Apparatus and Scenario ............................................................................................................................ 25

2.5 Dependent Variables ................................................................................................................................ 28

2.5.1 Performance Measures ....................................................................................................................... 28
2.5.2 Subjective Ratings ................................................................. 29
2.6 Procedure ................................................................................. 29
2.7 Hypotheses ............................................................................... 30
2.8 Data Analysis ........................................................................... 32

3 Results ......................................................................................... 37

3.1 Performance Measures .............................................................. 37
  3.1.1 Intruder Selection Accuracy .................................................. 37
  3.1.2 Response Time ..................................................................... 40
  3.1.3 Pilot Attention Allocation ..................................................... 44
  3.1.4 Correlation Analysis ............................................................. 47
  3.1.5 Summary of Results ............................................................. 49

3.2 Subjective Measures ................................................................. 51
  3.2.1 Workload ........................................................................... 51
  3.2.2 Intruder Selection Confidence ............................................. 52
  3.2.3 Display Effectiveness .......................................................... 53
  3.2.4 Ease of Understanding ......................................................... 54
  3.2.5 Perceived Performance ......................................................... 55
  3.2.6 Display Feature Preference ................................................ 56

4 Discussion ..................................................................................... 58
  4.1 Target Choice Accuracy .......................................................... 58
  4.2 Response Time ........................................................................ 60
  4.3 Pilot Gaze Patterns ................................................................. 61
4.4 Correlation Between Response Time and Gaze Proportion ...................... 63
4.5 Subjective Measures .................................................................................. 64
5 Conclusions.................................................................................................... 67
  5.1 Applications ............................................................................................... 68
  5.2 Limitations ................................................................................................. 69
  5.3 Future Work ............................................................................................... 71
References......................................................................................................... 73
Appendix A TCAS Time-to-Contact Thresholds ............................................... 78
Appendix B Experiment Procedure .................................................................... 79
Appendix C Informed Consent Form .................................................................. 87
Appendix D Demographic Questionnaire ......................................................... 89
Appendix E Prototype CDTI Operation ............................................................. 90
Appendix F Post-Block Questionnaire ............................................................... 91
Appendix G Post-Experiment Questionnaire .................................................... 92
Appendix H Intruder Selection Accuracy Contingency Tables ......................... 95
LIST OF TABLES

Table 1.1: Variables and Thresholds for Cue Changes.......................................................... 16
Table 2.1: Intruder TTCs ........................................................................................................ 24
Table 3.1: Effect of Cues on Intruder Selection Accuracy .................................................... 38
Table 3.2: Effect of Data Tags on Intruder Selection Accuracy ........................................... 39
Table 3.3: Contingency Analysis Statistics for the Effect of FASD on Intruder Selection
   Accuracy ............................................................................................................................. 40
Table 3.4: Spearman Correlation Coefficients for Each Cue Type by Data Tag Combination
   ............................................................................................................................................... 48
Table 3.5: Summary of Performance Measure Results .......................................................... 50
Table 3.6: 95% Confidence Intervals for Ease of Understanding Ratings ............................. 55
Table 3.7: Display Feature Preference Responses ................................................................. 57
Table 3.8: Most Helpful Display Feature Responses .............................................................. 57
LIST OF FIGURES

Figure 1.1: Garmin GMX200 CDTI ................................................................. 2
Figure 1.2: TCAS Display .............................................................................. 14

Figure 2.1: Intruder Icons Used in the Prototype CDTI: (a) Baseline Perceptual Cue and No Velocity Tag, (b) Baseline Perceptual Cue with Velocity Tag, and (c) Color Change with Velocity Tag ................................................................................................................. 23
Figure 2.2: Labeling of Intruders by Conflict Angle ........................................ 24
Figure 2.3: Experiment Simulator Setup .......................................................... 26
Figure 2.4: Screenshot of the Prototype CDTI .................................................. 27
Figure 2.5: Continuous Ratings Scale with Two Anchors................................... 29
Figure 2.6: Normal Probability Plots for Response Time (Left) and the Log-Transformed Response Time (Right) ................................................................................................................................. 34
Figure 3.1: Tukey HSD Groupings for the Interaction Between Cue Type and Data Tag ..... 41
Figure 3.2: Tukey HSD Groupings for the Interaction Between Cue and FASD ........... 43
Figure 3.3: Tukey HSD Groupings for the Interaction Between Data Tag and FASD ....... 44
Figure 3.4: Tukey HSD Groupings for the Three-Way Interaction.......................... 46
Figure 3.5: Tukey HSD Groupings for the Interaction Between Cue Type and FASD ....... 47
Figure 3.6: Scatterplot of RT by Proportion of Pilot Gazes to the CDTI .................... 48
Figure 3.7: Tukey HSD Groupings for the Effect of Cue Type on Workload Ratings ........ 51
Figure 3.8: Tukey HSD Groupings for the Interaction Effect on Confidence Ratings ........ 53
Figure 3.9: Tukey HSD Groupings of the Effect of Cue Type on Display Effectiveness Ratings ..................................................................................................................................................... 54
Figure 3.10: Tukey HSD Groupings for Display Feature Type on Perceived Performance .. 56
### LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>ATC</td>
<td>Air Traffic Control</td>
</tr>
<tr>
<td>CDTI</td>
<td>Cockpit Display of Traffic Information</td>
</tr>
<tr>
<td>CFIT</td>
<td>Controlled Flight Into Terrain</td>
</tr>
<tr>
<td>CPA</td>
<td>Closest Point of Approach</td>
</tr>
<tr>
<td>dBA</td>
<td>Decibel (A-Weighted)</td>
</tr>
<tr>
<td>EMM</td>
<td>Electronic Moving Map</td>
</tr>
<tr>
<td>FASD</td>
<td>First Arrival Start Distance</td>
</tr>
<tr>
<td>GA</td>
<td>General Aviation</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HSD</td>
<td>Honestly Significant Difference</td>
</tr>
<tr>
<td>IFR</td>
<td>Instrument Flight Rules</td>
</tr>
<tr>
<td>IMC</td>
<td>Instrument Meteorological Conditions</td>
</tr>
<tr>
<td>KT</td>
<td>Knots (Nautical Miles per Hour)</td>
</tr>
<tr>
<td>NAS</td>
<td>National Airspace System</td>
</tr>
<tr>
<td>NGATS</td>
<td>Next Generation Air Transportation System</td>
</tr>
<tr>
<td>NM</td>
<td>Nautical Miles</td>
</tr>
<tr>
<td>NTSB</td>
<td>National Transportation Safety Board</td>
</tr>
<tr>
<td>OpenGL</td>
<td>Open Graphics Library</td>
</tr>
<tr>
<td>SA</td>
<td>Situational Awareness</td>
</tr>
<tr>
<td>SVS</td>
<td>Synthetic Vision System</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>TCAS</td>
<td>Traffic Alert and Collision Avoidance System</td>
</tr>
<tr>
<td>TTC</td>
<td>Time-to-Contact</td>
</tr>
<tr>
<td>VFR</td>
<td>Visual Flight Rules</td>
</tr>
</tbody>
</table>
1 Introduction

1.1 Background

In the coming decades, the demand for aircraft operations is expected to increase to a level at which the current National Airspace System (NAS) cannot safely handle (Joint Planning and Development Office, 2010). With advancing technologies and the switch from the current radar-based system to a higher performance system based on Global Positioning System (GPS) technology, the airspace capacity is expected to increase and address the projected future demand. This new system, called the Next Generation Air Transportation System (NGATS), is expected to be a safer, higher capacity, and more efficient system than the current NAS.

One approach to future airspace accommodation of projected higher demand is the decentralization of air traffic control (ATC). It is envisioned that pilots will have increased responsibility for maintaining separation and preventing conflicts with other aircraft. Currently, this task is performed by ATC in airspaces that utilize Instrument Flight Rules (IFR) or by pilots using out-of-cockpit views in airspaces under Visual Flight Rules (VFR). The move to GPS technology will allow pilots (in both VFR and IFR airspaces) to use Cockpit Displays of Traffic Information (CDTI), which present accurate position information on surrounding aircraft, to maintain required separation distances and prevent conflicts. Figure 1.1 presents an example display with a pilot’s ownship at the center and several surrounding aircraft identified with small hexagonal icons and numerical identifiers. This
technology is currently available to pilots, but it is expected to become increasingly commonplace in aircraft cockpits.

Figure 1.1: Garmin GMX200 CDTI

The use of CDTIs has the potential to impact the General Aviation (GA) domain more than the commercial or military domains because GA pilots typically fly in uncontrolled airspace (i.e., airspace in which there is no direction provided by ATC). GA pilots are responsible for avoiding conflicts with surrounding aircraft when flying under VFR. According to the National Transportation Safety Board (NTSB), this responsibility is a contributing factor in aircraft incident rates being higher in the GA domain than in commercial flight operations (NTSB, 2011). In addition to the higher accident rates, another study by the NTSB (2010) showed that accident rates in GA for aircraft equipped with glass cockpits (which typically include a CDTI) are higher than for GA aircraft that use traditional
steam-gauge cockpits. The higher rate for glass cockpits was attributed, in part, to a lack of pilot familiarity with new display types or a lack of experience in use. Furthermore, it is possible that pilots who are accustomed to traditional steam gauge instrument panels may exhibit resistance toward acquiring information from new, advanced displays. These findings highlight the need for new cockpit technologies as well as human-centered designs that highlight important information for pilots while decreasing the cognitive workload required to use these tools.

1.2 Biases in Time-to-Contact Judgments

GA pilots use the positions, velocities, and headings of proximate aircraft displayed on a CDTI (referred to as “intruders”) as a guide to maneuvering their aircraft (referred to as “ownship”) in order to avoid conflicts with intruders. To perform this task, pilots must be able to accurately estimate the time-to-contact (TTC) of the ownship with each intruder and identify the intruder that poses the greatest risk to ownship. In terms of situational awareness (SA), pilots must be able to perceive intruders (Level 1 SA), understand what the position of an intruder means to the ownship trajectory (Level 2 SA) and project the future status or location of an intruder relative to ownship (Level 3 SA; Endsley 1995). Research on pilot TTC judgments has suggested that accurately estimating the future positions of multiple intruders is difficult, especially when the velocities and distances relative to ownship are continuously changing (see below).

In a series of experiments using non-pilot participants, it was shown that display users tend to over-rely on distance information when making relative TTC judgments (Law, et al.,
Participants were presented with two objects with differing distances to their destinations as well as different speeds of travel. Participants were asked to predict which object would reach its destination first. The accuracy of the judgments increased as the arrival-time differential increased and when the difference between intruder velocities decreased (i.e., intruder selection accuracy was highest when both intruders were traveling at the same speed and decreased as the difference between the velocities increased when the arrival-time differential was held fixed). When the arrival-time differential was held fixed and the intruders were traveling at the same speed, their arrival times were reflective of their distance to destination; thus, facilitating higher accuracies in judgments. This was not the case when the intruder velocities differed substantially. These results suggest that human judgments of TTC are overly influenced by an object's distance to its destination rather than a combination of both the relative velocities and distances to destinations. Subsequent experiments were also conducted suggesting that participants were capable of estimating relative distances and relative velocities separately but struggled when they were required to integrate the two pieces of information in working memory to make TTC judgments. This over-reliance on distance information when making TTC judgments is hereafter referred to as the “distance bias” and is considered to be, in part, a product of human working memory limitations in multi-target judgment situations (Wickens, 2002).

The distance bias has also been shown to affect pilot TTC judgments when using cockpit displays. Xu and Rantanen (2007) presented pilots with a simulation of an air traffic scenario involving a single intruder with variations on speed and distance-to-conflict-point. The simulation was frozen after 15 seconds and pilots were asked to cognitively extrapolate
the scenario to estimate the TTC and the position of the closest point of approach (CPA). Results were similar to those obtained in the Law et al. research and revealed that pilot estimation errors increased with increasing distance and time-to-CPA or increasing intruder velocity differential. In another set of experiments using a Traffic Alert and Collision Avoidance System (TCAS) display for intruder threat assessments, results suggested pilots over-relied on intruder proximity (Zuschlag, Chandra, & Grayhem, 2011). Additionally, many participants indicated that proximate aircraft must be higher threats than non-proximate intruders, which was not always the case. The results of both studies suggest that the distance bias affected pilot performance.

In another study, pilots using a Synthetic Vision System (SVS) display exhibited behavior indicative of distance bias in judgments of distance to terrain (Bolton and Bass, 2001). A SVS display depicts terrain ahead of the aircraft using an on-board database to prevent Controlled Flight Into Terrain (CFIT) during Instrument Meteorological Conditions (IMC). In Bolton and Bass’ (2001) experiment, participant pilots made spatial judgments regarding the location of terrain points presented on the SVS display. Results revealed a significant main effect of distance in TTC estimation error and a statistically significant correlation between relative distance judgments and TTC judgments. These results suggested that pilots used relative distance judgments in their TTC estimates. Taken together, the results of the above studies show that the distance bias occurs across different types of cockpit displays.

There are numerous theories that have been proposed to explain the occurrence of distance bias in CPA and TTC judgments. Wickens (2002) cited limitations in the working
memory capacity as the main reason for the effect of distance bias. Of the four basic mathematical operations (addition, subtraction, multiplication, and division), division is the most difficult operation to perform in working memory, increasing the difficulty of accurately judging TTC (which is obtained by dividing the distance of an object to a target by it’s velocity). Continuous changes in object distance and velocity make this operation even more difficult to perform in working memory. There are many situations in which humans do not have the capacity to process all requisite information for error-free decision-making. Sanders and McCormick (1993) stated that, “humans are generally conservative and do not extract as much information from sources as they optimally should”. Consequently, we tend to adopt decision-making heuristics, which are often adequate but not always accurate (Tversky and Kahneman, 1974). Thus, in making TTC judgments, pilots tend to adopt heuristics based mostly on distance information, since the resources required for mental estimation, extrapolation, and arithmetic may exceed the capacity of working memory. These heuristics may have their basis in one or more of the following concepts:

- **Anchoring** - At the outset of an air traffic scenario, a pilot may make an initial relative TTC judgment based solely on the distances of surrounding intruders. The relative velocities, which are observed and processed over time, are not enough to overturn the initial diagnosis.

- **Availability** - Retrieval of long-term memories on previous experiences of similar traffic may lead pilots to believe a closer intruder has a shorter TTC, especially if this has been true in a large proportion of the pilot’s previous experiences.
• *Salience*- The distance to an intruder is a much more salient cue than the velocity at which the intruder is traveling, leading to greater pilot reliance on the distance in TTC judgments.

### 1.3 Information Acquisition and Analysis Automation in Cockpit Displays

One way to alleviate the potential impact of the distance bias on pilot judgments of TTC is to add features to displays that highlight TTC-related information. Two methods include: (1) encoding information as perceptual cues (e.g., color changes, blinking, etc.); or (2) presenting information in text form for the pilot. Since there is limited research on how to specifically highlight TTC information using such methods, it is useful to review the effectiveness of such methods for conveying other types of information to a pilot (e.g., relative altitude, separation distance at CPA, etc.).

#### 1.3.1 Perceptual Cues to Encode Information

##### 1.3.1.1 Color Change

The most common cue used to convey information to pilots in a display is color change. One reason color is so effective as a cue is that colors commonly have strong associations with specific meanings (Wickens, 1992). For example, the color green is associated with a system state being good, while yellow tends to indicate caution and red tends to indicate a warning or danger. These associations easily carry over into the aviation domain and can, therefore, be used effectively to convey information to a display user. A review of the literature on both aviation and non-aviation displays suggests that memory of
target colors decreases significantly less than memory of target size, orientation, or shape cues (Christ, 1975). Additionally, this review concluded that there is evidence color change cues are superior to size, brightness, and shape cues for both search and identification of information.

In the aviation domain, color change in display of targets has been used to convey different types of information to pilots. A study comparing color-change cues with textual representations for conveying relative altitudes of intruders (Beringer et al., 1993) confirmed the conclusions of Christ (1975). In Beringer et al. study, the color-encoded treatment displays yielded faster response times and more accurate altitude judgments than displays presenting textual information alone. In another study, a three-level alerting system for conveying miss distances was compared to a baseline display with no alerts (Xu, Wickens, & Rantanen, 2007). The alert display used cyan intruders to indicate no alert, yellow to indicate a low alert, and red to indicate high alert. Since these colors changed based on miss distances, pilots were able to estimate the distances more accurately in the alert condition than in the baseline condition. These two studies provide evidence that color can be used effectively to increase pilot performance and awareness of the states of intruder aircraft.

While it is important that performance improves when adding features to a display, it is equally important to ensure that pilot cognitive workload is not significantly increased with new display elements. Equally important, pilot acceptance ratings should be as high as possible or they may resist using new forms of automation. Lancaster et al. (2010) tested pilot acceptance and mental workload in a study of color change cues in an airport surface display. The study compared a baseline display with no alerts with a treatment display that
used yellow alerts to indicate caution and red alerts to indicate warning. A post-study questionnaire showed that the added features did not significantly increase pilot mental workload and they exhibited a preference for the display with color-coded alerts. Another study investigated the use of a display using two color-coding methods, each conveying different information about intruder aircraft (Riley et al., 2003). The first set of colors conveyed relative altitude information: blue for aircraft at a higher altitude, white for aircraft at the same altitude, and brown for aircraft at a lower altitude. This color scheme exploited meanings associated with colors. The blue intruders are associated with the blue sky and the brown intruders are associated with the ground; as in the color of dirt. Thus, a connection was likely made in the mind of the display user regarding the relative altitude associated with the colors. The second color cue was a conflict detection aid, which turned an intruder aircraft yellow when its projected distance at CPA was less than 5 nm. Overall, pilot acceptance of this color-coding system was 5.1 out of 7, indicating a high acceptance rate. The studies referenced in this section suggest that color change cues are not only useful in terms of increasing performance, but tend to have high acceptance rates without significantly increasing pilot cognitive workload.

1.3.1.2 Object Fill

Two of the studies using color-change cue also used visual object fill cue to convey information about intruder aircraft. For this investigation, “object fill” refers to changing from an outline of an intruder to a symbol that has been filled with a solid color. In addition to the color-change cues used in the airport surface display by Lancaster et al. (2010),
intruder symbols were filled when they were converging on a pilot’s ownship and left unfilled when not converging. In the Riley et al. (2003) experiment, the intruder aircraft symbols appeared solid yellow when the conflict alert was for an intruder at the same altitude as the pilot’s ownship, or as a yellow outline when the intruder was at a different altitude. In general, the performance and subjective acceptance ratings of using object fill to convey information were favorable in these two studies.

1.3.1.3 Other Perceptual Cues Used to Encode Information

Color change and object fill are the most widely used cues for information encoding for piloting applications; however, there are other types of cues that have been used in pilot display experiments. Hart and Loomis (1979) experimented with a display incorporating text information to indicate an intruder aircraft’s groundspeed. Results suggested that the addition of textual information alone did not improve pilot performance and was actually associated with an increase in pilot error. Another experiment tested the effectiveness of size and contrast of targets to convey relative altitude information (Palmer, Clausner, & Kellman, 2008). In the treatment scenarios utilizing intruder symbol size, a larger symbol represented an intruder at a higher altitude. Since all scenarios were viewed from a bird’s eye perspective looking down on the x-y plane, the display design exploited relative size cues for user depth judgments (Wickens, 1992). A larger image is associated with an object being closer than a smaller image; therefore, a larger image appears to have a higher altitude when viewed from the bird’s eye perspective. In the treatment scenarios utilizing contrast, contrast sharpness increased as intruder altitude increased. This design used the principle of aerial perspective in
depth judgments, which states that more distant objects tend to be less clearly defined than closer objects. Results showed that conflict detection in the two cue conditions was significantly better than in the baseline, no-cue scenario. The findings of these experiments suggest that textual information alone may not be beneficial to pilots, but size and contrast cues are useful for conveying relative altitude information since the cues take advantage of the way humans perceive depth in a two-dimensional image.

1.3.1.4 Redundant Perceptual Cues

Experimental displays have also been developed that exploit redundant cues to convey information to pilots. Palmer, Clausner, and Kellman (2008) used redundancy in one treatment trial of an experiment by combining size and contrast cues in the same display. While the response time for the redundant case was significantly shorter than that of the baseline case (i.e., no cue), the response time was not significantly shorter than in scenarios that used only one of the cues. In another study of an airport surface display, Jones et al. (2010) used various combinations of size, outline, color change and textual information to convey surface conflict warnings to pilots. A treatment display using these cues was compared to a baseline display with no conflict warnings. Results indicated that the outlines and size changes were rated as the most useful cues while the textual distance information was rated as somewhat useful. In addition to these results, Riley et al. (2003) and Zuschlag, Chandra and Grayhem (2011) concluded that pilots preferred more information in displays to be encoded with the perceptual cues used in their respective experiments. Overall, pilots
were receptive to redundant perceptual cues, but results suggest that redundant cues (specifically, combining size and contrast) may not improve response time.

### 1.3.2 Perceptual Cues to Capture Pilot Attention

Rather than using perceptual cues to encode information (e.g., color as a caution/warning, size to convey relative altitude, etc.), many experiments have used perceptual cues to attract pilot attention before conveying important information textually. As with the studies that used cues to encode information, color change has been widely used to capture display user attention. In his seminal literature review on the use of color in displays, Christ (1975) reported that color is inferior to an alphanumeric display for information encoding. Additionally, this review reported that information search time with color cues was significantly shorter than search time with size, brightness, shape and alphanumeric symbols across 42 different experiments. Similar research has indicated that these findings are consistent for pilot performance with aviation displays (Beringer et al., 1993). The results of these two studies suggest that the use a color change cue to attract pilot attention, followed by alphanumeric presentation of essential information, may be superior for performance in, for example, high-risk intruder identification with a CDTI.

Another cue that has been investigated is the use of a flashing intruder symbol in a display. Thackray and Touchstone (1991) tested the use of a baseline display with no cue compared to a series of treatment displays using color change, flashing, or a combination of the cues in a CDTI with 64 student participants. In all of the conditions, a data block displaying altitude and groundspeed information accompanied each intruder aircraft. The
detection times for flashing conditions were significantly lower than for non-flashing conditions. The same result occurred for color-change versus non-color-change conditions. In comparing the flashing cue to the color change cue, flashing cues had a significantly smaller detection time than the color cue. Using the flashing and color-change together also resulted in a significantly smaller detection time than the conditions that used only one of the two cues. Further, detection times using the flashing cue were not affected by task load or intruder position on the display, lending further support to the effectiveness of flashing targets.

1.3.3 Traffic Alert and Collision Avoidance System (TCAS)

The TCAS display, shown in Figure 1.2, is an existing system that uses perceptual cues to convey information about nearby traffic to pilots (Federal Aviation Administration, 2011). Unlike a CDTI, TCAS uses radar technology to determine the positions of surrounding aircraft, which does not provide the level of accuracy that can be achieved with a GPS-based system. TCAS uses a variety of cues to indicate the status of intruders for a pilot. Since it is a system that is currently mandatory in aircraft with a maximum takeoff weight of over 13,000 lbs., or authorized to carry 19 or more passengers, the design of such systems can provide insight into how to effectively present traffic information to pilots in a CDTI. When an intruder aircraft’s distance is less than 6 nm horizontally and 1,200 feet vertically (above or below ownship), the white diamond outline in the TCAS display becomes a filled white diamond. When the intruder’s TTC reaches a time threshold (between 20 sec and 48 sec, depending on altitude - see Appendix A), the solid white diamond becomes a solid
yellow circle; this is known as a “Traffic Advisory.” When the intruder’s TTC reaches the next threshold (between 15 sec and 35 sec, depending on the altitude), the TCAS issues a “Resolution Advisory” and the intruder symbol is turned to a solid red square. When this occurs, the pilot is instructed to immediately perform the maneuver presented by the TCAS system in order to avoid a collision with the intruder (i.e., the TCAS overrides ATC when a “Resolution Advisory” is issued). This system is meant to serve as a last resort to prevent a conflict in case there is any breakdown in communication between the pilot and ground-based ATC.

Figure 1.2: TCAS Display
1.3.4 Variables and Thresholds for Cue Changes

Table 1.1 presents the variables and thresholds used to cause perceptual cue changes in prior research on horizontal situation displays as well as TCAS. In the table, “current distance” refers to the actual, real-time distance between the intruder and ownship while “miss distance” refers to the projected distance between the two aircraft at CPA. Jones et al. (2010) manipulated TTC as an independent variable and experiment results showed that pilots preferred earlier alerts (i.e., alerts of a conflict approximately 30 sec before contact). Overall, the results from these experiments indicate that using a distance threshold (current distance or miss distance) is not effective for mitigating the effect of the distance bias through perceptual cue presentation. From a human information processing standpoint, this should be expected since these thresholds highlight the distance information for display users, which is sometimes incorrectly used to make relative threat assessments. Using a TTC threshold for cue changes would be expected to have a greater mitigating effect on pilot distance bias, as TTC is most relevant to relative threat judgments.
Table 1.1: Variables and Thresholds for Cue Changes

<table>
<thead>
<tr>
<th>Reference</th>
<th>Perceptual Cue</th>
<th>Driving Variable</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Funabiki, Iijima, &amp; Nojima (2004)</td>
<td>Color Change</td>
<td>Miss Distance</td>
<td>1 nm (Caution)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.6 nm (Warning)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time-to-Contact</td>
<td>25 sec (Warning)</td>
</tr>
<tr>
<td>Jones et al. (2010)</td>
<td>Multiple</td>
<td>Time-to-Contact</td>
<td>Early, Mid, Late</td>
</tr>
<tr>
<td>Lancaster et al. (2010)</td>
<td>Color Change</td>
<td>Time-to-Contact</td>
<td>30 sec (Caution)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15 sec (Warning)</td>
</tr>
<tr>
<td></td>
<td>Object Fill</td>
<td>Convergence</td>
<td>Converging</td>
</tr>
<tr>
<td>Riley et al. (2003)</td>
<td>Color Change</td>
<td>Miss Distance</td>
<td>5 nm</td>
</tr>
<tr>
<td>TCAS (FAA, 2011)</td>
<td>Object Fill</td>
<td>Current Distance</td>
<td>6 nm</td>
</tr>
<tr>
<td></td>
<td>Color Change</td>
<td>Time-to-Contact</td>
<td>Depends on Ownship Altitude</td>
</tr>
<tr>
<td>Xu, Wickens, &amp; Rantanen (2007)</td>
<td>Color Change</td>
<td>Miss Distance</td>
<td>3.5 nm (Caution)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.5 nm (Warning)</td>
</tr>
<tr>
<td>Zuschlag, Chandra, &amp; Grayhem (2011)</td>
<td>Object Fill</td>
<td>Current Distance</td>
<td>6 nm</td>
</tr>
</tbody>
</table>

1.4 Attention Allocation in Display Use

Pilots often perform multiple tasks simultaneously in the cockpit. Consequently, it is important to examine the effect of any change in cockpit interfaces on pilot allocation of attentional resources. This is often accomplished by tracking gaze patterns between the instrument panel, out-of-cockpit view, and CDTI. Wickens, Helleberg and Xu (2000) examined the difference in pilot attention allocation in a GA cockpit integrating a CDTI for higher-workload “conflict” trials (i.e., trials in which one or more intruders were projected to conflict with ownship) vs. lower-workload “non-conflict trials” (i.e., trials in which intruders were visible but were not projected to conflict with ownship). In the lower workload trials, pilots spent 16% of the time gazing at the CDTI while in the higher workload trials, they looked at the CDTI 28% of the time. These values provide a baseline for which to compare
attention allocation in research on using displays in the cockpit. In a similar experiment testing the use of assistive automation in an electronic moving map (EMM) display of airport ground traffic compared to a baseline EMM with no automation, Lorenz and Biella (2006) found that the attention allocated to the EMM decreased for both expert and novice pilots in trials for which the automation was active. The automation provided pilots with airport runway and taxiway configurations (which were colored green if they were clear of all traffic or red if they were unsafe for use), the route the pilot was cleared to travel to reach his or her destination gate, depictions of proximate traffic accompanied by their distances from ownship, and data-linked communication in some display configurations. These results suggest that adding assistive automation to a CDTI decreases the amount of attention required by the CDTI; thus, freeing pilot attentional resources for the instrument panel, other cockpit interface or the out-of-cockpit view.

1.5 Motivation

Based on the findings from the existing literature, there is evidence that the effect of the distance bias could be mitigated with enhancements to CDTIs. Enhancements addressing this issue with CDTI use likely have not yet been implemented because a small percentage of GA aircraft are equipped with GPS transponders, thus limiting the number of aircraft that can be presented on a CDTI display. As more aircraft are designed with GPS capabilities, it is envisioned that more research will be dedicated toward display design and how to effectively convey critical information to the pilot.
Based on the conclusions of Christ (1975) and Beringer et al. (1993), a superior method for conveying information to a pilot is to use a perceptual cue to capture pilot attention accompanied by an alphanumeric representation of the relevant information. Referencing the model presented by Parasuraman, Sheridan, and Wickens (2000), this type of automation assists pilots in the information acquisition and information analysis phases of processing, compared to the baseline CDTI. When implemented effectively, such automation assistance can reduce pilot workload without negatively affecting SA; more information is provided to pilots but they retain decision making and action authority. Furthermore, by presenting the velocity as opposed to the TTC, there is little risk in pilots lacking trust in the feature; pilots may be hesitant to trust a metric that is derived using two variables (i.e., automatic calculation of the TTC based on the distance and velocity) as opposed to simply using the velocity, which is obtained from an aircraft’s raw sensor data. Also, trajectory projection is a new technology for cockpit displays so many pilots may not be accustomed to using this type of information. The velocity presentation requires pilots to perform mental arithmetic to make a TTC judgment, but simplifies the process by removing the uncertainty in their velocity estimations. According to Endsley’s model of SA, perceptual cueing supports “level 1 SA;” or identification of aircraft states. The alphanumeric display of information contributes to “level 2 SA;” that is, comprehension of perceived cues relative to flight goals. Once level 2 SA has been achieved, the pilot may be able to achieve “level 3 SA;” or project future states of the aircraft. Achieving level 3 SA may ultimately facilitate more accurate TTC judgments.
Law et al. (1993) reported that with training, relative distance judgments become more accurate, but the accuracy of relative velocity and, consequently, relative TTC judgments do not significantly improve. These findings highlight the importance of displaying velocity information to pilots in a CDTI; thus, reducing the amount of information processing required by the pilot compared to displays with which they must estimate an intruder’s rate of speed. Similarly, Hickey (1990) reported that novice or “low ability” participants had difficulty integrating speed and distance into a TTC judgment, as compared with expert or “high ability” participants. Further, the “low ability” participants made worse judgments when they attempted to estimate object velocity than when they simply used the distance information. It is unsafe to assume that all pilots who use a CDTI have “high ability” in TTC estimation. The findings on participants with “low ability” in TTC estimation further emphasize the importance of displaying intruder velocity textually in a CDTI.

There is substantial evidence in the literature that designing displays with color cues can be highly effective for drawing user attention to the relevant information. However, based on the results of the experiment performed by Thackray and Touchstone (1991), there is evidence that a blinking cue could be more effective than a color-change cue for this purpose. In accordance with these results, either cue might be used effectively in a CDTI to draw pilot attention to an intruder aircraft posing the highest risk in a traffic situation.

Based on the information summarized in Table 1.1, there are distance and TTC thresholds that can be used to trigger cue changes in a CDTI:
1. A cue may activate if the projected distance between ownship and an intruder at CPA (i.e., minimum miss distance) is less than 5 nm. Air traffic controllers use this distance threshold operationally.

2. There is evidence that a 40-second TTC threshold may be effective for alerting pilots of an intruder with high risk of collision. A TTC threshold may increase pilot performance in assigning relative risk to intruders, as compared to a distance threshold. Jones et al. (2010) found that pilots tended to prefer an early TTC threshold when using a traffic information display.

1.6 Objectives

The overarching objective of this research was to identify superior forms of CDTI design for effectively communicating TTC information without significantly increasing pilot visual attention demands and cognitive workload. An experiment was conducted to test the effect of various forms of CDTI content and formatting for mitigating the effect of the distance bias exhibited by GA pilots when assigning conflict risk to intruders. In specific, the study tested the effect of textually presenting intruder velocity as well as the effect of adding blinking or color changes to display icons representing intruders in a prototype CDTI. In addition to assessing the overall effect of the added information and display formatting, the research determined which perceptual cue, blinking or color change, most effectively captured pilot attention, facilitated quick and accurate risk assessments, and yielded more favorable subjective ratings.
2 Method

2.1 Participants

Fourteen (14) male certified pilots participated in a flight simulation experiment. This number of participants was consistent with the number of participants used in the studies examined in the literature review, which generally used 10-20 certified pilots. Defining this range with a minimum of ten ensured that the statistical model had the requisite degrees of freedom to provide valid and accurate inferences. The final sample size of fourteen was based on real-time review of the response data and the significance of the effects to ensure sensitivity of the statistical tests.

The fourteen pilots who participated had an average age of 37.14 years (range: 21-66, standard deviation: 16.04). All participants had 20/20 or corrected vision. Nine pilots had private certification and five had commercial certification. Those who had a commercial rating indicated no commercial flight hours; they simply had enough total hours to qualify for the commercial certification. The mean total flight time for the participants was 646.5 hours (range: 73-2,500, standard deviation: 717.27). Eight participants indicated experience using a CDTI (either in an aircraft or in a simulator). Among those with experience, the mean rating was 26.9 out of 100 (range: 1-70, standard deviation: 21.1). This observation generally indicated a low level of display use experience.
2.2 Independent Variables

Three independent variables were manipulated in the experiment, including: first-arrival start distance (FASD; as simulated in the prototype CDTI), perceptual cue type, and the presence or absence of the velocity data tag. The experiment tested two levels of the FASD: 2 nm and 3 nm. In the 2-nm FASD scenarios, the intruder aircraft designated to collide first with ownship started the scenario 2 nm from the conflict point while a second intruder started at 3 nm. In the 3-nm FASD scenarios, the intruder designated to collide first with ownship started the scenario 3 nm from the conflict point while a second intruder started at 2 nm. Performance in the 3-nm FASD scenarios was expected to be influenced by the distance bias since the relative start distances of the intruders did not reflect the relative TTCs. The three levels for the perceptual cue were baseline (i.e., no cue), blinking, and color-change. The perceptual cue alerted the pilot that an intruder crossed the 40-second TTC threshold (i.e., the cue was activated when the intruder’s TTC was 40 sec or less). Again, this is the threshold used in TCAS systems. When the blinking cue was active, the intruder icon blinked at a rate of 2.51 Hz (based on the processing speed of the computer system used to present the CDTI prototype). When an intruder changed colors, it changed from the baseline color of teal to yellow. These colors are commonly used in existing CDTIs for intruder icons. The velocity tag, when present, appeared directly above the intruder and indicated the intruder’s speed in knots (kt; nm per hr). The intruder icons are presented in Figure 2.1.
2.3 Experiment Design

A completely within-subject design was utilized for the experiment. In each trial, two intruders appeared on the prototype CDTI and both were on a collision course with the pilot’s ownship. The two FASDs were crossed with two velocities (120 kts and 240 kts) resulting in four TTCs (shown in Table 2.1) and two types of trials: one with TTCs of 30 sec and 60 sec and another with TTCs of 45 sec and 90 sec. Four conflict angles were used (45, 135, 225, and 315 degrees; see Figure 2.2). There were no scenarios in which both intruders approached from the same conflict angle. Any scenarios with two trailing intruders (i.e., conflict angles of 45 and 315 degrees) or two head-on intruders (i.e., conflict angles of 135 and 225 degrees) were not included in order to promote the complexity of conflict judgments and reduce the total number of trials. The combinations of start distances, velocities, and conflict angles resulted in 16 unique traffic scenarios. Each scenario was tested with each display format, resulting in a total of 96 trials (3 cues * 2 data tag conditions * 16 scenarios) for each participant. The experiment was performed in blocks of each combination of
perceptual cue and data tag to allow for subjective ratings of each unique display content and format. Within each block, the order of the 16 scenarios was randomized and, for each experiment, the order of the blocks was randomized within-subjects to prevent any order effects.

Table 2.1: Intruder TTCs

<table>
<thead>
<tr>
<th>Intruder</th>
<th>Velocity</th>
<th>Starting Distance from CPA</th>
<th>Time to Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Arrival</td>
<td>240 kt</td>
<td>2</td>
<td>30 sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>45 sec</td>
</tr>
<tr>
<td>Second Arrival</td>
<td>120 kt</td>
<td>2</td>
<td>90 sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>60 sec</td>
</tr>
</tbody>
</table>

Figure 2.2: Labeling of Intruders by Conflict Angle
In all scenarios, the aircraft flying at 240 kts arrived at the collision point before the aircraft traveling at 120 kts regardless of whether it had a starting distance of 2 nm or 3 nm. This yielded eight scenarios in which the intruder starting at a distance of 3 nm was the first arrival and eight scenarios in which the intruder starting at 2 nm was the first arrival. This design facilitated testing of whether the added perceptual cue and/or data tag features mitigated the effect of the distance bias. The first arrivals were balanced such that there were four instances in which the first arrival had a conflict angle at each of the four angles (i.e., four instances where the 45-degree intruder was the first arrival, four instances where the 135-degree intruder was the first arrival, etc.). This balancing was done to eliminate any effect of the conflict angle on the pilot’s TTC judgments or subjective ratings of the automation levels.

2.4 Apparatus and Scenario

The experiment was performed using the flight simulator in the Ergonomics Lab in the Department of Industrial and Systems Engineering at North Carolina State University (shown in Figure 2.3). The simulator hardware included an X-Plane workstation, yoke control, throttle controls, and rudder pedals. Two Dell OptiPlex workstations were integrated with a flat panel display and a touchscreen at the workstation. The simulation software was X-Plane Version 10 and the aircraft model flown was a Cessna 172 aircraft. The aircraft out-of-cockpit view and cockpit displays and controls were presented on one of the computer screens directly in front of the participant. The flight was controlled using the yoke, rudder pedals, and throttle controls, to the right of the participant. During each block of trials, the
participant was required to track a heading of 0 degrees and a vertical velocity of 0 ft/min (i.e., maintain straight and level flight). The simulation was not integrated with the intruders shown in the prototype CDTI; the flying task served only as a secondary loading task while the pilot used the CDTI to make TTC judgments. To increase the realism of the simulation, speakers were set to project an in-cockpit sound level of 88.3 dBA, which is the approximate noise level experienced by Cessna 172 pilots when wearing a circumaural headset (Lamm & Lawrence, 2010).

![Experiment Simulator Setup](image)

**Figure 2.3: Experiment Simulator Setup**
The touchscreen display was positioned to the right of the out-of-cockpit view and presented the prototype CDTI. Shown in Figure 2.4, the prototype CDTI was developed with the C++ programming language using the Open Graphics Library (OpenGL). The prototype was a replicate of the Garmin GMX200 model CDTI, which is a popular display currently used in GA aircraft (this is the model shown in Figure 1.1). The participant was told that in all scenarios: (1) the ownship was flying a straight and level course to a waypoint above and out of the range of the screen; (2) all intruders were at the same altitude as the ownship; and (3) the miss distance of all of intruders was 0 nm, placing them on collision courses with the pilot’s ownship. The participant selected the first arrival (highest risk intruder) by touching the particular intruder using the touchscreen interface.

Figure 2.4: Screenshot of the Prototype CDTI
The perceptual cues (e.g., blinking intruder icons) and velocity data tags used in the prototypes were activated according to the TCAS algorithm; that is, when an intruder crossed the 40-sec TTC threshold the cues were triggered. Therefore, in scenarios in which the TTC of the first arrival was 30 sec, the added display feature was active when the scenario began. In the scenarios in which the TTC of the first arrival was 45 sec, the perceptual cue and/or data tag was not triggered until five seconds had elapsed from the start of the scenario. The levels of the FASD independent variable captured these two types of scenarios.

2.5 Dependent Variables

2.5.1 Performance Measures

Three performance measures were examined in the experiment, including pilot accuracy in selecting the correct target (highest risk intruder) as well as the response time (RT) for selection. Additionally, pilot visual attention allocation to the aircraft “dashboard” vs. the CDTI was assessed using video-based glance analysis in order to compare the different CDTI formats and content. A work sampling technique (Niebel & Freivalds, 2003) was used in which an observer with no knowledge of the hypotheses of the experiment recorded pilot gaze direction at one-second intervals during times when the CDTI was active (no eye-tracking hardware or software was used). Slow-motion video recordings of pilots’ faces during experimentation were synchronized with the CDTI activation times for each flight scenario. The observer painstakingly watched each video to record the gaze direction from moment to moment.
2.5.2 Subjective Ratings

After each block of 16 trials, subjective ratings of workload, confidence, and display effectiveness were collected. Upon completion of the experiment, display preference ratings, ease of understanding, and perceived performance ratings were collected. All ratings were collected on a continuous scale with anchors of “low” and “high”, shown in Figure 2.5. Ratings were measured from the “low” anchor with a resolution of 0.5mm and transformed to a 100-point scale.

![Continuous Ratings Scale with Two Anchors](image)

**Figure 2.5: Continuous Ratings Scale with Two Anchors**

2.6 Procedure

Every participant performed the experiment as presented in the experiment procedure (Appendix B). To begin the experiment, participants were presented with an informed consent form for signature (shown in Appendix C), indicating that he or she consented to participate in the experiment. Once completed, the participant was given a demographic survey, which requested basic background information (Appendix D). After completion of the demographic form, participants were escorted to the flight simulator. They were shown the various flight controls and were allowed up to 5 min to fly the simulated Cessna 172 Aircraft on a straight and level course without using the prototype CDTI. Once the
participant was comfortable with the flight controls, he was introduced to the prototype CDTI functionality and was required to complete a series of training trials using the software until comfortable with its operation.

At the beginning of each block of trials, the participant was informed of the display content and format to be presented in the subsequent scenarios (i.e., which cues would be used and whether the velocity tag would be present). When the participant was ready, the experimenter started the flight simulator and the participant was told that when comfortable, he could start the CDTI scenarios. Before starting a scenario, the CDTI screen was blank and simply said, “Touch Anywhere to Begin”. When the participant touched the screen, the air traffic scenario started immediately. When an intruder was selected, the CDTI returned to the blank introductory screen (the prototype CDTI operation is depicted in 0). Therefore, as the participant flew on a straight and level flight path, he was able to start the next scenario at his convenience. After a block of 16 trials, a blank screen appeared indicating that the block was complete and the experimenter handed the participant a subjective rating form (0). This procedure was repeated for the remaining five blocks of trials. After the third block, the participant was given the opportunity to take a short break, if desired. At the conclusion of the trials, the participant was handed a post-experiment questionnaire for the preference, ease of use, and performance ratings (see Appendix G). In total, the duration of the experiment was approximately 1 hour and all participants were compensated at a rate of $20 per hour.

2.7 Hypotheses

The following hypotheses were formulated based on the review of the literature:
1. The addition of blinking cues, color-change cues, and velocity data tags to the CDTI will reduce/mitigate the effect of the distance bias, as evidenced by increased accuracy in first arrival intruder selection in scenarios where the distance bias is expected to affect pilot intruder selection.

2. The mean RT for pilots using the blinking cue display will be lower than the RT when pilots use the color-change display. Both blinking and color-change will produce lower RTs than the baseline display, in which no cue is presented. These differences will be greatest in scenarios where the distance bias is expected to affect the RT.

3. The mean RT for displays including the velocity data tag will be shorter than for displays without the data tags, particularly in scenarios where the distance bias is expected to affect the RT.

4. The displays using the blinking or color-change perceptual cues will require a smaller proportion of pilot attention (i.e., a reduced gaze frequency for the CDTI) than the baseline displays.

5. The displays containing the velocity data tag will require less attention than those that do not contain the velocity data tag since the tag serves to decrease the processing time and cognitive workload imposed on pilots.

6. Pilots will report lower workload for displays that utilize the blinking cue, color cue, or velocity data tag than those that do not utilize them.

7. Pilots will report higher confidence in high-risk intruder selection for displays that use blinking cues, color cues, or velocity data tags than in those that do not.
8. Pilots will report high effectiveness, ease-of-understanding, and perceived performance ratings for the displays that use blinking cues, color cues, or velocity tags.

9. The majority of pilots (>50%) will prefer color-change displays, followed by blinking displays as compared with the baseline displays. Pilots will also prefer the presence of the velocity data tags to displays that do not present the data tags.

2.8 Data Analysis

In analyzing intruder selection accuracy based on pilot projections of TTC, contingency analyses were used to assess the effect of the three levels of perceptual cue and the two levels of the velocity data tag. If an intruder was selected before a display feature was presented (cue and/or data tag at the 40 sec TTC threshold), the trial was classified as a “baseline-absent” trial (i.e., no perceptual cue or data tag was present at the time of the pilot’s decision). For all contingency analyses, the likelihood ratio $\chi^2$ test statistics are reported. In two trials, pilots encountered a malfunction in using the touch screen to select an intruder. These two observations were removed from the analyses, leaving 1,342 data points for analysis.

An analysis of variance (ANOVA) was used to assess the effects of display format and content on pilot response time. The model was structured as a split-plot design with two error terms, one based on the variability between the participant*cue*tag blocks, and one based on the individual scenarios within the blocks. The model included a full crossing of perceptual cue type, data tags, and FASDs. The Tukey post-hoc tests for the main effects of
cue and data tag as well as the interaction effect between the two were assessed using the whole-plot error term. The remaining post-hoc tests utilized the subplot error. In 118 trials, the prototype CDTI did not register a pilot’s selection when he first attempted to select one of the intruders, either because the participant did not touch the screen within the boundaries of an intruder icon or did not press hard enough. These 118 trials were excluded from analysis along with 44 additional trials in which pilot intruder selection was incorrect (i.e., RT associated with a selection error was not of interest to the study), leaving 1,182 observations for the RT analyses. As with the contingency analyses, if an intruder was chosen before a display manipulation was presented, the display was considered a “baseline-absent” display type in the analysis.

Diagnostics were conducted on an ANOVA model of the untransformed RT and revealed violations of the normality and homoscedasticity assumptions of the parametric test. A plot of the model residuals against the predicted values revealed increasing deviation of the residuals with larger predicted values and a normal probability plot of the residuals confirmed that they were not normally distributed. Consequently, a log transformation was applied to the response measure in order to address the non-constant variance across levels of pilot performance, as recommended by Montgomery (1991) and Neter, Wasserman and Kutner (1990). The transformation was effective in stabilizing the variance and providing a distribution which better resembled a normal distribution (see Figure 2.6); however, a Shapiro-Wilk test proved the log-transformed RT to be non-normal (W = 0.965, p < 0.001) and Bartlett tests conducted on the main effect terms revealed significant heteroscedasticity for the perceptual cue (F(2,1179) = 9.523, p < 0.001) and FASD (F(1,1180) = 45.510, p <
0.001) and homoscedasticity for the data tag (F(1,1180) = 1.658, p = 0.198). To address these issues, two rank-transformed models were analyzed: one that utilized a rank transformation on the untransformed RT as the response and one that utilized a rank transformation on the log-transformed RT data. The results of the both rank-transformed models were identical to the results revealed by the log-transformed RT models. According to Montgomery (1991), the similarity between the results of the nonparametric rank-transformed models and the parametric log-transformed model is sufficient to conclude that the log-transformed model is valid (i.e., the model is robust to any violations of the normality or homogeneity of variance assumptions). Therefore, all RT results presented below are based on the parametric, split-plot ANOVA on the log-transformed response.

![Normal Probability Plots](image_url)

**Figure 2.6: Normal Probability Plots for Response Time (Left) and the Log-Transformed Response Time (Right)**
Diagnostics were conducted on the distribution of the proportion of glances to the CDTI for each display setting, including an assessment of normality using a normal probability plot. Both the response data within levels of the IVs as well as the distribution of the model residuals were found to be non-normal in nature. Consequently, the gaze proportion response was transformed to global ranks and a non-parametric ANOVA was applied. The ANOVA model was structured similarly to the RT model, utilizing a split-plot design with a whole-plot error term (to account for blocks of participant*cue*tag) and a subplot error term. The model included a full crossing of the cue, data tag, and FASD and used participant as a blocking variable. As with the RT model, the Tukey post-hoc tests performed on the cue, tag, and cue*tag effects were assessed using the whole-plot error while the remaining post hoc tests used the subplot error. The data set included the same 1,182 observations that were analyzed in the RT analysis. Since the scenarios were not of a fixed duration (i.e., the elapsed time of each scenario differed due to termination being dependent on the timing of participant selection of an intruder icon), the number of observations within each trial differed. The mean number of glance observations for each trial was 7.31 (range: 1-42, standard deviation: 6.66). A normal probability plot of the residuals resulting from the model with the rank-transformed response revealed the residuals to be normally distributed around a mean on zero, satisfying the normality assumption of the ANOVA

Due to the lack of normality of the CDTI gaze proportions, a Multivariate Analysis of Variance (MANOVA) could not be performed on all pilot performance measures. However, a non-parametric correlation analysis was performed to assess the relationship between pilot RT and the CDTI gaze proportion. The analysis was conducted using the Spearman’s ρ test.
An ANOVA was applied to the pilot subjective ratings of workload, high-risk intruder selection confidence, display effectiveness, and perceived performance. Unless otherwise noted, the models included the main effects of perceptual cue type and data tag presence, the two-way interaction effect, and participant as a blocking variable. One-tailed t-tests and 95% confidence intervals were conducted on the ease of understanding ratings in order to assess whether the mean rating for each display format and content combination was statistically greater than the scale’s midpoint. Student’s t tests were also used to assess whether there was a difference in mean ratings between the perceptual cue and data tag ratings. All ratings were made on the continuous scale shown in Section 2.5.2 with translated values ranging from 0-100. A value of zero indicated the lowest workload, lowest confidence, lowest effectiveness, etc. and a value of 100 indicated the highest. The residuals for all of the subjective-rating ANOVA models in this section were normally distributed with a mean of zero via inspection of diagnostic plots. Finally, counts are presented for display feature preference and the most helpful display feature.
3 Results

3.1 Performance Measures

3.1.1 Intruder Selection Accuracy

The contingency analysis conducted on the intruder selection accuracy used the FASD as a grouping variable in order to determine whether the cue mitigated the effect of the distance bias in scenarios for which the FASD was 3 nm. The analysis revealed a significant effect of the cue type when the FASD was 3 nm ($\chi^2 = 13.47$, $p = 0.001$), but not when the FASD was 2 nm ($\chi^2 = 2.20$, $p = 0.333$). Table 3.1 reveals the percentage of correct intruder selections was significantly higher when blinking ($\chi^2 = 10.30$, $p = 0.001$) or color-change ($\chi^2 = 8.82$, $p = 0.003$) cues were used in the displays compared to the baseline display when the FASD was 3 nm (i.e., the condition in which pilots were expected to be most susceptible to the distance bias). However, there was no significant difference between the blinking and color change displays when the FASD was 3 nm ($\chi^2 = 0.06$, $p = 0.807$). The full contingency tables comparing the three levels of the cue when the FASD was 3 nm can be found in Appendix H.
Table 3.1: Effect of Cues on Intruder Selection Accuracy

<table>
<thead>
<tr>
<th>Count</th>
<th>First Arrival Start Distance: 2 nm</th>
<th>First Arrival Start Distance: 3 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Correct</td>
<td>Incorrect</td>
</tr>
<tr>
<td>Baseline</td>
<td>224</td>
<td>0</td>
</tr>
<tr>
<td>Blinking</td>
<td>223</td>
<td>1</td>
</tr>
<tr>
<td>Color</td>
<td>224</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>671</td>
<td>1</td>
</tr>
</tbody>
</table>

The contingency analyses examining the effect of the velocity data tags in the CDTI were also separated based on the FASD setting in order to determine whether the data tag mitigated the effect of the distance bias. Analyses revealed there to be no significant effect of the velocity data tag on intruder selection accuracy in scenarios in which the FASD was 2 nm ($\chi^2 = 1.39$, $p = 0.239$) and in scenarios in which the FASD was 3 nm ($\chi^2 = 2.42$, $p = 0.120$). The results are presented in Table 3.2.
Table 3.2: Effect of Data Tags on Intruder Selection Accuracy

<table>
<thead>
<tr>
<th>Count Row% Expected</th>
<th>First Arrival Start Distance: 2 nm</th>
<th>First Arrival Start Distance: 3 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Correct</td>
<td>Incorrect</td>
</tr>
<tr>
<td><strong>Absent</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>335</td>
<td>335</td>
<td>1</td>
</tr>
<tr>
<td>99.70%</td>
<td>0.30%</td>
<td>0.50</td>
</tr>
<tr>
<td>335.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Present</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>336</td>
<td>336</td>
<td>0</td>
</tr>
<tr>
<td>100.00%</td>
<td>0.00%</td>
<td>0.50</td>
</tr>
<tr>
<td>335.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>671</td>
<td>1</td>
</tr>
</tbody>
</table>

A third set of contingency analyses was performed to assess the effect of the various combinations of the perceptual cue type and data tag on pilot decision making, similar to analyzing an interaction in an ANOVA. Six separate contingency analyses were generated for each combination of cue type and data tag. Overall, there was a significant effect of the FASD on intruder selection accuracy for every combination except for the blinking-absent display format. Further, the likelihood ratio test statistic was smaller for all display formats featuring a perceptual cue and/or a velocity data tag. The results of these six contingency analyses are presented in Table 3.3.
Table 3.3: Contingency Analysis Statistics for the Effect of FASD on Intruder Selection Accuracy

<table>
<thead>
<tr>
<th>Cue</th>
<th>Data Tag</th>
<th>Likelihood Ratio $\chi^2$</th>
<th>p-Value</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>Absent</td>
<td>28.30</td>
<td>&lt;0.001*</td>
<td>2nm &gt; 3nm</td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td>11.39</td>
<td>0.001*</td>
<td>2nm &gt; 3nm</td>
</tr>
<tr>
<td>Blinking</td>
<td>Absent</td>
<td>2.98</td>
<td>0.084</td>
<td>2nm = 3nm</td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td>5.62</td>
<td>0.018*</td>
<td>2nm &gt; 3nm</td>
</tr>
<tr>
<td>Color</td>
<td>Absent</td>
<td>5.66</td>
<td>0.017*</td>
<td>2nm &gt; 3nm</td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td>8.48</td>
<td>0.004*</td>
<td>2nm &gt; 3nm</td>
</tr>
</tbody>
</table>

3.1.2 Response Time

Analysis of the log-transformed RT revealed significant main effects for cue type (F(2,65) = 32.98, p < 0.001), data tag (F(1,65) = 10.89, p = 0.002), and FASD (F(1,1092) = 13.82, p < 0.001) as well as two-way interactions between the cue type and data tag (F(2,65) = 4.99, p = 0.010), the cue type and FASD (F(2,1092) = 10.19, p < 0.001), and the data tag and FASD (F(1,1092) = 15.70, p < 0.001). The three-way interaction included in the statistical model did not prove significant in terms of the log RT (F(2,1092) = 2.57, p = 0.077). Due to the presence of the two-way interactions, the simple effects of the model were analyzed. Figures 3.1-3.3 present the results on the simple effects analyses on RT. The number overlaid near the top of each bar is the average, non-transformed RT (the values are presented in the original units of the response to facilitate interpretation). The error bars displayed in the charts show one standard deviation on the positive side of the bar and the letters overlaid at the base of the bars are the Tukey Honestly Significant Difference (HSD) post-hoc groupings conducted on the log-transformed RT.
A chart displaying the RTs for the six cue type by data tag combinations is presented in Figure 3.1. The RT was longest for the “baseline-absent” display type, followed by the “baseline-present” type. The displays integrating a blinking or color-change cue generally resulted in a shorter RT than the baseline displays. Additionally, with the exception of the baseline displays, the presence of the velocity data tag had little effect on the RT. The Tukey HSD groupings confirmed these trend observations. All of the display types resulted in significantly shorter RTs than the “baseline-absent” type. The “blinking-present” display type produced (on average) the shortest RT, although it was not significantly shorter than the “blinking-absent” display or either of the color displays.

Figure 3.1: Tukey HSD Groupings for the Interaction Between Cue Type and Data Tag
The mean RTs for the interaction between cue type and FASD are shown in Figure 3.2. The mean RTs were longer for the baseline displays than for the blinking or color-change displays, regardless of whether the FASD was 2 nm or 3 nm. Additionally, the mean RTs and their standard deviations were generally greater when the FASD was 3 nm, as compared to when the FASD was 2 nm. The Tukey HSD post-hoc groupings provided evidence that the mean RT for the baseline display was significantly longer than the mean RT for either the blinking or color-change displays within each FASD (p < 0.05). The mean RT for the blinking displays was (on average) shorter than the mean RT for the color-change displays for both FASDs; however, this difference was not statistically significant. Between FASDs, the mean RTs for the blinking and color-change displays were significantly shorter when the FASD was 2 nm than when the FASD was 3 nm (p < 0.05). However, there was no significant difference between the mean RTs for the FASDs when the baseline displays were used.
The effect of the interaction between the data tag and the FASD on RT is presented in Figure 3.3. Within FASD, displays in which the data tag was absent resulted in longer RTs than those in which the data tag was present. Additionally, as was seen with the cue by FASD interaction, the mean RTs and corresponding standard deviations were generally larger when the FASD was 3 nm, as compared to scenarios in which the FASD was 2 nm. The Tukey HSD post-hoc test results supported these trends.
Figure 3.3: Tukey HSD Groupings for the Interaction Between Data Tag and FASD

3.1.3 Pilot Attention Allocation

The split-plot ANOVA on the rank-transformed proportion of gazes to the CDTI revealed a significant main effect of FASD (F(1,1092) = 133.78, p < 0.001), but no main effect of the cue type (F(2,65) = 1.65, p = 0.199) or data tag (F(1,65) = 0.75, p = 0.389). The analysis also revealed a significant two-way interaction between cue type and FASD (F(2,1092) = 5.55, p = 0.004), but no significant interaction between cue and data tag (F(2,65) = 2.52, p = 0.088) or data tag and FASD (F(1,1092) = 2.57, p = 0.109). The three-way interaction between cue type, data tag, and FASD was also significant (F(2,1092) = 4.63, p = 0.010). Due to the presence of the interactions, the analysis focused on the effects
from the three-way interaction as well as the simple effects obtained from the significant two-way interactions.

The three-way interaction for the effect on the mean gaze proportion to the CDTI was assessed using Tukey’s HSD post-hoc test. The groupings of means are presented in Figure 3.4. As the chart shows, the proportion of attention allocated to the CDTI in the 3-nm FASD scenarios was generally smaller than that of the 2-nm FASD scenarios. Furthermore, it appeared that attention allocation was generally higher when the data tag was present compared to scenarios in which it was absent. The cue type generally did not have a substantial effect on the pilot visual attention allocation. Due to the lack of definitive trends and difficulty in interpreting the statistical results from the analysis of the three-way interaction, the simple effects for the significant two-way interactions were also examined.
The simple effects for the interaction between the cue type and FASD are presented in Figure 3.5. Within each level of cue type, the proportion of gazes to the CDTI was significantly higher for the 2 nm FASD scenarios compared to the 3 nm FASD scenarios ($p < 0.05$). Additionally, within the 3 nm FASD scenarios, the proportion of visual attention required by the CDTI was significantly lower when the display used the blinking or color change features compared to the baseline displays. There was no difference in the gaze proportions for the cue levels when the FASD was 2 nm. These trend observations were supported by the Tukey HSD post-hoc test results.
3.1.4 Correlation Analysis

A correlation analysis was performed to assess the relationship between pilot RT to a traffic situation and the proportion of pilot gazes to the CDTI in those scenarios where the pilot selected the correct intruder. The non-parametric Spearman’s \( \rho \) test was used for this analysis as neither untransformed response was normally distributed. The test revealed a significant negative correlation between the RT and the gaze proportion (\( \rho = -0.434, p < 0.001 \)). Figure 3.6 presents the scatterplot for the two response measures along with a trend line. The plot reveals the RT to increase as the proportion of pilot gazes to the CDTI decreases.
Spearman correlation analyses were also performed for each combination of cue type and data tag; the correlation coefficients and their p-values are presented in Table 3.4. The table shows the association between the RT and the proportion of gazes to the CDTI to be strongest for the “baseline-absent” display type and weakest for the “blinking-present” type.

Table 3.4: Spearman Correlation Coefficients for Each Cue Type by Data Tag Combination

<table>
<thead>
<tr>
<th>Rank</th>
<th>Cue</th>
<th>Data Tag</th>
<th>Spearman’s $\rho$</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Baseline</td>
<td>Absent</td>
<td>-0.607</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2</td>
<td>Color</td>
<td>Absent</td>
<td>-0.583</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>3</td>
<td>Color</td>
<td>Present</td>
<td>-0.579</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>4</td>
<td>Baseline</td>
<td>Present</td>
<td>-0.493</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>5</td>
<td>Blinking</td>
<td>Absent</td>
<td>-0.467</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>6</td>
<td>Blinking</td>
<td>Present</td>
<td>-0.249</td>
<td>0.001</td>
</tr>
</tbody>
</table>
3.1.5 Summary of Results

A summary of the results for the intruder selection accuracy, RT to traffic situations, and attention allocation analyses is presented in Table 3.5.
Table 3.5: Summary of Performance Measure Results

<table>
<thead>
<tr>
<th>Response Statistical Test Transformation</th>
<th>Independent Variable</th>
<th>Result</th>
<th>p-Value</th>
<th>Post-Hoc Comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intruder Selection Accuracy</td>
<td>Cue (FASD=2nm)</td>
<td>$\chi^2$=2.20</td>
<td>0.333</td>
<td>Not Significant</td>
</tr>
<tr>
<td></td>
<td>Cue (FASD=3nm)</td>
<td>$\chi^2$=13.47</td>
<td>0.001*</td>
<td>C&gt;BA &amp; BL&gt;BA</td>
</tr>
<tr>
<td></td>
<td>Data Tag (FASD=2nm)</td>
<td>$\chi^2$=1.39</td>
<td>0.239</td>
<td>Not Significant</td>
</tr>
<tr>
<td>Contingency</td>
<td>Data Tag (FASD=3nm)</td>
<td>$\chi^2$=2.42</td>
<td>0.120</td>
<td>Not Significant</td>
</tr>
<tr>
<td></td>
<td>FASD (BA*A)</td>
<td>$\chi^2$=28.30</td>
<td>&lt;0.001*</td>
<td>2nm&gt;3nm</td>
</tr>
<tr>
<td></td>
<td>FASD (BA-P)</td>
<td>$\chi^2$=11.39</td>
<td>0.001*</td>
<td>2nm&gt;3nm</td>
</tr>
<tr>
<td></td>
<td>FASD (BL*A)</td>
<td>$\chi^2$=2.98</td>
<td>0.084</td>
<td>Not Significant</td>
</tr>
<tr>
<td></td>
<td>FASD (BL*P)</td>
<td>$\chi^2$=5.62</td>
<td>0.018*</td>
<td>2nm&gt;3nm</td>
</tr>
<tr>
<td></td>
<td>FASD (C*A)</td>
<td>$\chi^2$=5.66</td>
<td>0.017*</td>
<td>2nm&gt;3nm</td>
</tr>
<tr>
<td></td>
<td>FASD (C*P)</td>
<td>$\chi^2$=8.48</td>
<td>0.004*</td>
<td>2nm&gt;3nm</td>
</tr>
<tr>
<td>Response Time</td>
<td>Cue</td>
<td>F(2,65)=32.98</td>
<td>&lt;0.001*</td>
<td>C&lt;BA &amp; BL&lt;BA</td>
</tr>
<tr>
<td></td>
<td>Data Tag</td>
<td>F(1,65)=10.89</td>
<td>0.002*</td>
<td>P&lt;A</td>
</tr>
<tr>
<td></td>
<td>FASD</td>
<td>F(1,1092)=13.82</td>
<td>&lt;0.001*</td>
<td>3nm&lt;2nm</td>
</tr>
<tr>
<td></td>
<td>Cue*Data Tag</td>
<td>F(2,65)=4.99</td>
<td>0.010*</td>
<td>BA<em>A&gt;BA</em>P&gt;BL*P</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Cue*FASD</td>
<td>F(2,1092)=10.19</td>
<td>&lt;0.001*</td>
<td>C&lt;BA &amp; BL&lt;BA within both FASDs</td>
</tr>
<tr>
<td></td>
<td>Data Tag*FASD</td>
<td>F(1,1092)=15.70</td>
<td>&lt;0.001*</td>
<td>P&lt;A within both FASDs</td>
</tr>
<tr>
<td></td>
<td>Cue<em>Tag</em>FASD</td>
<td>F(2,1157)=2.57</td>
<td>0.077</td>
<td>Not Significant</td>
</tr>
<tr>
<td>Log Transformation</td>
<td>F(2,65)=1.69</td>
<td>0.199</td>
<td>Not Significant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F(1,65)=0.75</td>
<td>0.389</td>
<td>Not Significant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F(1,1092)=133.78</td>
<td>&lt;0.001*</td>
<td>3nm&lt;2nm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cue*Data Tag</td>
<td>F(2,65)=2.52</td>
<td>&lt;0.088</td>
<td>Not Significant</td>
</tr>
<tr>
<td></td>
<td>Cue*FASD</td>
<td>F(2,1092)=5.55</td>
<td>0.004*</td>
<td>3nm&lt;2nm within each Cue</td>
</tr>
<tr>
<td>Attention Allocation</td>
<td>Tag*FASD</td>
<td>F(1,1092)=2.57</td>
<td>0.109</td>
<td>Not Significant</td>
</tr>
<tr>
<td></td>
<td>Cue<em>Tag</em>FASD</td>
<td>F(2,1092)=4.63</td>
<td>0.010*</td>
<td></td>
</tr>
</tbody>
</table>

Note: BA=Baseline Cue, BL=Blinking Cue, C=Color Cue, P=Present Data Tag, A=Absent Data Tag
3.2 Subjective Measures

3.2.1 Workload

An ANOVA performed on the subjective workload ratings revealed a significant main effect of cue type (F(2,65) = 23.55, p < 0.001), but no significant main effect of the presence of the velocity data tag (F(1,65) = 0.70, p = 0.406) nor a significant interaction effect (F(2,65) = 1.05, p = 0.355). Figure 3.7 shows that the baseline displays resulted in the highest subjective workload, followed by displays that integrated the blinking cue and those that used the color-change cue. Tukey HSD post-hoc groupings revealed the workload ratings for the blinking and color-change cues to be significantly lower than the ratings for the baseline display (p < 0.05), but there was no significant difference between the mean workload ratings for the displays integrating blinking or color-change cues.

![Figure 3.7: Tukey HSD Groupings for the Effect of Cue Type on Workload Ratings](image)
3.2.2 Intruder Selection Confidence

An ANOVA performed on pilot confidence in high-risk intruder selection revealed significant main effects of cue type (F(2,65) = 38.18, p < 0.001) and data tag (F(1,65) = 7.14, p = 0.010) as well as a significant interaction between cue type and data tag (F(2,65) = 5.14, p = 0.009). Due to the significance of the interaction, simple effects were examined, as shown in Figure 3.8. Overall, the “color-present” display (i.e., use of the color-change cue along with velocity data tags) received the highest average confidence rating from the pilots, although not statistically greater than the ratings for the “color-absent,” “blinking-present,” or “blinking-absent” display formats. All displays that included a blinking or color-change cue received a higher confidence rating than either of the baseline displays. Additionally, the baseline displays that included a velocity data tag resulted in higher confidence ratings than the baseline displays that did not include the data tag. These trends were supported by Tukey HSD post-hoc test groupings.
3.2.3 Display Effectiveness

An ANOVA performed on the ratings of the display effectiveness revealed a significant effect of cue type \((F(2,65) = 22.72, p < 0.001)\), but no significant effect of the data tag \((F(1,65) = 1.61, p = 0.209)\) nor an interaction effect \((F(2,65) = 0.09, p = 0.916)\). Figure 3.9 shows displays integrating the blinking and color-change cues were rated as being more effective in conveying information to pilots than the baseline displays, with color-change displays being rated slightly higher than blinking displays. A Tukey HSD post-hoc test revealed that the baseline displays were rated significantly less effective than the blinking
and color-change displays (p < 0.05), but no significant difference occurred between the mean ratings for the blinking and color-change displays.

![Figure 3.9: Tukey HSD Groupings of the Effect of Cue Type on Display Effectiveness Ratings](image)

3.2.4 Ease of Understanding

One-tailed Student’s t-tests revealed that the mean ease of understanding rating for cue type (t(13, 0.05) = 32.32, p < 0.001) as well as the data tag (t(13, 0.05) = 4.10, p = 0.001) were both significantly higher than the scale’s midpoint of 50. The confidence intervals, reported in Table 3.6, show that pilots found the added cues and data tags easy to understand. Additionally, the cues were rated as easier to understand than the velocity data tags. A one-
tailed Student’s t-test assuming unequal variances revealed this difference to be marginally significant (t(13.817, 0.05) = -1.61, p = 0.065).

Table 3.6: 95% Confidence Intervals for Ease of Understanding Ratings

<table>
<thead>
<tr>
<th>Automation Feature</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cues</td>
<td>92.118</td>
<td>4.877</td>
<td>89.303</td>
<td>94.934</td>
</tr>
<tr>
<td>Data Tags</td>
<td>80.120</td>
<td>27.492</td>
<td>64.246</td>
<td>95.993</td>
</tr>
</tbody>
</table>

### 3.2.5 Perceived Performance

A one-way ANOVA revealed display features (i.e., blinking, color-change, or data tags) to be significant (F(2,26) = 8.18, p = 0.002) on pilot perceptions of performance. Figure 3.10 shows that the perceptual cues and velocity data tags increased pilot perceived performance, as compared to the “baseline-absent” display type. Displays with the blinking cue resulted in the highest perceived performance ratings followed closely by the color-change cue displays and then the data tag displays. A Tukey HSD post-hoc test revealed there to be no significant difference in perceived performance between the blinking and color-change cues, but both resulted in a significantly higher rating of perceived performance than the velocity data tags (p < 0.05).
### 3.2.6 Display Feature Preference

Upon completion of the experiment, pilots were asked to identify their preferences for display features and settings and to select which features they thought were the most helpful. One pilot who selected blinking as his preferred cue feature also selected color-change as the most helpful feature. The remaining 13 pilots were consistent in choosing the same cue for both the “preference” response and the “most helpful” response. As reported in Table 3.7, more pilots preferred the color-change cue compared to the blinking cue; however, the difference among the features amounted to the preference of one pilot. In addition, a majority of pilots preferred the displays in which the velocity data tag was present as opposed to
displays in which it was not present. Logistic regression analyses revealed no significant
effect of age on cue preference ($\chi^2 = 2.23, p = 0.136$) or on velocity tag preference ($\chi^2 = 2.36,$
p = 0.125). Finally, the color change feature was most frequently chosen as the most helpful
feature and the data tags were never chosen in favor of one of the cues (see Table 3.8).

Table 3.7: Display Feature Preference Responses

<table>
<thead>
<tr>
<th>Display Feature</th>
<th>Response</th>
<th>Number of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cue Type</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Blinking</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Color</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>No Preference</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>Data Tag</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absent</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Present</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

Table 3.8: Most Helpful Display Feature Responses

<table>
<thead>
<tr>
<th>Display Feature</th>
<th>Number of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blinking</td>
<td>5</td>
</tr>
<tr>
<td>Color</td>
<td>9</td>
</tr>
<tr>
<td>Data Tag</td>
<td>0</td>
</tr>
<tr>
<td>No Preference</td>
<td>0</td>
</tr>
</tbody>
</table>
Discussion

4.1 Target Choice Accuracy

Hypothesis 1 stated that the addition of the blinking and color-change cues, as well as velocity data tags, to the prototype CDTI was expected to mitigate the effect of the distance bias, as indicated by greater intruder selection accuracy, particularly in scenarios in which the distance bias was expected to have an effect on pilot judgments. There was a significant effect of the perceptual cue type in the scenarios where the FASD was 3 nm but not in the scenarios where the FASD was 2 nm. In agreement with Hypothesis 1, this finding suggests that the distance bias did affect pilot intruder selection and that the presence of the cues was effective for reducing the effect of the bias. Furthermore, analyses suggested that while both cues resulted in significantly greater intruder selection accuracies compared to the baseline display, there was no significant difference in accuracy between the color-change and blinking displays.

Contingency analyses revealed no significant effect of the data tags on intruder selection accuracy for either of the FASDs. This suggests that the velocity data tags alone did not improve intruder selection accuracy regardless of the traffic scenario. The lack of a significant effect of the data tags suggests that any increase in pilot SA that might have resulted from the additional display features was attributable to the perceptual cue (cf., Parasuraman, Sheridan & Wickens, 2000). Even when pilots were provided with explicit velocity information, they did not make the effort to perform long division in working
memory in order to estimate the TTC for each intruder and to make accurate high-risk intruder selection. It is likely that the time pressure of the traffic scenarios used in the experiment lead to reliance on the distance bias in the presence of the data tags, premature intruder selection, and inaccurate responses. This finding might be contingent upon the starting distances of intruders to ownship; i.e., less time pressure on pilots might lead to greater use of the data tags.

The third set of contingency analyses revealed a significant effect of the FASD for each combination of cue type and data tags with the exception of the “blinking-absent” displays. This suggests that the “blinking-absent” displays were the only displays to fully mitigate the effect of the distance bias on intruder selection accuracy since there was no significant difference in accuracy between the two FASD levels. This result lends further support to the possibility that pilots were not using the velocity information to make mental calculations of TTC, particularly when the perceptual cues were present. This behavior may be attributable to perceived time constraints in making a TTC judgment in order to allow for sufficient time for aircraft maneuvering, if necessary. However, the p-value was close to the α level of 0.05, meaning that the lack of a significant effect may be due to chance, a sampling bias, or some other factor rather than being a true representation of the assistance provided by the display. Overall, the results support Hypothesis 1 for the addition of the cues, but refute the hypothesis when considering the effect of the velocity data tags.
4.2 Response Time

Hypothesis 2 posited that the mean RT would be shortest when pilots used displays with blinking cues, followed by those with the color-change cues, followed by the baseline displays. This trend was expected to be most pronounced in scenarios in which the distance bias was expected to occur (i.e., when the FASD was 3 nm). The interaction between the cue type and FASD shows that the difference in RT among the cue levels was, in fact, more pronounced in the 3-nm FASD scenarios than in the 2-nm FASD scenarios, suggesting that the cues were effective in mitigating the effect of the distance bias by reducing the RT, as compared to displays in which no cue was presented. Referencing the model of types and levels of automation outlined by Parasuraman, Sheridan and Wickens (2000), the perceptual cues investigated here had their greatest impact on the information acquisition and analysis phases of pilot information processing. The cues and data tags allowed pilots to more quickly make a TTC judgment and select the highest risk intruder aircraft. The results suggest that the displays including either of the cues were more effective than the baseline displays in directing pilot attention to the CDTI and potentially increasing pilot SA on aircraft traffic; however, there was no evidence of blinking being superior to color-change for information acquisition and analysis. These findings support Hypothesis 2 in that the color-change and blinking displays were associated with shorter mean RTs than the baseline display, but there was no evidence that the mean RT for the blinking-cue display was shorter than the mean RT for the color-change-cue display.
Hypothesis 3 posited that the mean RT in displays presenting the velocity data tag would be smaller than in those that did not display the data tag. The interaction between the cue type and the data tag showed that the presence of the data tags resulted in significantly shorter RTs in the baseline displays, but not in displays including either the blinking or the color-change cues. These results suggest that when there was no perceptual cue present in the CDTI, pilots might have used the added velocity data tags to reduce effort in estimating intruder TTC through calculations in the working memory for high-risk identification, as compared to the baseline display with no data tag. However, the results demonstrate that the cue attracted greater pilot attention to the CDTI and had a more profound effect on the RT than the data tags. These results support Hypothesis 3. In general, it is likely that pilots developed a strategy in which they exploited the perceptual cues when presented simultaneously with the data tags and used the data tags only when there was no perceptual cue.

4.3 Pilot Gaze Patterns

Hypothesis 4 stated that the displays integrating blinking or color change cues would require less pilot visual attention resources as compared with the baseline displays. The results of the split-plot ANOVA on the rank-transformed proportion of gazes to the CDTI demonstrated this to be true when the FASD was 3 nm, but not when the FASD was 2 nm. The lower proportion of attention required by the CDTI when the blinking or color-change cue was used suggests that the added features reduce the amount of time a pilot needs to achieve SA on a traffic situation and decrease the visual workload in judgments on intruder
TTC. However, these differences may be a result of the experiment’s design rather than a true representation of the effect of the FASD. As mentioned above, for scenarios in which the FASD was 2 nm, the perceptual cue was active when the scenario started, but this was not the case for scenarios in which the FASD was 3 nm. In the 2-nm FASD scenarios, pilots could immediately identify the high-risk intruder and the number of glances to the display was limited. In the 3-nm FASD scenarios, intruders traveled for 5 sec before the display features were activated. Pilots had to focus on the X-plane simulation display during this time in order to maintain the aircraft on straight and level flight. They infrequently sampled the CDTI, watching for the perceptual cue and/or data tags to appear. However, as a result of the concentration on the flight simulation, the proportion of gazes to the CDTI remained low, as in the 2-nm FASD scenarios, but for this alternate reason. Hypothesis 4 is supported in scenarios in which the FASD is 3 nm, but not in scenarios in which the FASD is 2 nm.

Hypothesis 5 posited that displays containing the velocity data tag would require a smaller proportion of pilot visual attention than those that did not include the velocity data tag. This hypothesis was based on the premise that theoretically, the velocity data tag decreased the workload imposed on the pilot when attempting to make TTC calculations in working memory. The hypothesis was refuted by the ANOVA on the rank-transformed proportion of gazes to the CDTI. Within each level of the combination of FASD and cue, the presence of the data tags seemed to required more attention from pilots to the CDTI than the displays featuring the perceptual cues alone. It is likely that pilots perceived the cues and then attempted to verify accuracy through mental arithmetic based on the data tags, prolonging their visual attention to the CDTI. In the absence of the data tag, pilots simply
used the perceptual cues to quickly make an intruder selection. These findings refute Hypothesis 5.

4.4 Correlation Between Response Time and Gaze Proportion

It was not known whether a relationship existed between pilot RT in selecting the correct intruder and the proportion of pilot visual attention to the CDTI. One explanation of the negative correlation among these responses is that pilots who allocated a higher proportion of their visual attention to the CDTI were able to process the information more quickly to make a correct TTC judgment. For each type of scenario, there is some minimum length of time required for the pilot to process the information on the display and make a TTC judgment. Pilots who dedicated a higher proportion of attention to the CDTI met this minimum processing time earlier than those who dedicated a lower proportion of attention to the CDTI, thus resulting in a lower RT. This observation was further supported by analysis of the relationship of RT with gaze proportion for each display format. The negative correlation of RT and attention allocation proportion was greatest for the “baseline-absent” displays ($\rho = -0.607$). Variations in the strength of association of these responses among display conditions can be explained in terms of differences in task requirements based on the features present in the CDTI. Pilot use of the CDTI changed when the cues and/or data tags were added to the display. In the “baseline-absent” format, the pilot task was to use the presented information to calculate intruder TTCs; however, with the displays featuring a perceptual cue or data tag, the task was to scan the screen until an a feature was presented. It is likely that when using displays that included both the perceptual cue and data tag, pilots scanned the screen for an
intruder that featured one of the cues followed by an estimation of the TTC using the textual velocity information. Thus, for the displays featuring the perceptual cues, the strength of the relationship between attention allocation and RT may be indicative of how well the feature attracted pilot attention; a weaker relationship would be indicative of display features that were superior in terms of drawing pilot attention. The weak relationship between the gaze proportion and response time for the displays that used blinking cues suggests that the blinking cue was able to effectively capture pilot attention and convey relevant information more quickly than either the color-change cue or the baseline displays. According to the strengths of association for the six different display formats, the color-change cue was less effective than the data tag in capturing pilot attention, and the blinking-cue displays were the most effective for drawing pilot attention to the CDTI.

4.5 Subjective Measures

Hypothesis 6 posited that pilots would rate workload as being lower for displays that included the blinking cues, color-change cues and/or the velocity data tags than those in which no cues or data tags were presented. The significance of the main effect for cue type on perceived workload demonstrated this hypothesis to be partially true. It is not surprising that the blinking and color-change cue displays resulted in lower workload ratings than the baseline displays since they facilitated more efficient information processing (i.e., precluding the need for pilots to mentally calculate intruder TTC). However, there was no significant effect of the data tag, indicating no workload benefit or cost compared to the displays in
which the velocity was not presented to the pilots. Again, this is not surprising given that the cues provided no benefit for intruder selection accuracy or pilots attention allocation.

Hypothesis 7 conjectured that pilots would indicate higher confidence in their intruder selections with displays that included blinking cues, color-change cues, or velocity data tags compared to displays that did not utilize these features. The Tukey HSD post-hoc test performed on the interaction between the cue type and data tag supported this hypothesis. Although the data tags had a significant effect within the baseline level of the cue, the results suggest that the cues had a more profound effect on the confidence ratings than the velocity tags alone. This could be attributed to the fact that the perceptual cues drew pilot attention to the displays more effectively than the data tags alone, and they supported pilot information processing to a greater extent in terms of information acquisition and analysis. Furthermore, the results provide support for the postulation that pilots were using the data tag only in scenarios in which no cue was presented: the lower confidence ratings may be associated with pilot use of the velocity data tag to perform mental calculations of TTC when no perceptual cue was presented vs. using cues in conjunction with data tags to make TTC judgments with greater confidence. The results provided support for Hypothesis 7.

Hypothesis 8 stated that pilots were expected to provide high effectiveness, ease-of-understanding, and perceived performance ratings for displays that used blinking targets, color-changing targets, and/or velocity tags. In general, the results provided evidence supporting Hypothesis 8. The added display features effectively increased the salience of the most important information required by pilots to make relative TTC judgments; thus,
decreasing the amount of information processing. The added features also increased pilot confidence in their relative risk assessments.

Hypothesis 9 posited that most pilots would prefer the color-change displays, followed by the blinking displays, as well as both of these display types over the baseline displays. Additionally, Hypothesis 9 stated that pilots would prefer the presence of the velocity data tags compared to the displays in which the data tag was not present. The fact that one perceptual cue was not selected significantly more than the other suggests that the “best” cue for drawing pilot attention to the CDTI is likely a matter of pilot preference. Color is an effective cue since it is so widely used in other types of displays (e.g., traffic lights); the color yellow is often associated with a system state requiring caution. Blinking can be even more effective than color-change in terms of drawing pilot attention, especially compared to a color-change cue that is presented on top of a colored background. On the other hand, some pilots may find blinking cues to be too distracting; thus, preferring the color-change. In rating their preference for the data tag, a majority of pilots preferred the presence of the data tags because the tag simply provided more information than the baseline display. Although the results indicate that the velocity data tags did not enhance performance, it is possible that the presence of the data tags simply inspired confidence in pilot TTC judgments. These findings and inferences corroborate Hypothesis 9.
5 Conclusions

The objective of this research was to assess the effectiveness of adding features to a prototype CDTI, including perceptual cues and velocity data tags for intruder aircraft representations in order to mitigate the effect of distance bias exhibited by GA pilots when making relative TTC judgments. The results of the experiment suggest that the addition of the cues and data tags provides a benefit to pilots in terms of assessing the relative risk of multiple intruders in RT and selection accuracy. There was also evidence that the proportion of pilot visual attention allocated to the CDTI was reduced when cues were featured in the display, specifically when the FASD was 3 nm. Furthermore, subjective ratings revealed that pilots actually preferred the added display features and felt that they provided a significant benefit to their performance.

There appears to be statistically important improvements in pilot performance in making relative TTC judgments as a result of incorporating a blinking cue, color-change cue, and/or velocity data tag in a CDTI. In comparing the display formatting and content manipulations, the format cues were the driving factor in observed performance improvements in terms of all response measures. However, the presence of the data tag was significant only for pilot RT. While the displays containing the cues were associated with significantly superior performance than those without cues, there was no evidence of a performance difference between the blinking and color-change cues. Similarly, none of the subjective ratings provided any significant difference between the color-changing cue and the blinking cue. When pilots provided preference ratings, the color-cue displays were chosen.
more often than the blinking-cue displays. Considering all of these results together, there appears to be a benefit to including velocity data tags in a CDTI to decrease the amount of information processing for the display user in the absence of other graphical perceptual cues providing information on intruder TTC. In addition, there appears to be a benefit to including perceptual cues for drawing attention to intruder icons, which seems to drive improved performance. The results suggest that the addition of the cues changed the nature of pilot tasks associated with using the display; in the “baseline-absent” displays, the task was to acquire distance and velocity information to make TTC estimates and judgments of intruder risk. However, in the displays including perceptual cues, the pilot’s task was changed to sampling the display until a cue was activated. Given the lack of significant difference between the blinking and color-change cue displays, it is suggested that either may be used to support increased pilot performance with CDTI technology. User preference should also be taken into account in the display feature implementation.

5.1 Applications

The findings of this research may be most useful for GA pilots, who are responsible for monitoring and maneuvering among other air traffic with limited contact with ATC. Consequently, any cockpit display features that may reduce cognitive load for pilots may also be beneficial to performance. In general, the results of this study are applicable to any domain that presents displays with which a user is expected to make relative judgments of TTC of multiple targets. Such domains include marine vessels with GPS-based displays for traffic detection, commercial and military aviation cockpits with displays presenting satellite-
based information on other aircraft, as well as ATC displays and unmanned aircraft control setups. Since pilots in these domains are in contact with ATC, a GPS display with the features presented in this research could serve as another measure to prevent potential aircraft conflicts, similar to the TCAS system that is currently used. Using a GPS-based display would provide pilots with more accurate position and velocity information than the current radar-based TCAS system.

5.2 Limitations

The present research used a simplified mock-up of an aircraft cockpit; the simulated aircraft was controlled with a single throttle lever, a yoke, and rudder pedals. The out-of-cockpit view and CDTI display were presented on computer monitors. Additionally, the touch screen presenting the CDTI was placed to the right of the out-of-cockpit screen, which does not accurately represent where the display would typically be located in a Cessna 172 aircraft cockpit (typically appearing in front of a pilot, to the right or directly below a navigation display). A more realistic cockpit setup, facilitating greater pilot immersion in simulation stimuli and task performance, might have resulted in different results (e.g., greater differences among conditions).

Only 16 unique conflict geometries were used to test the prototype CDTI featured in this study. In specific, only two FASDs and two intruder velocities were used, resulting in four TTCs. Due to the small number of geometries and velocities, many of the participants were able to develop an “internal clock” as to when the display features would be triggered. Adding more levels of the FASD and/or the velocity of intruders would have made it more
difficult for the participant pilots to anticipate the onset of display feature presentation and possibly provide more definitive results on the effects of the display format and content manipulations.

Beyond these limitations, all display features were activated at a TTC of 40 sec in every scenario. Testing a range of feature activation thresholds might provide more information in terms of optimal CDTI formats and content for performance and pilot acceptance. Furthermore, the 40-sec feature trigger threshold resulted in the perceptual cues and data tags being active at the start of the 2-nm FASD scenarios, but not in the 3-nm FASD scenarios (i.e., scenarios which were expected to be influenced by the distance bias). This difference might have influenced the results of the experiment in terms of greater actual observations of “baseline-absent” display performance for the 3-nm FASD scenarios than the 2-nm scenarios.

Some pilots commented that the flight control task was easy for them to perform. They were asked to simply maintain a heading of 0 degrees and keep the vertical velocity gauge as close to 0 ft/min as possible. The simplicity of the simulated task may not have been as cognitively demanding as flying a real aircraft; thus, making the use of the CDTI for intruder assessment possibly easier than under real flight circumstances. Additionally, choosing between two intruders may have been easy for the participant pilots, considering that intruder selection accuracy was generally high. In the operational environment, pilots may encounter situations where relative TTC judgments need to be made for more than two intruders. Adding more intruders to selected scenarios would have made the task more demanding and potentially more realistic.
With respect to the pilot gaze data, a work sampling technique was used with a video recording of the participants. The video was slowed and observations were taken at one-second intervals, when the CDTI was active during each scenario. While the data was parsed by a third-party with no knowledge of the experiment’s hypotheses, there is the chance that the gaze proportions collected are not representative of the true gaze proportions due to the low flight task workload. Additionally, since there was no fixed time for which each scenario was active, the number of observations collected within each trial was not consistent. Therefore, the increased number of samples in the longer trials and the decreased number of samples in the shorter trials may have affected the gaze proportions that were reported.

5.3 Future Work

As previously mentioned, one of the limitations of this study was the simplicity of the flight simulator setup. Any future research investigating the effect of enhanced CDTI features on relative TTC judgments should use a high-fidelity simulator to make flight scenarios more realistic. Furthermore, the use of advanced eye-tracking equipment would allow for more detailed analysis of pilot gaze and patterns of visual attention while using the displays. Future research may also investigate the effects of the CDTI display features in conjunction with more complex flight tasks such as a takeoff, instrument landing system approach, during pilot use of a checklist, or during ground operations. In addition, the use of a CDTI should be compared with the current TCAS system in order to determine whether the higher-fidelity GPS system may provide pilot performance benefits over the TCAS system.
This research focused on the effect of blinking cues, color-change cues, and velocity data tags in CDTIs. However, there are many other types of perceptual cues that could be implemented in such displays that might be more effective than those tested. During the experiment, some pilots suggested that they would have liked to use displays that combined both the blinking and color-change features; this should be considered for future research. Similar displays described in the literature have incorporated aural alerts, haptic alerts, increasing/decreasing size of visual features, different colors, and velocity trend vectors. Furthermore, many display systems use a three-level alerting system as opposed to the two-level system tested in this research. A CDTI may be more effective if it only uses two colors for intruder representation (e.g., yellow for caution and red for danger), two blinking frequencies (e.g., slow blinking for caution and fast for danger), or a two-level combination of the blinking and color change cues. Future research should examine whether there are other, more effective ways to convey the distance, velocity, or TTC information to a pilot through a CDTI.

Finally, many advanced head-up displays are being developed to prevent pilots from looking away from the out-of-cockpit view for extended periods of time. Creating a head-up display similar to the head-down CDTI used in this research has the potential to further reduce pilot RT and allow for a greater proportion of pilot visual attention to remain with the instrument panel and out-of-cockpit view. This could be particularly beneficial for GA pilots who do not have constant contact with ATC and must always be aware of their surroundings via the out-of-cockpit view.
References


Boston: WCB/McGraw-Hill.

Boston, MA: Richard D Irwin.


APPENDICES
Appendix A  TCAS Time-to-Contact Thresholds

<table>
<thead>
<tr>
<th>Ownship Altitude (feet above ground level)</th>
<th>Time-to-Contact (sec)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Traffic Advisory</td>
<td>Resolution Advisory</td>
</tr>
<tr>
<td>&lt;1,000</td>
<td>20</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>1,000-2,350</td>
<td>25</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>2,350-5,000</td>
<td>30</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>5,000-10,000</td>
<td>40</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>10,000-20,000</td>
<td>45</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>20,000-42,000</td>
<td>48</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>&gt;42,000</td>
<td>48</td>
<td>35</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B  Experiment Procedure

[] indicates required actions.
An experimenter needs to read to participants the text in *italics* in the sections below.

1. Checklist before starting the Introduction

<table>
<thead>
<tr>
<th></th>
<th>Two informed consent forms are printed (one for the university and one for the participant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>One demographic form is printed and the heading is completed</td>
</tr>
<tr>
<td>3</td>
<td>Six post trial questionnaires are printed and the headings are completed</td>
</tr>
<tr>
<td>4</td>
<td>One post experiment questionnaire is printed and the heading is completed</td>
</tr>
<tr>
<td>5</td>
<td>Two copies of the payment form are printed</td>
</tr>
<tr>
<td>6</td>
<td>Pen(s) are available to fill-out forms</td>
</tr>
<tr>
<td>7</td>
<td>The sign on the lab door is ready- “Experiment in Progress, Do Not Disturb”</td>
</tr>
<tr>
<td>8</td>
<td>Simulated aircraft cockpit is set up and running (heading<del>353, alt</del>4,300, speed~100kts)</td>
</tr>
<tr>
<td>9</td>
<td>Scenario input file is ready and follows the correct (randomized) order of experiment trials</td>
</tr>
<tr>
<td>10</td>
<td>CDTI (cockpit display of traffic information) application is running on the touch-screen computer</td>
</tr>
<tr>
<td>11</td>
<td>Training scenario is ready</td>
</tr>
<tr>
<td>12</td>
<td>All recording equipment is set up and working properly</td>
</tr>
</tbody>
</table>

2. Orientation
   a. Introduction

   [Escort participant into conference room (Daniels 456) and record the time at which the experiment has started]

   *Thank you for participating in this experiment. The objective of this experiment is to assess the effect of automation in a cockpit display of traffic information on pilot judgments of relative time-to-contact. This study is not meant to test your personal abilities in any way; it is an assessment of cockpit display technology. The study will last approximately 2 hours, for which you will be compensated at a rate of $20 per hour. The experiment trials will be recorded using a video camera, but every step will be taken to preserve your anonymity in the experiment. Once the experiment is complete, all recordings will be destroyed. At this time, I ask that you turn off your cell phone or any other electronic device that may be a distraction to you during the experiment.*
b. Informed Consent Form

[Present participant with both copies of the informed consent form and a pen]

*This form summarizes everything you need to know about the experiment, including your compensation, any potential risks, and your rights as an experiment participant. Please take the time to read the form carefully and if you consent to participate, please sign and date both copies of the form.*

[Give participant time to read and sign form]

c. Demographic Questionnaire (DQ)

[After completion of the informed consent form, present the participant with a copy of the DQ]

*Now you will complete a questionnaire requesting general information about your background. Please answer all questions as accurately as possible. As stated in the informed consent form, all of your answers will be kept confidential and none of this information will be published in any form that will enable someone to trace the results back to you.*

*Now we will move to the laboratory, where the experiment will take place.*

[After completion of the DQ, escort the participant to the flight simulator in the ergonomics lab (Daniels 457) and display the “Experiment in Progress” sign]

3. Training Session

[NOTE: All equipment should be turned on and running before the participant arrives in the lab.]

[Ensure that the sign on the door indicates an experiment is in progress]

a. Introduction to Equipment

[Seat the participant at the flight simulator (Daniels 457)]

*Here is the ergonomics lab flight simulator where the experiment will take place. All of the hardware and software is based on the X-Plane flight simulation system. In front of you is the yoke, on the floor are rudder pedals, and to your right are the throttle controls. The screen directly in front of you is the out-of-cockpit view of the aircraft and the touch screen to your right is the screen that will be displaying the cockpit display of*
traffic information. You can note from your out-of-cockpit view that you’ll be flying a simulated Cessna 172 aircraft model.

Using the flight controls and the out-of-cockpit view, you will be required to fly the flight along a straight and level path. While performing this flying task, you’ll be using the touch screen cockpit display to identify intruder aircraft as well as selecting the aircraft that has the lowest time-to-contact with your vehicle. The miss distance for all aircraft will be 0 nm, or in other words, all aircraft that are shown on the screen will be on a collision course with your aircraft.

b. Apparatus and Scenario Training

Before I show you how to operate the cockpit display on the touch screen, you will first be given up to five minutes to become accustomed to flying the aircraft using the instruments in front of you. During the task, the goal will be to maintain a bearing of zero degrees and maintain a vertical velocity of zero, thus keeping a consistent altitude. The aircraft is controlled using the yoke, pedals, and throttle control as if you’re flying a real aircraft. Whenever you are ready, we can begin. Once you feel comfortable with the setup and with flying the aircraft, let me know and the simulation will be paused.

[When the participant is ready, start the simulator by pressing “P” on the keyboard]

[When the participant is comfortable, pause the simulator by pressing “P” on the keyboard (NOTE: this time should be limited to 5 minutes).]

Now that you are comfortable with the flight simulator, I will now show you how to operate the cockpit display of traffic information.

[NOTE: No automation should be active in the first training trial.]

[NOTE: The second training trial should present a display with both target velocity tags and color change cues during 45 seconds of time-to-contact with a target.]

To start the experiment, touch this introductory screen anywhere. [Touch the introduction screen.] The scenario begins immediately after touching the screen.

The white aircraft at the bottom is the aircraft you are flying. You are flying straight to a waypoint that is out of the range of the display. [Point to a spot above the cockpit display, indicating that this is the point to which the aircraft is flying.]

During the trial, you want to select the surrounding aircraft that will come into contact with your aircraft before the other aircraft. [Identify the surrounding aircraft as well as the pilot’s aircraft.]
As I mentioned earlier, every aircraft that is presented during the experiment, the miss distance is zero, so all surrounding aircraft are on a collision course with your aircraft. As soon as you determine which surrounding aircraft has the shortest time-to-contact (in other words, which aircraft you’ll collide with first), select it by touching it on the touch screen. [Demonstrate this by choosing an aircraft on the screen.]

After you choose an aircraft, the introductory screen will appear again. This screen will appear only if you choose one of the two aircraft; if you touch elsewhere on the screen, the introductory screen will not appear. The next trial will start when you touch the introduction screen again. [Touch the introduction screen again.]

[Touch an area that does not contain an intruder to show that the introduction screen does not appear unless an intruder aircraft is chosen]

This next scenario shows an example of a trial with automation added to the display of traffic information. In all trials, the automation is activated when a surrounding aircraft has a time-to-contact of less than 40 seconds. In other words, when the time-to-contact of an aircraft reaches 40 seconds, the aircraft will change color or start blinking and a data tag will appear displaying the aircraft’s velocity. As you can see in this scenario, the aircraft that changed color did so when its time-to-contact fell below the 40-second threshold. [Identify the aircraft changing color.] Additionally, in all trials that present aircraft with data tags, the tags always display the velocity of the intruder above the symbol. [Identify the velocity tag.]

[NOTE: the next screen should be a post-block screen]

This screen will appear at the conclusion of each block of 16 trials. When this screen appears, I will pause the simulator and hand you a ratings form. There are four additional training scenarios so you to familiarize yourself with. Once you have gone through them, we can begin the experiment.

[Participant completes CDTI training]

Do you feel comfortable with the presentation of information on the display and how to use the display?

[at the end of the familiarization, delete all data in …/My Documents/Visual Studio 2005/Projects/CDTI/CDTI/input_output/output.csv]

[at the end of the familiarization, delete all data in …/My Documents/Visual Studio 2005/Projects/CDTI/CDTI/input_output/disapactivity.csv]
[at the end of the familiarization, load the first input file to …/My Documents/Visual Studio 2005/Projects/CDTI/CDTI/input_output/input.txt]

4. Experiment Trials

*If you have any questions about the experiment, please feel free to ask either now or in between trial blocks. It is worth repeating that in all scenarios, the automation is triggered when the time-to-contact with any intruder is less than 40 seconds. Also, in terms of the flight simulation, remember that you want to maintain a heading of zero degrees and a vertical velocity as close to zero as possible.*

[Restart the display with the experiment input file: (1) close the CDTI display; (2) rename “input.txt” as “input_training.txt”; (3) rename “input_experiment.txt” as “input.txt”; (4) restart the CDTI display.]

[Ensure that there is a pen available for the participant.]

*We will now begin the first block of experimental trials. There will be 16 scenarios during this block and you will be exposed to different CDTI conditions. Some may include the automation features you were shown in the training and others may or may not. Again, you need to maintain the flight-path tracking task for the duration of the experiment.*

*Now, I will start recording video on the cameras. Once they have started recording, we will start the experiment.*

[Start recording with both the front-facing and behind-participant cameras]

*When you are ready, I will start the flight simulator. Once you feel that you have sufficient control over the flight, you may begin the experiment by touching the display screen.*

a. Experiment Procedure

*In this block of trials, the automation level will be none/blinkng/color and the velocity tags will be on/off.*

[Block 1 (16 scenarios with one cue and tags present or absent. Traffic geometries should be randomized.).]

[At the completion of the trial block, pause the flight simulator. The participant should complete the post-trial questionnaire.]
This concludes the first block of 16 trials. This form will ask you to rate your perceived workload, confidence, and display effectiveness. To complete this form, please rate each statement by marking a place on the rating scale line that you feel most accurately represents your rating [point to ratings scale line]. Once you have completed the ratings form, I will restart the flight simulator and we will begin the next block of trials.

In this block of trials, the automation level will be none/blanking/color and the velocity tags will be on/off.

[Start flight simulator
Block 2 (16 scenarios)
Pause flight simulator
Post trial questionnaire]

This concludes the second block of 16 trials. Please complete this form, which asks for the same three ratings as the form you completed after the first block of trials. Once you have completed the ratings form, I will restart the flight simulator and we will begin the next block of trials.

In this block of trials, the automation level will be none/blanking/color and the velocity tags will be on/off.

[Start flight simulator
Block 3 (16 scenarios)
Pause flight simulator
Post trial questionnaire]

This concludes the third block of 16 trials. Please complete this form, which asks for the same three ratings as the forms you completed after the first two blocks of trials. Once you have completed the ratings form, we will take a 10-15 minute break.

[10-15 minute break]

Now we will begin the fourth block of trials. When you are ready, I will restart the flight simulator and we will begin the next block of trials.

In this block of trials, the automation level will be none/blanking/color and the velocity tags will be on/off.

[Start flight simulator
Block 4 (16 scenarios)
Pause flight simulator
Post trial questionnaire]
This concludes the fourth block of 16 trials. Please complete this form, which asks for the same three ratings as the form you completed after the previous trial blocks. Once you have completed the ratings form, I will restart the flight simulator and we will begin the next block of trials.

In this block of trials, the automation level will be none/blink/velocity and the velocity tags will be on/off.

[Start flight simulator
Block 5 (16 scenarios)
Pause flight simulator
Post trial questionnaire]

This concludes the fifth block of 16 trials. Please complete this form, which asks for the same three ratings as the form you completed after the previous trial blocks. Once you have completed the ratings form, I will restart the flight simulator and we will begin the next block of trials.

In this block of trials, the automation level will be none/blink/color and the velocity tags will be on/off.

[Start flight simulator
Block 6 (16 scenarios)
Pause flight simulator
Post trial questionnaire]

This concludes the sixth and final block of 16 trials. Please complete this form, which asks for the same three ratings as the form you completed after the previous trial blocks.

b. Post Experiment Questionnaire (PEQ)

[Hand the PEQ to the participant]

The experiment is almost complete. Here is one last questionnaire that asks for your overall opinions of the different display features you encountered in the experiment. If you have any questions about the questionnaire, please don’t hesitate to ask.

5. Debrief
   a. Complete Payment Form

[Hand payment form to the participant.]
[Calculate the participant’s compensation.]

_The experiment is now finished. Here is the form for your compensation for participation in the experiment. For your time today, you will be compensated _____ dollars._

[Make a copy of the payment form for lab records.]

b. Departure and Thank You

[Give the participant a copy of his or her signed informed consent form as well as the original payment form.]

_The data collected today will be used to assess the benefit of adding automation to cockpit displays of traffic information to assist general aviation pilots in judging time-to-contact and, subsequently, the risk that is imposed by surrounding aircraft. If you are interested in future information about this experiment, you may contact Dr. David Kaber, whose contact information is in the informed consent form._

[Escort participant to Hakan Sungur, Department Contracts Manager, in Daniels 406.]

_Your participation in this study is greatly appreciated and will be very beneficial to our research._
Appendix C  Informed Consent Form

North Carolina State University
INFORMED CONSENT FORM for RESEARCH
Title of Study: Mitigating Biases in Risk Assessments in General Aviation Cockpit Displays of Traffic Information

Principal Investigator: Carl Pankok, Jr.  Faculty Sponsor: Dr. David Kaber

What are some general things you should know about research studies?
You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time without penalty. The purpose of research studies is to gain a better understanding of a certain topic or issue. You are not guaranteed any personal benefits from being in a study. Research studies also may pose risks to those that participate. In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above.

What is the purpose of this study?
The purpose of this study is to assess the effect of new Cockpit Display of Traffic Information (CDTI) features on pilot risk assessments of intruder aircraft within proximity of the pilot’s aircraft.

What will happen if you take part in the study?
If you agree to participate in this study, you will be asked to:

1. Submit a demographic questionnaire asking for information about your age, gender, and flying experience
2. Participate in a brief training and question/answer session to familiarize yourself with the experiment procedure and tools
3. Watch a series of air traffic scenarios and assign risk to the surrounding aircraft while performing some simple flying and tracking tasks
4. Rate the effectiveness of the display information, mental workload associated with the use of the display, and confidence in decision making based on use of the display after each block of trials
5. At the conclusion of the study, complete one final questionnaire regarding the displays used in the experiment

These steps will take place in the Human Factors and Ergonomics Lab (Daniels Hall, Room 457). In total, the experiment is expected to be approximately 2 hours in duration.

Risks
Looking at the display for an extended period of time may cause discomfort or strain on the eyes. One 10-minute break will be taken half way through the experiment, but if you experience strain or discomfort that prevents you from effectively participating in the experiment, you are encouraged to inform the experimenter and the study will stop either permanently or until you are comfortable enough to continue again.

Benefits
The results of this research are expected to increase the potential safety features that can be added to CDTIs by designers and manufacturers in the future. There is no direct benefit to pilots expected as a result of participation in the experiment.

Confidentiality
The information in the study records will be kept confidential to the full extent allowed by law. Data will be stored securely on the hard drives of a laboratory computer and the principle investigator’s computer. Additionally, all trials will be video recorded and stored on tapes and will be destroyed at the conclusion of the study. No reference will be made in oral or written reports which could link you to the study. You will NOT be asked to write your name on any study materials so that no one can match your identity to the answers that you provide.

**Compensation**
For participating in this study you will receive $20 per hour. If you withdraw from the study prior to its completion, you will receive a rate of $20 per hour for the time you spent participating in the study.

**What if you are a NCSU student?**
Participation in this study is not a course requirement and your participation or lack thereof, will not affect your class standing or grades at NC State.

**What if you are a NCSU employee?**
Participation in this study is not a requirement of your employment at NCSU, and your participation or lack thereof, will not affect your job.

**What if you have questions about this study?**
If you have questions at any time about the study or the procedures, you may contact the researcher, Carl Pankok, Jr., at cjpankok@ncsu.edu, or (609) 458-2435.

**What if you have questions about your rights as a research participant?**
If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Deb Paxton, Regulatory Compliance Administrator, Box 7514, NCSU Campus (919/515-4514).

**Prior Knowledge of the Study and its Goals**
If you have prior knowledge of the experiment and any goals, expected results, or other information that may affect the integrity of the experiment (e.g., based on conversations with other participants or experimenters), please let the experimenter know before signing below.

**Consent to Participate**
“I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled.”

Participant’s signature_______________________________________ Date _________________

Investigator’s signature_______________________________________ Date _______________
Appendix D  Demographic Questionnaire

Participant Number:_________  Date:______________

Experimenter(s) Present:________________________________________

Age:_________
Gender:________________________

1. Pilot Certificate Grade (circle one):
   
   Student  Sport  Recreational  Private  Commercial

2. Total Flight Hours:____________________

3. Do you have experience using a Cockpit Display of Traffic Information?
   
   Yes  No

If you answered “yes” to question 3, where did you use it?

   In an aircraft cockpit  In a simulator or experiment  Both

If you answered “yes” to question 3, how experienced would you rate yourself? (circle one)

Very Inexperienced  |  |  Highly Experienced

Example: To complete the following ratings, mark along the line at the point that you believe most accurately represents your rating:

   Low  |  |  High
Appendix E  Prototype CDTI Operation

1. Introductory Screen

2. Active CDTI Screen

Was an Intruder Selected? no

yes

End of Block? no

yes

3. Post Block Screen

This is the end of the block of trials.
Now you will fill out a ratings form.

Once the ratings form has been completed,
touch anywhere to begin the next block of trials
Appendix F  Post-Block Questionnaire

Participant Number:________  Date:__________________

Experimenter(s) Present:____________________________________________________

Automation Type: Baseline  Blinking  Color  Data Tags: On  Off

**Example:** To complete the following ratings, mark along the line at the point that you believe most accurately represents your rating:

| Low | High |

Considering only this display, I would rate my *mental* workload in use as:

| Low Workload | High Workload |

Considering only this display, I would rate my confidence in my decision on which aircraft has the shortest time-to-contact as:

| Low Confidence | High Confidence |

Rate the effectiveness of the display in directing your attention to the surrounding aircraft:

| Ineffective | Effective |
Appendix G  Post-Experiment Questionnaire

Participant Number:________  Date:______________________

Experimenter(s) Present:____________________________________________________________________

**Example:** To complete the following ratings, mark along the line at the point that you believe most accurately represents your rating:

```
Low  \__________________________\ High
```

Rate the ease of your understanding of the added display features (i.e., aircraft icon color change or blinking):

```
Easy to Understand  \__________________________\ Difficult to Understand
```

Rate the ease of your understanding of the velocity tags for the aircraft icons:

```
Easy to Understand  \__________________________\ Difficult to Understand
```

Rate the degree to which you feel that the color-changing displays affected your performance compared to the display with no additional visual features

```
Increased Performance  \__________________________\ Decreased Performance
```

Rate the degree to which you feel the blinking displays affected your performance compared to the display with no additional visual features

| Increased Performance | Decreased Performance |

Rate the degree to which you feel the presence of the velocity tags affected your performance compared to displays in which velocity tags were not present

| Increased Performance | Decreased Performance |

Select the automation level that you would most prefer to use in a cockpit display of traffic information (circle one):

None  Blinking icons  Color-change icons  No preference

Select whether you prefer the velocity tags to be present or absent in a cockpit display of traffic information (circle one):

Present  Absent

Overall, which display feature do you feel was most helpful to traffic information processing?

Blinking icons  Color-change icons  Velocity tags

No feature was more helpful than any others
If you selected a particular feature, please state why you feel this feature was most helpful? Or if you thought that no feature was more helpful than any other, why do you feel this was the case?

Please feel free to write down any additional comments you may have about any of the features added to the cockpit display of traffic information:
## Intruder Selection Accuracy Contingency Tables

### Count Row% Expected

<table>
<thead>
<tr>
<th>First Arrival Start Distance: 3 nm</th>
<th>Correct</th>
<th>Incorrect</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>196</td>
<td>87.89%</td>
<td>12.11%</td>
<td>223</td>
</tr>
<tr>
<td>205.04</td>
<td>17.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Blinking</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>215</td>
<td>95.98%</td>
<td>4.02%</td>
<td>224</td>
</tr>
<tr>
<td>205.96</td>
<td>18.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>411</td>
<td>36</td>
<td>447</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>First Arrival Start Distance: 3 nm</th>
<th>Correct</th>
<th>Incorrect</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>196</td>
<td>87.89%</td>
<td>12.11%</td>
<td>223</td>
</tr>
<tr>
<td>204.50</td>
<td>18.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Color</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>213</td>
<td>95.52%</td>
<td>4.48%</td>
<td>223</td>
</tr>
<tr>
<td>204.50</td>
<td>18.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>409</td>
<td>37</td>
<td>446</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>First Arrival Start Distance: 3 nm</th>
<th>Correct</th>
<th>Incorrect</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Blinking</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>215</td>
<td>95.98%</td>
<td>4.02%</td>
<td>224</td>
</tr>
<tr>
<td>214.48</td>
<td>9.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Color</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>213</td>
<td>95.52%</td>
<td>4.48%</td>
<td>223</td>
</tr>
<tr>
<td>213.52</td>
<td>9.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>428</td>
<td>19</td>
<td>447</td>
</tr>
</tbody>
</table>