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Effect of a Range Ring and of Intruder Vertical Rate on Pilot Perception of Separation on a Cockpit Display of Traffic Information

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EFFECT OF A RANGE RING AND OF INTRUDER VERTICAL RATE ON PILOT PERCEPTION OF SEPARATION ON A COCKPIT DISPLAY OF TRAFFIC INFORMATION

by

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This thesis was prepared under the direction of the candidate's thesis committee chairman, Dr. John Wise, Department of Aeronautical Science, and has been approved by the members of the thesis committee. This thesis was submitted to the Office of Graduate Programs and was accepted in partial fulfillment of the requirements for the degree of Master of Aeronautical Science

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Most of all, I would like to express my heartfelt thanks to my wife, Arlene, for the patience and strength she has shown me over the years.

Abstract

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This study was conducted to determine the effect of a range ring and intruder vertical rate on pilots' perception of aircraft separation as viewed on a cockpit display of traffic information. A group of 30 pilots from Embry-Riddle Aeronautical University participated as subjects. SuperCard® Version 1.6 software and a Macintosh IIsi® personal computer were employed to generate the simulation of a cockpit display of traffic information. Each pilot monitored 80 unique scenarios in which they determined, as early as possible, what the vertical miss distance would be when a single intruder passed ownship. The pilots' decision time and perceived vertical miss distance were compiled for each scenario. Range ring did not have a significant effect on the perception of vertical miss with regards to time or error while vertical rate had a significant effect on time and error. Exploratory research was also performed on miss distance and approach angle.

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Introduction

The Federal Aviation Administration (FAA) has predicted that commercial air traffic will increase 15% by the year 2002 (FAA, 1992). This fact is important from a safety standpoint because the hub-&-spoke system, used by commercial carriers since deregulation in 1978, concentrates aircraft in terminal airspace as a means of increasing airline efficiency. Relatively rare but sensationalistic midair collisions have continued to stimulate study into viable methods of maintaining safe separation distances between aircraft. As the present air traffic control (ATC) system reaches its maximum capacity, and the future automated air traffic control systems is only now beginning to be tested, airborne systems are being relied on to provide some measure of collision avoidance. The possibility of midair collisions has necessitated the use of cockpit display of traffic information (CDTI) technology as a means of ensuring safe separation of aircraft by pilots and air traffic controllers. Traffic displays in the cockpit are already a mandated reality in the form of traffic alert and collision avoidance systems (TCAS) in commercial aircraft with a minimum capacity of 30 passengers.

The difference between a CDTI and TCAS is that a CDTI displays intruding aircraft that are in a certain volume of airspace and only provides basic information, such as altitude and ground speed, of those aircraft. TCAS, on the other hand, displays intruding traffic based on complicated computer predictions of intersecting flightpaths. The TCAS II system also issues resolution advisories (RA) instructing the pilot to perform a vertical maneuver in order to increase aircraft separation when necessary. Britt, Davis, Jackson, and McCellan (1984) found that piloting decisions could be affected when non-threatening aircraft were included on the traffic display. This suggests that pilots need information on aircraft that will become a conflict only if an evasive maneuver is made due to another aircraft.

A CDTI is a more perceptually complex display than the radar display used by air traffic controllers because of the misleading apparent motion of the other aircraft caused by the rotation of the CDTI equipped aircraft (Palmer, Jago, Baty, & O'Conner, 1980). Whereas ATC displays present dynamic air traffic on a stationary map with a North-up orientation, the CDTI depicts a dynamic traffic situation from a moving frame of reference (heading-up). This makes the aircraft interactions harder to correctly interpret. Like ATC displays, CDTIs show the surrounding traffic from a bird's-eye point of view (plan-view). This 2-dimensional format lacks a vertical component which makes it difficult for a pilot to perceive the vertical separation of traffic when viewing a climbing or descending intruder, especially when the pilot's own aircraft (ownship) is moving vertically. Despite poor presentation of vertical information, the plan-view format is still the only format in use today in order to conform with other displays such as weather radar and moving maps. Intruder altitude information, when available, can be presented to the pilot in the form of a numerical value in the intruder's datatag or as a coded symbol. The pilot must mentally process the available information to obtain a 3-dimensional picture of the airspace.

Most literature that specifically includes vertical separation and vertical rates (Ellis, McGreevy, & Hitchcock, 1987; Hart & Loomis, 1980; Lester & Palmer, 1983; Palmer, 1983; Palmer & Ellis, 1983; and Smith, Ellis, & Lee, 1982) focuses on the effect of altitude coding and pilot maneuver responses. No studies made specific determinations as to the effect of different vertical rates on a pilot's ability to correctly perceive vertical separation. Rooney (1992) found that the effect of intruder vertical rate was significant with regards to a pilot's ability to determine future vertical separation, unfortunately a problem in the data collection necessitates further research to verify this result.

Little research has been conducted on the placement of a range ring. A range ring is defined as a circle which represents a fixed distance placed around the pilot's own aircraft on the CDTI display. It would appear that there is an optimum distance, and possibly an optimum number of rings, for each scale on the display. This research will try to determine if a range ring provides a significant improvement in either the accuracy of separation determination or equal accuracy with increased horizontal distance.

The plan-view format is the only display format in use and will most likely remain so for some years. The ability to predict aircraft separation in the vertical plane is as important as judging separation in the horizontal plane, but not as visually obvious. Because it is more difficult to determine vertical separation, this factor must be fully investigated so as to realize the full potential of the display. A better understanding of how pilots form a 3-dimensional image of the surrounding airspace using the vertical information on a plan-view display will be developed by understanding the effects of different intruder vertical rates, range ring placement, and the methods pilots use to determine the separation. If a CDTI is to compliment the automated ATC system to better serve pilots, a clear understanding of how pilots interpret plan-view presented information is essential. This research is intended to contribute to the evaluation of CDTI as a factor in the future automated ATC system and as an effective piloting tool.

Statement of the Problem

The purpose of this study was to determine the effect of: (1) a 3-mile range ring and, (2) intruder's vertical rate on the pilot's perception of future vertical separation while viewing a cockpit display of traffic information. Exploratory research was also conducted on intruder approach angle and the effect of the amount of vertical separation at time of passing. For the purpose of this study, a cockpit display of traffic information is a cockpit instrument displaying the location and motion of surrounding aircraft with respect to the operator's aircraft called the "ownship."

Review of Related Literature

History

The most basic collision avoidance system for pilots is to "see and avoid." The Federal Aviation Regulations (FAR) state that all pilots in visual conditions (even if on an instrument flight plan) are responsible for traffic separation. Unfortunately, limitations of the eye, environmental factors, boredom, workload, etc. result in a system that does not work all of the time.

In the 1940s, it was thought that a pilot's situational awareness could be increased by displaying traffic information in the cockpit. The RCA Princeton Electronic Laboratory refined this idea for use as a backup to the monitoring of traffic conflicts by pilots and controllers. The concept was to place a televised image of the ATC ground controller's radar display in the cockpit which the pilots could use to assess their surroundings. The technological limitations of the time only allowed a constant North-up presentation, which meant the displayed information did not turn with the aircraft and was disorienting when flying in directions other than North. During the early 1970s, Massachusetts Institute of Technology (MIT), prompted by the automated radar terminal system (ARTS) and new developments in airborne computers, embarked on an air traffic situation display study. Researchers at MIT examined factors such as display size, orientation, and content. MIT also defined several operating parameters which would be used in future research (Anderson, Curry, Weiss, Simpson, Connelly, & Imrich, 1971).

Starting in the late 1970s and continuing through the 1980s, NASA's Ames and Langley Research Centers studied traffic display formats and pilot reactions. These CDTI studies used heading or track-up displays (with constantly changing orientation), so the displayed traffic information corresponded to ownship's heading.

Significant research was performed by the NASA centers which examined how pilots used CDTI displays to provide aircraft separation. These experiments were divided into the following three areas of investigation: (1) pilots' ability to maintain separation, (2) pilots' maneuver responses, and (3) pilots' perception of separation.

Separation studies employed approaches and departures to a terminal area to study pilots' ability to use the display to maintain spacing during terminal sequences. While avoiding traffic conflicts was the primary purpose of the CDTI, these studies were conducted since it was thought that airport operations could be increased by allowing pilots to be responsible for their own aircraft separation during takeoffs and landings. Maneuver studies used approach, departure, and level flight scenarios to test how pilots would respond to a conflict situation presented on the display. The perception studies were performed to better understand the information pilots received from traffic displays. The experiments involved judging future positions of intruding aircraft during various phases of flight. These studies were the most recent and were done as a series of experiments that built upon the results of previous experiments. These NASA studies involved dynamic cockpit displays and make up the bulk of information known about CDTIs.

Traffic alert and collision avoidance systems (TCAS) are an advanced form of CDTI used exclusively for traffic avoidance. TCAS provides warnings about conflicting traffic and issues resolution advisories based on complex calculations of passing geometries. The level of automation associated with TCAS seems to suggest that it will not be referred to in the normal cockpit duties unless an advisory is issued. TCAS has been mandated for use in transport category aircraft with more than 30 seats as of 1992 (Federal Aviation Regulation 121.356).

CDTI Design Factors

Display Size and Orientation. Flight decks on current transport aircraft are not configured for stand-alone CDTI. This is unlikely to change in the future as there is only limited room for equipment. This makes the weather radar or moving map cathode-ray tube the usual display area. A problem arises in that while these displays and their location may (or may not) be optimized for their primary task, little thought was given to the uniqueness of the mission of a CDTI.

Anderson, Curry, Weiss, Simpson, Connelly, and Imrich (1971) tried to determine if display size had an effect on pilot perception of separation. They found that there was no significant difference in pilot performance when using a 7 in. x 7 in. display or a 7 in. x 5 in. display. This may have been more the result of the geometry of the intruding aircraft's path rather than display size. All intruders approach ownship head-on thus negating the concern for the difference in width.

Hart and Loomis (1980) conducted a subjective study on CDTI display formats and found that half of the general aviation pilots indicated a 5 in. x 5 in. display was the smallest acceptable display, whereas only one airline pilot was willing to accept a display smaller than 7 in. x 7 in. This is most likely the result of the subjects choosing what they were most used to.

Abbott and Moen (1981) studied the effect of display size on a simulated three nautical mile spacing task during an approach. The simulation was configured to mimic a Boeing 737. The five rectangular display sizes ranged from 3 in. x 4 in. to 6.5 in. x 6.5 in. and also a four in. diameter round display. Six map scales were employed: one, two, four, eight, sixteen, and thirty-two nautical miles per inch.

Throughout the study, the test subjects consistently used the smallest scale factor (greatest position resolution) that would keep the lead aircraft within the viewing area of the CDTI display. The larger map scales were used at one or two minute intervals and for periods less than ten seconds to get "the big picture." The smallest display size was judged to be usable, though more difficult, for the task. The pilots, as expected, indicated a preference for the larger displays. Spacing performance improved as display height increased, suggesting that display size has an effect on pilot performance.

Display orientation refers to whether ownship is fixed on the screen and the background rotates as heading changes (similar to the directional gyro) or whether magnetic North is always represented at the top of the screen and ownship rotates as heading changes. A study by O'Conner, Jago, Baty, and Palmer (1980) found that while pilots preferred a heading-up display orientation over a North-up orientation, performance was not significantly different. This may be the result of the fact that the subjects only had to concentrate on the CDTI, rather than using it to increase situational awareness. The findings of Anderson et al. (1971) showed that the majority of the data sets had better scores using the heading-up display orientation.

Update Factors. The rate at which information on the CDTI is updated is based on the source of that information. Information which is obtained via datalink or as a result of normal transponder squawks is limited to the sweep time of a ground-based radar (approximately four seconds). Aircraft with onboard beacon collision systems could increase the update rate to once per second, while ownship navigational data can be updated continuously by onboard equipment.

Jago, Baty, O'Conner, and Palmer (1981) examined the effects of update type (i.e., continuous rotation while ownship/intruder update and translate every 4 seconds; rotation and translation at the same rate for ownship and intruder; rotation and translation continuous with varying intruder update rates) and rate (4, 2, 1, 0.1 seconds).

All pilots preferred displays with a continuous rotation, translation, and update of ownship and intruder, although these factors did not affect pilot performance significantly. The findings are consistent with those of Palmer, Jago, Baty, and O'Conner (1980) and Anderson, et al. (1971).

However, Abbott and Moen (1981) suggest that the traffic update rate affects the amount of time that the pilot's visual attention is away from his or her primary flight instruments. This is compounded when the CDTI is out of the primary visual scan pattern. Fixation due to a slow update rate could be a safety factor during terminal operations or while flying single pilot operations.

Length of viewing time and time to encounter were examined by O'Conner, Palmer et al. (1980) to see if there was an effect on pilot's perception of conflict situations. Subjects were given different viewing times and times to encounter for each test. Separation at the point of encounter was set at 3,000 ft and was not necessarily the point of closest approach. No scenario would result in a collision between ownship and the intruder. Pilots were allowed to view the display for a fixed amount of time and then asked to make judgments as to whether the intruder would pass in front of or behind ownship. The researchers found that viewing time did not significantly alter the ability of the subjects to accurately perceive an encounter. It was also determined that subjects had more difficulty making accurate decisions when the time to encounter was greater.

Symbology. The symbology used on CDTIs includes: background, aircraft symbols, altitude codes, datatags, predictors, and history lines. Most CDTI research has focused on how the 3-dimensional traffic situation can be best presented to the pilot in a 2-dimensional format. The purpose of this research was to get the most useful information to the pilot in the quickest manner while not distracting from other cockpit duties.

Several experiments examined whether on-screen objects other than those associated with ownship and intruding aircraft affected pilot perception of separation. These background objects, now associated with a moving map display, include: navigational fixes, airways, airports, and terrain (Figure 1). Hart and Loomis (1980) evaluated different types of background symbology. A number of pilots responded that "significantly" high terrain features, natural or man-made, should be graphically represented at pilot request or automatically if ownship were below minimum safe altitude. Pilots, however, also acknowledged that this information would not affect the primary task of traffic separation. O'Conner, Jago, Baty, and Palmer (1980) examined the effects of display backgrounds. A moving background image was thought to assist the pilots in judging the ground speed of ownship, although ground speed was later found to have no significant effect on pilot performance. The different backgrounds tested included none, a grid, and an area navigation (RNAV) route complete with airport runways.

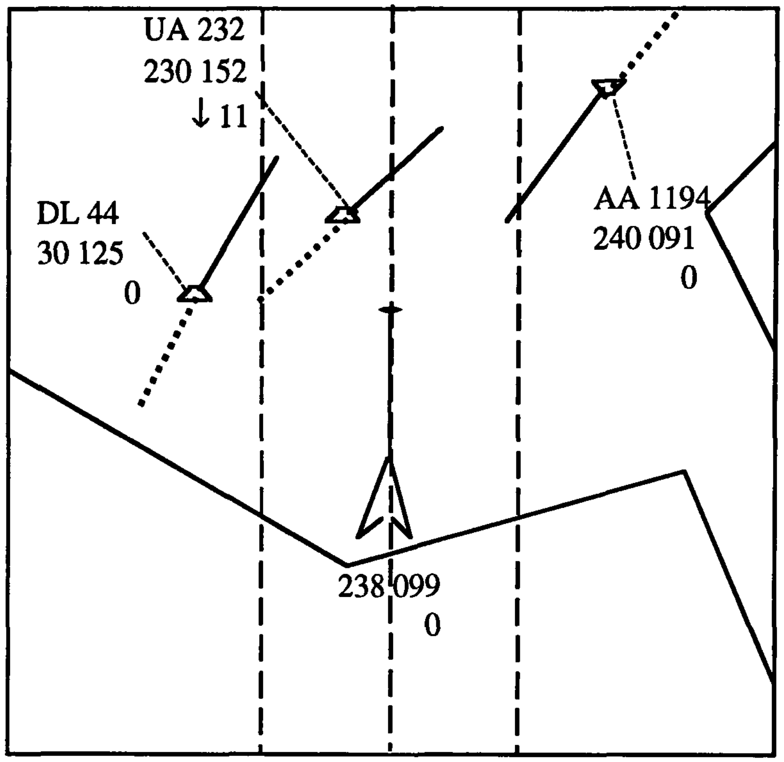

Figure 1. Example of a plan-view cockpit display of traffic information (adapted from Ellis, McGreevy, and Hitchcock, 1987).

Also included under background symbols are range rings around ownship. Most of the experiments conducted with CDTI have not included a range ring. For those that did have a ring, there is no reason given for its location, and there was little consistency regarding its use. Palmer (1983) used a 3-mile ring on a 10 nautical mile map scale while Chappell and Palmer (1983) used a 2-mile range ring on map scales of 2, 5, 10, 20, and 50 nautical miles. The lack of interest in range rings by researchers may be a result of the experimental design. Most of the research has been single-task and in a simulator which has allowed the subjects to concentrate on the intruder's horizontal location or datatag to the exclusion of all else.

Rooney (1992) stated that subjects reported the range ring as a useful judge of distance during the determination of separation.

Much of the research on symbology focused on various ways to represent ownship and the intruding aircraft. While the primary purpose of any aircraft symbol is to mark a position in space, research was conducted to determine if coding information into those symbols was beneficial. Hart and Loomis (1980) performed a subjective experiment on ownship and intruder symbols. A group of general aviation and airline pilots were shown pictures of a CDTI utilizing various combinations of symbols before responding to questions concerning the displays. General aviation pilots tended to pick the stick figure to represent ownship whereas airline pilots favored the chevron shape. All pilots felt that ownship symbol should be clearly differentiated from the symbols for other aircraft by size, shape, and/or color. Pilots were then given a set viewing time to monitor different symbol combinations and asked to determine if the intruder would pass in front or behind ownship.

The amount of information pilots wanted coded into the symbols for intruding aircraft was staggering at first. Almost 92% of the pilots responded that information about altitude, CDTI equipage, and ATC status should be coded into the symbols (Figure 2). Objective measures of performance in a simulator showed no improvement when relative altitude, CDTI equipage, or ATC status were coded into the intruder's symbol. Pilots later responded that they had no interest in the last two factors from an operational standpoint.

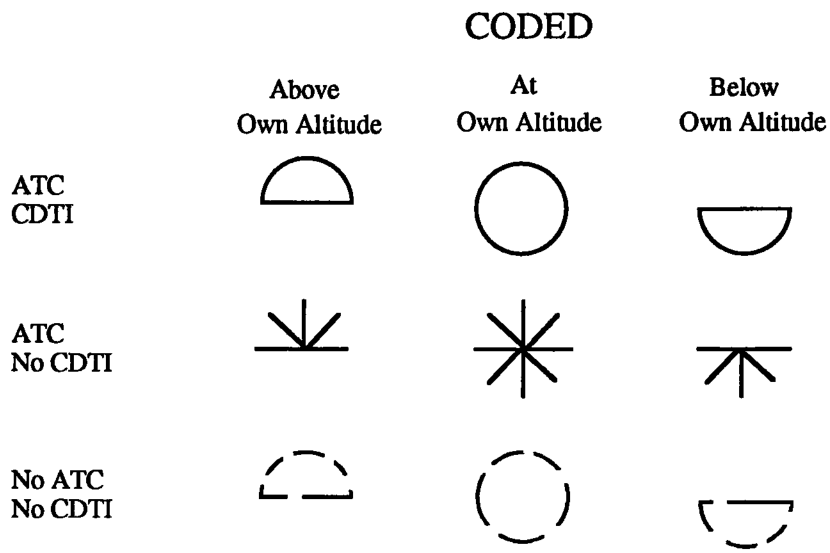

Figure 2. Traffic Symbology (adapted from Abbott, Moen, Person, Keyser, Yenni, & Garren, 1980)

Abbott, Moen, Person, Keyser, Yenni, and Garren (1980) compared the same coded intruder symbols with uncoded intruder symbols in a realistic environment. This was performed with a modified Boeing 737 flying 28 curved, decelerating approaches into the NASA Wallops area. All of the experimental data was acquired through subjective questionnaires following the approaches.

The subjective assessment by the pilots was that the only useful coded symbols were predictor lines and the relative altitude. Pilots responded that they used the coded relative altitude symbols for overall situational awareness, possibly because clutter was such a problem, and used the vertical information in the datatag to assess potential conflicts. Since datatags were selected during potential conflicts, it seems the altitude coding was not effective enough in and of itself. The coded symbol showed an intruder within 1000 feet of ownship's altitude to be at ownship's altitude. This shows that altitude encoding, even though a readily understandable symbol, lacks the accuracy needed by pilots to make precise decisions regarding conflict resolution.

The relative altitude information contained in a coded symbol does not provide the pilot with enough vertical information. Additional information must come from an intruder's datatag and must be easy to assimilate or the pilot will spend excessive time with his/her head in the cockpit waiting for the coded symbol to update. The objective is to find a format that helps pilots make accurate and timely predictions of the future vertical separation of an intruding aircraft.

The datatag designs were initially copied from air traffic control displays. This was not a workable solution because, just as with the North-up presentation, the operating environment was sufficiently different in the cockpit and necessitated different information and presentation formats. Optimal datatag location was examined in an experiment conducted by Anderson et al. (1971). Information was obtained from datatags that were stacked on the edge of the screen or attached to the aircraft targets. While stacked datatags reduced display clutter, response times for intruding aircraft with attached datatags were 30 to 50 percent faster. This was due to the pilots looking back and forth between the stacked datatags and the main display to identify which datatag corresponded to the aircraft of interest.

Hart and Loomis (1979, 1980) found that speed and accuracy were not significantly improved by the addition of either relative altitude information or a climb/descend arrow in the data tag. They did find that the length of time it took the intruder to climb or descend to within 500 ft of ownship's altitude was significantly related to response time and percent error. The later in the encounter that the intruder came to within 500 ft of ownship, the longer pilots waited to respond and the more accurate they were.

Another study concerning pilots use of vertical situation information was performed by Lester and Palmer (1983). Pilots were presented with a traffic display in an aircraft simulator. The display employed three intruder datatag formats. The normal intruder datatag contained the flight number, ground speed, altitude, and vertical speed. The absolute datatag contained the flight number, the current altitude, and the projected altitude at the closest point of approach. The relative datatag contained the same information as the absolute tag except the altitude at closest point of approach was given as an altitude relative to ownship. Reaction time and incorrect responses were found to be significantly lower for the absolute and relative datatag formats. Pilots preferred the relative datatag over the absolute, although no significant differences were found between the two.

Research has also been conducted on assisting pilots with making determinations of future horizontal relationships. While the horizontal component is intuitively easier to resolve due to the plan view display, many factors contribute to the degree of its accuracy.

A study by Hart and Loomis (1980) found that twice as many errors were made when intruders flew curved encounters than for straight-on encounters, and the time pilots took to respond was significantly greater. As approach angle increased from 45 to 135 degrees, symmetrical to the left and right of ownship, both response time and error rate increased significantly. One method examined to reduce this horizontal error was through the use of predictor and history lines. Predictor and history coding showed where aircraft would be 30 or 60 seconds in the future, and where the aircraft had been in the previous 30 seconds, respectively. Predictor and history options both included none, ground-reference straight, and ground-reference curved predictors, where the predictor was represented by a line and history by a series of dots.

Results of a study by O'Conner, Jago, Baty, and Palmer (1980) showed that the use of predictor lines aided pilots in the perception of turning encounters while history lines showed no improvement over the aircraft symbol alone. Displays employing curved predictors had a significantly lower error rate than those using ground-referenced history and straight predictors. Pilots were able to design their own display as part of this study. It is interesting to note that pilots tended to make fewer errors on the displays they designed.

Perspective Displays. The plan-view format was used out of necessity. Although it would require a dedicated screen in the cockpit, limited research has shown that pilots react faster using a perspective display. Capabilities of computers now make it possible to display a perspective view of traffic instead of the standard plan-view format. Ellis, McGreevy, and Hitchcock (1987) examined this approach to presenting traffic information in the cockpit. The display was a "correct-perspective view," from a point 30 kilometers behind ownship, looking down on ownship from an elevation of 30 degrees with a 50 degree field-of-view (Figure 3). All traffic possessed information relative to ownship. Information found valuable in the plan-view studies was applied to the perspective display. Pilots had to monitor a developing traffic conflict and determine whether action needed to be taken. When a need to maneuver ownship was determined, the pilot was asked to select an avoidance maneuver from one of nine maneuver options.

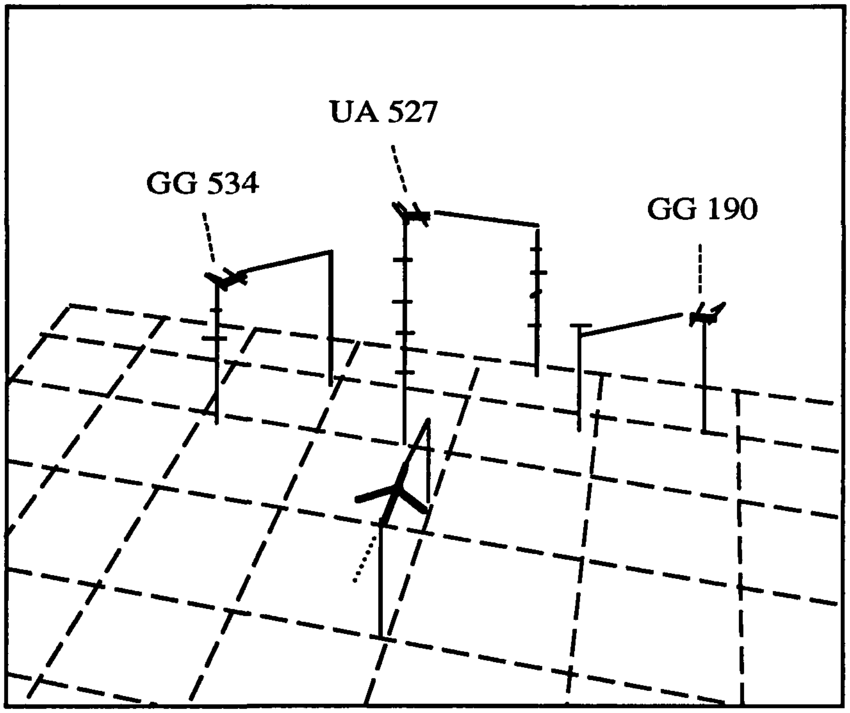

Figure 3. Perspective traffic display (adapted from Ellis, McGreevy, and Hitchcock, 1987).

It was found, except for head-on traffic, that pilots' decision times were three to six seconds faster using the perspective than when using the plan-view display. Head-on traffic was obscured by ownship, which explains the pilots' longer interpret time for that type of traffic. The usual bias of horizontal maneuvers was shifted towards a preference for vertical maneuvers with the perspective display. This suggests that the current TCAS, which only issues vertical resolutions, would be more compatible with a perspective display.

Pilot Avoidance Maneuvers

A pilot's reaction to a displayed conflict is dependent on many factors such as training, fatigue, display effectiveness, etc. Several studies have been conducted to determine not only if pilots notice a conflict, but what process they used to resolve the conflict. Palmer (1983) used a wide-body jet simulator to test pilots' abilities to select a maneuver that would keep the aircraft from deviating too far from the original flight path and still maintain a specified separation. The pilots flew a straight and level course until they were 60 seconds from the closest point of approach. At that time the pilots selected a maneuver that would keep ownship within 500 ft. and 1.5 nm. of their route. The preferred maneuver was a horizontal turn. The majority of the pilots' maneuvers followed a strategy that would uniformly increase the predicted separation between ownship and the intruder but made course deviations in excess of 500 ft. vertical and 1.5 nm. horizontal. The pilots' maneuvers avoided 80% of all the positive collision advisories, but often could not keep within the previously mentioned flight path restraints.

Ellis and Palmer (1982) studied the effects of intruders' minimum separation and time to minimum separation on the avoidance maneuvers selected by pilots. Pilots viewed photographs depicting CDTI conflict situations and ranked the stack of photos by degree of threat. Pilots chose an avoidance maneuver for each photo from a list of nine options. The maneuvers chosen were intended to maintain separation between ownship and the perceived threat (intruder). Analysis of maneuvers showed a tendency to turn toward the intruder and to descend. However, the tendency to use descending maneuvers was not strongly supported across all subjects. The descending tendency may have been due to the scenario (cleared for approach) used for the test. When questioned on the "turn towards" tendency, several pilots explained the maneuver as an attempt to keep the intruder in sight. Ellis and Palmer (1982) noted this explanation as especially interesting since the pilots were instructed that the task involved flying in instrument meteorological conditions.

A dynamic display was utilized by Smith, Ellis, and Lee (1982) to study avoidance maneuvers made by pilots. The pilots' subjective perception of collision danger was investigated by examining the effect of presenting geometrically identical encounters on a display with different map ranges.

The three variables were forward horizontal miss distance, intruder speed, and intruder initial starting altitude. The encounters were repeated for two map ranges, so each factor was crossed with map range. Ten airplane pilots were tested on 96 separate part-task scenarios of CDTI air traffic simulation. Pilots had to chose a maneuver if they felt the conditions warranted it. The time it took pilots to make a decision was recorded. After each scenario pilots rated their perceived collision danger on a scale of one to seven.

The results of the experiment showed that the independent variables did not influence maneuver selection or perceived collision threat. The pilots did tend to select an avoidance maneuver at least 30 seconds before minimum separation from an intruding aircraft. It was further inferred that pilots in the experiment adopted decision strategies sensitive to subjective aspects of the encounters (perceived threat or perceived miss distance) which varied between pilots.

Pilots selected more horizontal avoidance maneuvers than vertical maneuvers. This was possibly due to relatively poor representation of the vertical situation as is true with any plan-view format. As pilots were given less time to monitor the situation, the horizontal maneuver tendency shifted to a vertical tendency. It was felt that the reason for the shift was that vertical maneuvers are accomplished quicker.

A potentially dangerous tendency was for the pilots to indicate a turn towards an intruder during a traffic conflict, but this tendency lessened with greater reported collision hazard. Pilots tended to turn away from intruders when threat was perceived as high and towards the intruder when threat was deemed low. Pilots tended to turn toward intruders approaching more from the front, due to them having a lower perceived threat in those cases. Intruders that started below ownship caused pilots to chose climbing maneuvers. The opposite trend was present but could not be supported across all subjects.

Self Separation Tasks

Collision avoidance was the driving force behind the development of the CDTI. It was thought that the CDTI would provide a backup to the pilots' and controllers' conflict avoidance efforts much like the ground proximity warning system is a backup against controlled flight into terrain. Another possible use for CDTI allowed pilots to be responsible for aircraft separation during terminal phases of flight thus increasing airport operations. This could involve as little as a queue number from ATC and constant monitoring of the CDTI. Anderson et al. (1971) performed an experiment in which the objective was to pilot the simulator through a series of maneuvers, including: arriving at an assigned spacing behind another aircraft, following another aircraft through a turn, and maintaining separation during deceleration of the lead aircraft. Pilots were able to accomplish the tasks after minimal training and practice. An operational test was performed in a modified Boeing 737 flying 28 curved, decelerating approaches (Abbott et al., 1980). Pilots readily reduced separation to two and a half miles and stated they would probably fly closer separations with increased confidence in the display.

There are several problems associated with pilot-controlled separation. The first is how to mix CDTI and non-CDTI equipped aircraft in the traffic queue. Kreifeldt (1980) examined how pilots performed the tactical task of maintaining self-separation when not all aircraft had traffic displays. Three pilots, two with CDTI and one without, had to merge their simulated aircraft among other aircraft that were two minutes apart and already on final approach. Two conditions were analyzed: (1) vectoring, where the ground controller was the only source of separation information, and (2) non-vectoring, where the controller gave only sequencing information to the CDTI pilots and vectoring instructions to the non-CDTI pilot. There was a significant difference in the perceived workload of the CDTI versus non-CDTI pilots. The pilots with CDTI felt there was an increase in overall workload but also stated that it was acceptable for the increased control. The CDTI equipped pilots and controllers had a lower verbal workload during the non-vectoring flights. Within-cockpit verbal workload remained the same for both conditions. Performance for the non-vectored condition had faster runway threshold crossing times within the constraints set because of the non-CDTI equipped aircraft.

Williams and Wells (1986) looked at the mix of CDTI equipped and non-equipped aircraft from the alternate approach of understanding the basic differences of flying with and without the display. They compared pilot flight performance during simulated terminal area approaches and departures, with and without CDTI, and in instrument meteorological conditions (IMC). The study focused on pilot-controlled self-separation, traffic situation monitoring tasks, cockpit procedures, and workload. Experimental conditions consisted of no CDTI (all ground control), monitoring CDTI (vectors from ground control), and CDTI self-spacing (receive only sequencing number from ground control). The aircraft simulators modeled DC-9 series 30 aircraft and ground control stations simulated a Denver terminal radar approach control (TRACON) scope. Approach simulations originated at cruise altitude, descended into the Denver terminal area, and were completed by an instrument landing system (ILS) approach at Denver's runway 26L. Departure simulations took off from runway 35L and departed to the south of Denver's terminal area. Traffic simulating a nominal IMC flow at Denver were injected into the pattern. Pilots maintained a specific spacing interval behind another aircraft during the approach scenarios and avoided specific approaching aircraft during the climb-out phase of the departure scenario.

Checklist procedures were found to be unaffected by the use of a CDTI. The findings represent the fact that most procedures are initiated by specific, routine events such as arriving at certain distances from the runway. The study found that pilots spent an excessive amount of time monitoring the display, which drew their attention away from their primary flight instruments, possibly because of the novelty of the display.

A trend of increasing airspeed violations with increasing CDTI use was found. The data showed pilots were often occupied with monitoring the display when the violations occurred. Most violations (in the direction of slower speed) occurred during minimum airspeed configuration, causing stall problems when abrupt maneuvers were needed.

Pilots subjectively judged their traffic awareness and flight planning to be improved by the traffic display. Overall, pilots who formed self-separation techniques that more closely matched their normal flying techniques were more successful and confident with the self-separation task. When asked subjective questions about task demand, stress, and physical and mental effort, pilots responded that there was lower workload using the display in the monitoring role and higher workload when using the display in the self-spacing role. Pilots felt workload would decrease with experience and that crew coordination was important when performing the self-spacing task.

Interarrival time described the time between the lead aircraft and trailing aircraft crossing the runway threshold. Spacing performance at the runway threshold was better for the self-spacing task than without a CDTI. The difference between the "with CDTI" and "without CDTI" mean interarrival time was approximately seven seconds. The monitoring condition degraded the mean interarrival time performance to fifteen seconds above the "without CDTI" condition. Pilots, in the monitoring condition, made small variations in their speed and turn rate, thereby increasing their spacing behind the lead aircraft. This problem should dissipate with experience, but suggests that initial introduction of such a monitoring task could decrease runway operation rates (ROR) until experience levels increase sufficiently. Training could alleviate some of the problem as well. Spacing clearances given too early, when speed control and specific spacing were not essential, decreased the fuel efficiency of the self-spacing task. This suggests that careful development of CDTI procedures should be done in order to account for these types of problems.

The verbal workload of the ground controller during the approach scenarios showed a measured decrease during the self-separation task. The CDTI monitoring condition did not create additional pilot communications with the ground controller. The departure scenarios showed a marked increase in communication between the ground controller and pilot during the self-separation condition. The increase was caused by excessive communication to identify specific conflicting traffic, suggesting the need for the proper development of departure procedures (Williams & Wells, 1986).

The study showed the importance of developing CDTI procedures that provide optimum self-spacing results. The CDTI self-spacing task did show an ability to increase ROR and reduce controllers' verbal workload. A reduction in communication could be a mixed blessing as it may reduce the situational awareness of other aircraft on the same frequency.

The two different spacing techniques studied by Williams (1983) were constant-time-predictor and constant-time-delay. The predictor criteria bases the required spacing interval at any instant on the current ground speed of the trailing aircraft. The delay criteria requires aircraft to track the same speed profile, with a time delay, of the lead aircraft. Simulators modeled a Boeing 737 aircraft and flew approaches into a replica of Denver's Stapleton Airport terminal area. Denver's approach airspace was split into four corridors and a final approach. The task consisted of flying a manual instrument approach behind a lead aircraft which was guided by ground ATC. Pilots were responsible for their own separation and only required altitude clearances from ground control.

The delay technique was found to produce a more accurate spacing performance. The delay technique produced a mean interarrival time eleven seconds earlier than the predictor technique. This shows that the predictor technique slows down the overall speed profile of the trailing aircraft. The difference between the two techniques was determined to be statistically significant. Williams (1983) felt that the difference was inherent in the operational use of the predictor technique.

Even if a CDTI can provide pilots with the ability to safely control separation in a terminal area, another potential problem is the effect of many aircraft in-trail performing self-separation. Cars in bumper-to-bumper traffic exhibit "stop-and-go" or "accordion-like behavior," which is presumed to occur when many aircraft are in-trail and performing self-spacing. Kelly and Abbott (1984) analyzed the in-trail spacing dynamics of aircraft utilizing CDTI displays to determine separation during a self-spacing task. A queue of 7 to 9 aircraft on approach and employing CDTI was generated on a ground based simulator by flying separate approaches and pasting them together to make a queue. The pilots' task was to maintain separation from the aircraft in front of them while making a profile descent into Denver. The two spacing criteria were the same used by William's 1983 study.

The same slow-down tendency found by William's 1983 study was replicated by Kelly and Abbott (1984). No dynamic oscillations were found when employing the predictor criteria, and it was stated that the slow-down characteristic associated with this criterion made the display undesirable for this application. No dynamic oscillations or slow-down tendencies were found for the delay criteria. The authors cautioned against generalizing the result to actual operation. The reason was that all the aircraft in the queue had the same performance characteristics. A study such as this, but incorporating aircraft of mixed performance and aircraft without traffic displays, would better represent the actual operational environment.

Kreifeldt and Wempe (1973) compared three different management control conditions. The centralized condition (vectoring) was similar to flying IFR, where pilots were given direction vectors and speed control commands. The advisory condition gave pilots total control over the merging task and management of communications. The sequencing condition was a combination of the two previous conditions, where the pilot was given a sequence number and managed separation maintenance. The task consisted of merging three simulated aircraft between two aircraft that were five nautical miles apart and on final approach. The simulators had to descend from 3000 feet, intercept the ILS, and proceed for landing.

In the distributed modes (advisory and sequencing), pilots exhibited a strong self-organizing structure, in which they quickly established the order of the queue (Kreifeldt & Wempe, 1973). This means the three simulator pilots quickly determined a sequence and easily merged between the two aircraft on final as a set of three. The results showed that both distributed modes were equally useful leaving open the question of which was more workable. Pilots were found to prefer the distributed conditions, which is not a surprising result since it allows pilots more control over their own situation. The number of messages by the pilot or controller during a scenario was labeled as verbal workload. The pilot's verbal workload remained constant over all three conditions, while the controller's verbal workload in the distributed conditions was half of that of the vectoring condition. The time between each successive aircraft as they crossed the inner marker was termed the "intercrossing time" (Kreifeldt & Wempe, 1973). The mean intercrossing times were not significantly different across the three conditions. The pilots did produce less variable control results in the distributed conditions, which means the dispersion of intercrossing times was smaller.

A traffic display study was performed using curved descending approaches based on the microwave landing system (MLS), to remove pilots from their familiar landing procedures, was performed to study pilot opinion of separation tasks (Hart, McPherson, Kreifeldt, & Wempe, 1977). The task involved merging and maintaining one minute of separation on the different approaches that were available with MLS. Three simulators were randomly placed on approach paths with other computer-generated traffic. The conditions employed were controller vectoring (centralized) and controller sequencing where ATC took on a monitoring role (distributed).

There were no significant differences in average intercrossing times for the two conditions. The distributed dispersion time was half that of centralized. These results replicate the findings of studies mentioned earlier. Verbal workload was shown to decrease for the controller and remain constant for the distributed condition, again replicating findings stated earlier. Interestingly, controllers expressed a preference for the distributed condition whereas a preference for the centralized was found in other studies. Hart et al. (1977) felt that the change in preference was due to the great difficulty of the curved approach vectoring task. Pilots found vectoring to have a lower visual and total workload than sequencing, which was an expected result.

Conclusion

The reviewed CDTI studies concentrated on how pilots perceived and responded to the information displayed. Areas of investigation were: the interpretation of various forms of display symbology, pilot conflict resolution maneuvers, and the adaptation of CDTI for self-spacing during terminal operations.

The NASA studies have shown that what the pilots think they want and what they actually use are two different things. There is no consensus on where to draw the line between displaying enough relevant information to quickly resolve a conflict and cluttering the display. Much of the current symbology was selected by subjective measures. Research has shown that coded information such as whether an intruder is under ATC control is not needed. Other coded information such as relative altitude, while useful for quickly getting a picture of the surroundings, did not provide the accuracy necessary to resolve a conflict. There is also little data to support the need for background symbology, with the exception of predictor lines which were shown to significantly reduce error rates.

Range rings were used in several studies but never expounded upon. When a ring was used there was no reason given as to its distance from ownship. Rooney (1992) stated that subjects thought the range ring was useful, but this was not experimentally examined.

Many studies examined pilots' perceptions and responses to information describing the vertical plane situation. There were few studies which included vertical rate in the encounter geometry and of those, no specific conclusions were drawn on the effect of vertical rate on pilot perception. While Rooney (1992) did find a significant relationship between vertical rate and error, a problem with the experiment and data analysis makes the results suspect.

It was noted that judging vertical separation was a more difficult task than judging horizontal separation. This is due to the inadequate vertical information provided by plan-view CDTI. Research will be needed to understand pilots' ability to use the available vertical information because the plan-view display will remain the primary format. A more thorough understanding of the effects of vertical rate information and symbology on pilots' perception of traffic geometries will lead to an effective and efficient presentation of the vertical plane on a plan-view display.

Statement of the Hypotheses

While a majority of the past research has been performed on display symbology, the use of a range ring as an aid to perception has not been examined. It was felt that the inclusion of a range ring would provide a pilot with a fixed distance marker on a display without other scale reference, thereby making the task of judging vertical change over distance both quicker and more accurate. Therefore, it was hypothesized that a displayed 3-mile range Ring would decrease selection error and time needed to make a separation decision.

Additionally, various vertical rates have been used in past research but have not themselves been accurately studied to determine if they have an effect on a pilot's perception of aircraft vertical separation. In order to better understand pilots' capabilities with CDTI, research examining how accurately pilots perceive and respond to an intruder's vertical information is needed. Therefore, it was also hypothesized that as the intruder's vertical Rate increases, the error associated with perception of future vertical separation and time to make a decision will increase.

Method

Subjects

The subjects participating in this study were 30 student and staff volunteers from Embry-Riddle Aeronautical University (ERAU). All subjects held at least a private pilot license and satisfied FAA currency requirements (i.e., three takeoffs and landings within the previous 90 days). Subjects' ages ranged from 18 to 35 with a mean of 25 (*SD* = 5.0). Total flight time for the subjects ranged from 65 to 4000 hours with an average of 433 hours (*SD* = 756). Pilot certificates held by the subjects included 19 private, 7 commercial, and 4 certified flight instructors.

Instrument

A Macintosh IIsi® personal computer and SuperCard® software was used for this study. Actual design of the CDTI display and images were accomplished using Canvas® graphics software and transferred to SuperCard®. SuperCard® was implemented to construct and then simulate a dynamic CDTI which sent the experimental data (time, error, & scenario number) to individual text files. A spreadsheet was employed to manipulate this data before being imported into a statistical software package (SPSS-PC®) for analysis.

The keyboard was used to enter the last four digits of the subject's social security number (identity). All other inputs were made via the mouse. Development of the simulation program was aided by the use of graphics designed by Chng (1991) and Rooney (1992). The script (programming language, Appendix A) controlling the simulation was modified extensively from that used by Rooney.

Display Development

Although there is some consensus in the industry that display range should be 5, 10, and 20 miles (Chappell, 1988), it was felt that leaving the range at 7 miles would more closely parallel the previous work of Chng (1991) and Rooney (1992) without negatively influencing the generalizability of the results. The original CDTI displays generated by Chng (1991) had to be modified due to improper scaling of the aircraft and range rings with respect to the display range. The CDTI display size used in the experiment, which was a function of the Macintosh IIsi® screen size, was 5 3/8 inches by 6 inches. This display size is similar to the size used in earlier research (Abbott et al., 1980).

The pixel location information was critical for the layout of the display due to the need for proper scaling and the fact that the software employs pixel data to determine intruder position. The pixels that identify the corners of each display range and other important display locations are shown in Appendix B.

Chappell (1988) stated that the range ring size should be standardized, that additional rings on larger displays would be useful, and that a three nautical mile ring should be standard. Thus the range ring for this experiment was set at three nautical miles from ownship. The 3-mile range ring was also consistent with previous experiments (Palmer, 1983; Chng, 1991; Rooney, 1992).

The primary display for the experiment is presented in Figure 4. The objects used in this display included the general instrument layout as well as the intruder symbol, range ring, ownship symbol, and datatags. The intruder's relative altitude was displayed in a datatag that was positioned next to the intruder's symbol and moved as the intruder moved. A negative value indicated that the intruder was below ownship. The positive value indicated the intruder was above ownship. All graphics were designed in Canvas® and imported into SuperCard®.

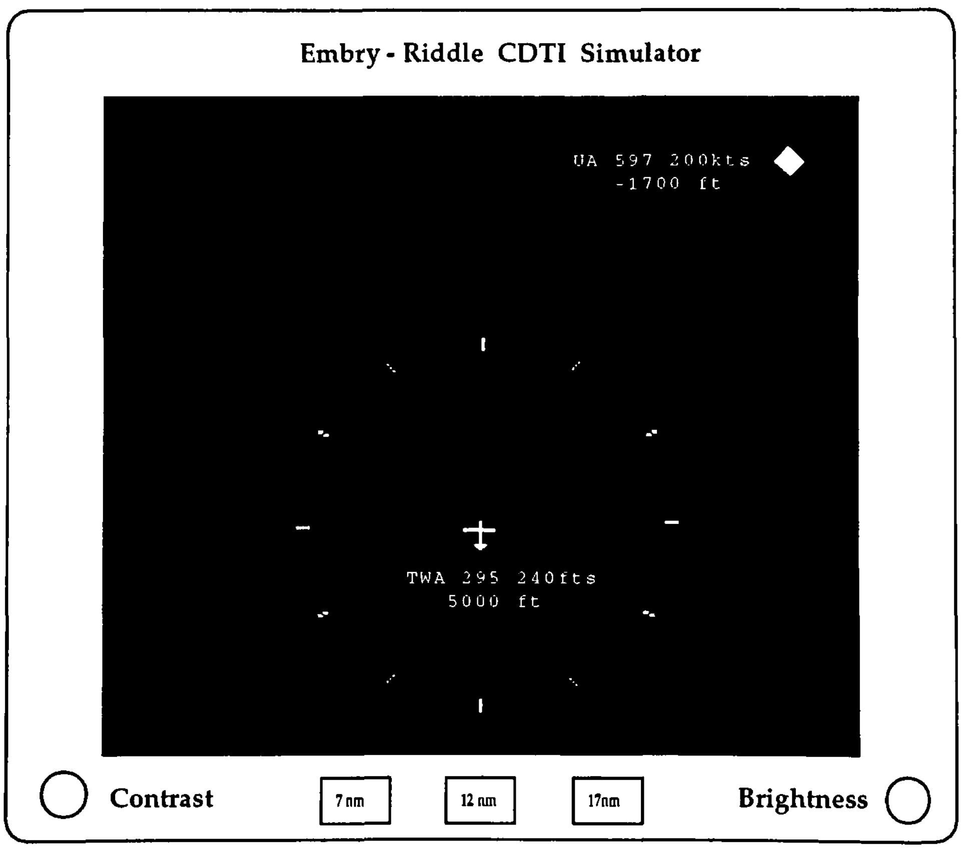

Figure 4. 7 nm. range display employed in the experiment.

The secondary display (Figure 5) was shown when a subject clicked the mouse, thereby stopping the scenario and indicating a readiness to select a vertical Miss distance. The variable scale for this display was designed to overcome one of the shortcomings of Rooney's experiment in which subjects selected intruder passing distance from seven discrete choices. It was felt that using a scale would not overly influence the pilot's choice of vertical Miss. The scale was designed in a manner to clearly separate the above-ownship and below-ownship choices. A height of 1500 feet above ownship to 1500 feet below ownship was selected to allow a range of more than twice the maximum vertical Miss (600 ft).

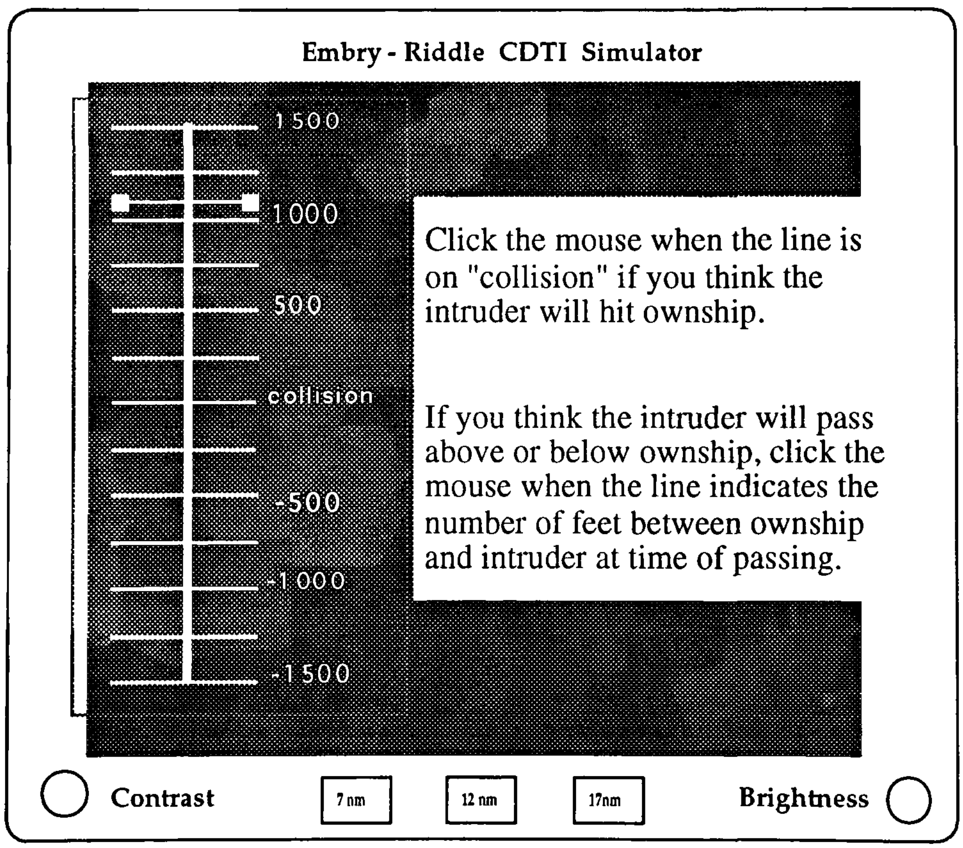

Figure 5. Scale screen used for selecting vertical Miss.

Development of the Simulation Software

The SuperCard® application was a highly modified version of the one used in the experiment conducted by Rooney (1992). The application consisted of two parts, the visual objects and the script.

A card was made for each scenario. There were no objects associated with the cards. The card script contained only the values for the variables that made each scenario unique. These variables included vertical Rate (feet/second), approach Angle (starting position and direction of movement), vertical Miss distance (feet), and whether the ring would be shown. These values were sent to the background script as each scenario was run. The background script controlled the portion of the simulation that the subject saw, and used the card variables to initially display the objects at the correct positions. The background script updated the screen until the subject clicked the mouse indicating they were ready to select a Miss distance. The background script then displayed the screen which contained the scale and pointer, which the subjects moved to indicate their choice of vertical Miss. When the subject indicated their choice by clicking the mouse, the script sent the scenario number and experimental information to a text file, reset all variables, and began the next scenario.

The window script initially obtained the last four digits of the subject's social security number for identification. The window script also randomized the scenarios so each subjects saw the 80 scenarios in a different order, thus controlling for carryover effects such as boredom, fatigue, and learning. A pilot study involving four licensed pilots with human factors research experience was conducted to evaluate and improve the training methods and the experimental simulation.

Mathematical Development of Intruder's Motion

The mathematical relationships of ownship and the intruding aircraft were used to translate their motion in three dimensional space to a two dimensional display. The experiment was designed so that ownship always flew straight, level, and at a constant ground speed. This meant that ownship only moved in one of three dimensions. As the following equations show, the only motion that had to be described by the software was the intruder's motion relative to ownship.

a = Ownship
b = Intruding aircraft

$$\bar{V}_a = (\bar{V}_i + \bar{V}_j + \bar{V}_k)_a$$

where $\bar{V}_a$ is the velocity vector for ownship
and $\bar{V}_{a_i} = \bar{V}_{a_k} = 0$

$$\bar{V}_b = (\bar{V}_i + \bar{V}_j + \bar{V}_k)_b$$

where $\bar{V}_b$ is the velocity vector for intruder

From the relative velocity relationship,

$$\bar{V}_b = \bar{V}_a + \bar{V}_{(b/a)}$$

$$\bar{V}_{(b/a)} = \bar{V}_b - \bar{V}_a$$

where $\bar{V}_{(b/a)}$ is the velocity vector for intruder relative to ownship

Substituting,

$$\bar{V}_{(b/a)} = \bar{V}_{b_i} + (\bar{V}_b - \bar{V}_a)_j + \bar{V}_{b_k}$$

Therefore,

$$\bar{V}_{(b/a)_i} = \bar{V}_{b_i}$$

where $V_{(b/a)_i}$ is the x-component of the velocity vector for intruder relative to ownship

$$V_{(b/a)_j} = (V_b - V_a)_j$$

where $V_{(b/a)_j}$ is the y-component of the velocity vector for intruder relative to ownship

$$\bar{V}_{(b/a)_k} = \bar{V}_{b_k}$$

where $V_{(b/a)_k}$ is the z-component of the velocity vector for intruder relative to ownship

The only component of the intruder's relative velocity that was affected by ownship's velocity is the j-component. The intruder's other two relative velocity components, i and k, were equal to the intruder's normal i and k velocity components. A description of the intruder's velocity in vector form is presented in Figure 6.

The i-component of the intruder's relative velocity was set at positive or negative values to generate approaches from the left or right of ownship, respectively. The two–dimensional depiction of intruder and ownship motion are depicted in vector form in Figure 7.

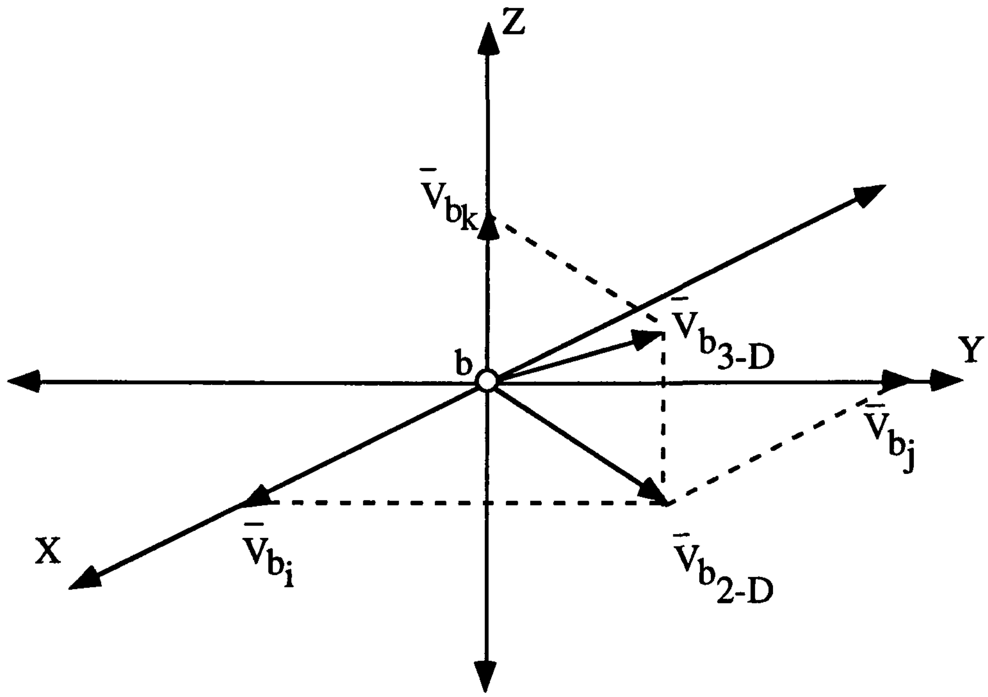

Figure 6. 3-D description of ascending intruder's velocity.

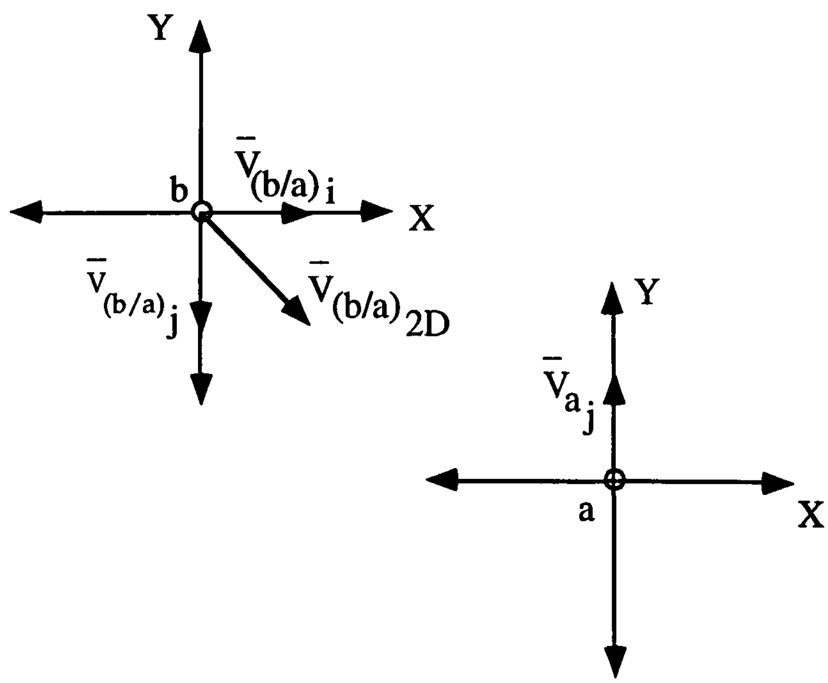

Figure 7. 2-D description of Intruder's relative velocity with respect to ownship (left approach).

A spreadsheet was generated to determine all of the necessary velocities to describe each scenario. The process used to determine the necessary velocities was as follows:

1) Pick $|V|_{(b/a)_{3D}}$ (three dimensional closure rate)

2) Use vertical rate (knots) and $|V|_{(b/a)_{3D}}$ to calculate $|V|_{(b/a)_{2D}}$

3) Calculate $V_{(b/a)_j}$ & $V_{(b/a)_i}$ from $|V|_{(b/a)_{2D}}$ & Approach angle

4) Pick $|V|_{a_j}$ (ownship velocity)

5) Calculate V_{b_j} from $V_{(b/a)_j}$ & V_{a_j}

6) Calculate $\bar{V}_{b_{2D}}$ from $\bar{V}_{b_j}$ & $\bar{V}_{b_i}$

7) Calculate $\bar{V}_{b_{3D}}$ from $\bar{V}_{b_{2D}}$ & $\bar{V}_{b_k}$

The resulting velocities, expressed in knots, were converted to pixels/second using a conversion factor between the seven nautical mile range and the size of the simulation on the computer monitor. A three-dimensional closure rate of 350 knots and an ownship velocity of 240 knots were selected as being representative of the speeds of aircraft flown in a terminal area. The results of the above calculations, for all combinations of the independent variables, are presented in Appendix C.

Experimental Design

The experiment employed a 2 x 4 x 5 x 2 within-subjects repeated measures design. The independent variables in this experiment were whether the 3-mile range ring was displayed, the intruder vertical Rate, the vertical Miss distance, and the Angle of approach for the intruder. The approach angles employed were 0 and 50 degrees from ownship heading. The vertical rates remained constant throughout each scenario, but were varied between scenarios. The four levels of intruder vertical Rate were 1000, 1500, 2000, and 2500 feet per minute. The five levels of vertical Miss distance were -600, -300, 0, +300, and +600 feet. Climbing and descending flight paths appeared the same on the display and were considered symmetrical, therefore climbs and descents were evenly distributed across scenarios. Approaching from the left or right was considered symmetrical, so the 50^{o} approaches were distributed evenly across the right and left portions of the screen. The five levels of the vertical Miss distance variable were evenly distributed throughout the scenarios. The vertical Miss distances could not be considered symmetrical about ownship. This was due to some scenarios being crossovers and others not. A crossover (Figure 8) occurred when the intruder flew through ownship's exact altitude before passing ownship and has been found to affect pilots' perceptions of the display in past studies (Hart & Loomis, 1980). This was controlled for by using an equal number of crossover and non-crossover for each condition.

The dependent variables were: (1) the time from the start of the scenario until the subject clicked the mouse button signifying a readiness to select a Miss distance (dv TIME), and (2) the absolute difference between the pilot's selection of vertical separation when intruder would have passed ownship and actual Miss distance for the scenario (dv ERROR).

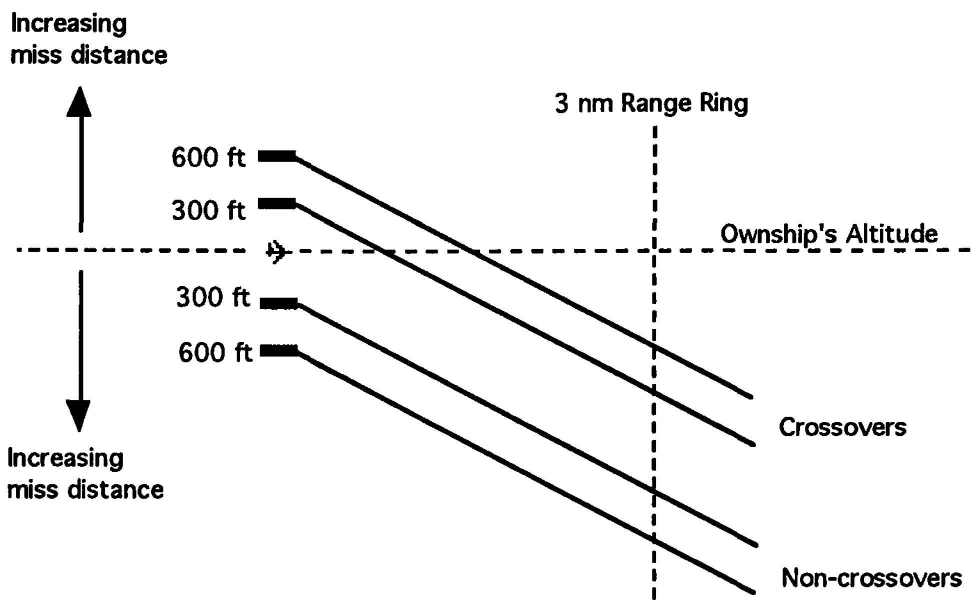

Figure 8. Crossovers and non-crossovers as viewed in the vertical plane.

Procedure

Subjects were tested on the Macintosh IIsi® personal computer located in the Human Factors Laboratory at Embry-Riddle Aeronautical University's (ERAU) Center for Aviation/Aerospace Research (CAAR). The software employed was an application created by the researcher and coded in SuperCard® script.

Upon arriving, each subject read and signed an informed consent form (Appendix D). Each subject was given verbal training about the experiment and what they needed to know to perform the task. The instructions used are presented in Appendix E.

The verbal instructions were followed by four different training scenarios in order to familiarize the subject with the simulator. Once the training scenarios were completed, the subjects completed 80 experimental scenarios.

Upon determining how the intruding aircraft would pass ownship, the subjects clicked the mouse button to halt the scenario and display the vertical Miss scale (to indicate their decision). Once the pilot selected a Miss distance, the computer stored the dependent variables for that scenario in a text file. The display was then blanked and the next scenario was randomly chosen. Subjects were given a break of up to 10 minutes after the 27th and 55th scenarios.

The researcher was not in the same room as the subject during the training scenarios or experiment, but was available if the subject had any questions after the training or during the breaks. All experiments were conducted in the same room with the same amount of ambient light.

Upon completing the experiment, the subjects were asked what strategy/method they used to make their separation determinations. Finally, the subjects were debriefed concerning the purpose of the experiment and were shown a comparison between their responses and the correct responses.

Results

Data

Two dependent variables (TIME and ERROR) were collected for each of the 80 scenarios. TIME was measured from the start of the scenario to the point when the subject clicked the mouse button, signifying a readiness to make an estimation of vertical Miss. The time was not recorded for how long it took the subjects to record each decision once the screen had changed to the vertical Miss scale. ERROR was defined as the absolute value of the difference between the actual vertical Miss distance for the scenario and the distance selected by the subject. There was no missing data for any of the scenarios. Appendix F shows the mean TIME, standard deviation of the TIME scores, mean ERROR, and standard deviation for the ERROR scores for each of the scenarios. Appendix G shows the same categories for the 30 subjects.

Correlation

The two dependent variables, TIME and ERROR, were analyzed using a pairwise Pearson correlation to determine if subjects traded time for accuracy. This tradeoff would manifest itself by the successful outcome of subjects waiting longer in order to make a more accurate determination of the vertical Miss. The resulting correlation yielded a coefficient of r=-0.639, n=30, p<0.01 (Figure 9). While it might be argued that a significant correlation should result in the use of multivariate statistics, the researcher felt that satisfactory results would be obtained with univariate statistics.

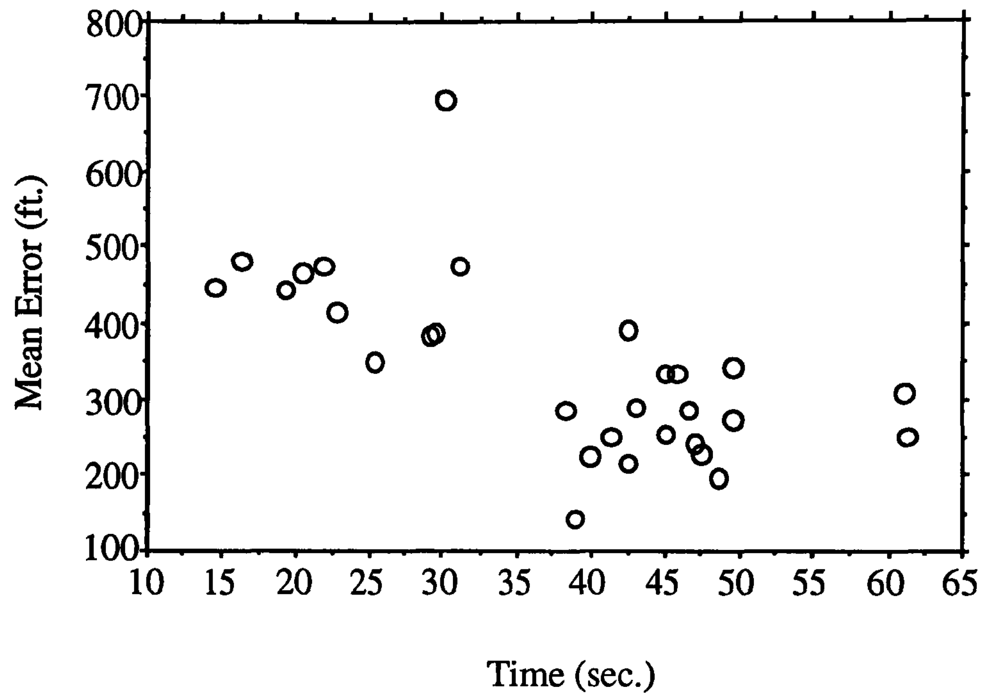

Figure 9. Scattergram showing dv ERROR versus dv TIME for 30 subjects.

Dependent Variable TIME

A four-way within-subjects Analysis of Variance (ANOVA) was performed on the dependent variable TIME using the factors: Ring (two levels), Rate (four levels), Miss (five levels), and Angle (two levels). Table 1 shows a summary of the results of the analysis of variance for the dv TIME.

Table 1 <u>Summary of ANOVA results for the dv TIME</u>

Source	*df*	*SS*	*MS*	*F*	*p*
Error (Subjects)	29	404613	13952		
Ring	1	133	133	0.51	.483
Error (Subjects x Ring)	29	7639	263		
Rate	3	14870	4957	8.39	.000
Error (Subjects x Rate)	87	51403	591		
Miss	4	4008	1002	4.67	.002
Error (Subjects x Miss)	116	24874	214		
Angle	1	100	100	0.29	.595
Error (Subjects x Angle)	29	10047	346		
Ring x Rate	3	356	119	0.47	.702
Error (Subjects x Ring x Rate)	87	21851	251		
Ring x Miss	4	47	12	0.06	.994
Error (Subjects x Ring x Miss)	116	23615	204		
Ring x Angle	1	24	24	0.13	.719
Error (Subjects x Ring x Angle)	29	5272	182		
Rate x Miss	12	671	56	0.29	.991
Error (Subjects x Rate x Miss)	348	67564	194		
Rate x Angle	3	1345	448	2.15	.100
Error (Subjects x Rate x Angle)	87	18177	209		
Miss x Angle	4	7480	1870	6.26	.000
Error (Subjects x Miss x Angle)	116	34637	299		
Ring x Rate x Miss	12	3284	274	1.46	.137
Error (Subjects x Ring x Rate x Miss)	348	65180	187		
Ring x Rate x Angle	3	1243	414	2.05	.113
Error (Subjects x Ring x Rate x Angle)	87	17620	203		
Ring x Miss x Angle	4	123	31	0.16	.958
Error (Subjects x Ring x Miss x Angle)	116	22341	193		
Rate x Miss x Angle	12	3478	290	1.46	.138
Error (Subjects x Rate x Miss x Angle)	348	69170	199		
Ring x Rate x Miss x Angle	12	3187	266	1.41	.159
Error (Subjects x Ring x Rate x Miss x Angle)	348	65519	188		
Total	2399	949871			

No significant main effect was found for Ring $F(1, 29)=0.51$, $p=0.483$. The subjects did not select a Miss distance significantly faster or slower when the Ring was not displayed (M=38.3 sec.) versus when it was (M=38.8 sec.).

The vertical Rate of the intruder was found to be significant for TIME; $F(3, 87)=8.39$, $p<0.001$. A Student Newman-Keuls (SNK) range test was performed on the four levels of vertical Rate using the following group means:

Rate	Group Means (TIME)
1000'/min	35.90 sec
1500'/min	36.16 sec
2000'/min	40.99 sec
2500'/min	41.01 sec

The result was a significantly faster response time for 1000'/min than for 2000'/min and 2500'/min. Response time for 1500'/min was also significantly faster than for 2000'/min and 2500'/min. There was no significance for 1000'/min versus 1500'/min or 2000'/min versus 2500'/min (Table 2). The significant difference in the time taken to determine a Miss distance between the two slowest vertical rates and the two fastest vertical rates, with no significant difference within each pair, can be seen in Figure 10.

Table 2

Student Newman-Keuls significance for vertical Rate on dv TIME

	1000'/min	1500'/min	2000'/min
1000'/min			
1500'/min			
2000'/min	< .01	<.01	
2500'/min	< .01	<.01	

Empty cells indicate p values greater than .05.

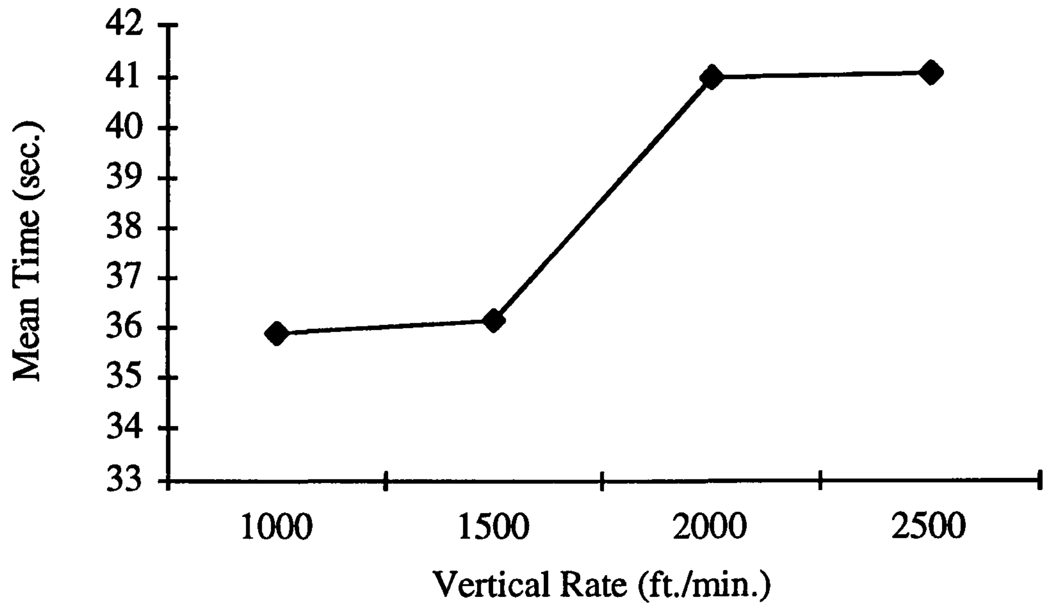

Figure 10. Mean Time taken to determine vertical Miss by vertical Rate.

The amount of time used to determine what the vertical Miss distance would be was also found to be significantly different between the five levels; $F(4, 116)=4.67$, $p=0.002$. The vertical Miss distance is comprised of two factors, a magnitude (feet from ownship) and a direction (above/ below). A plot of the group means (Figure 11) shows symmetry around the vertical axis which suggests that direction has little effect on TIME.

A SNK range test was performed on the five vertical Miss distances using the following group means:

Miss Distance	Group Mean (TIME)
+600 ft Miss	36.9 sec
+300 ft Miss	40.2 sec
0 ft Miss	38.6 sec
-300 ft Miss	39.6 sec
-600 ft Miss	37.2 sec

The results showed that the time required by the subjects to indicate they knew what the vertical passing distance would be was significantly less when the actual vertical Miss was +/- 600 ft then when it was +/- 300 ft (Table 3), suggesting that pilots could determine when intruder would not pass close to ownship.

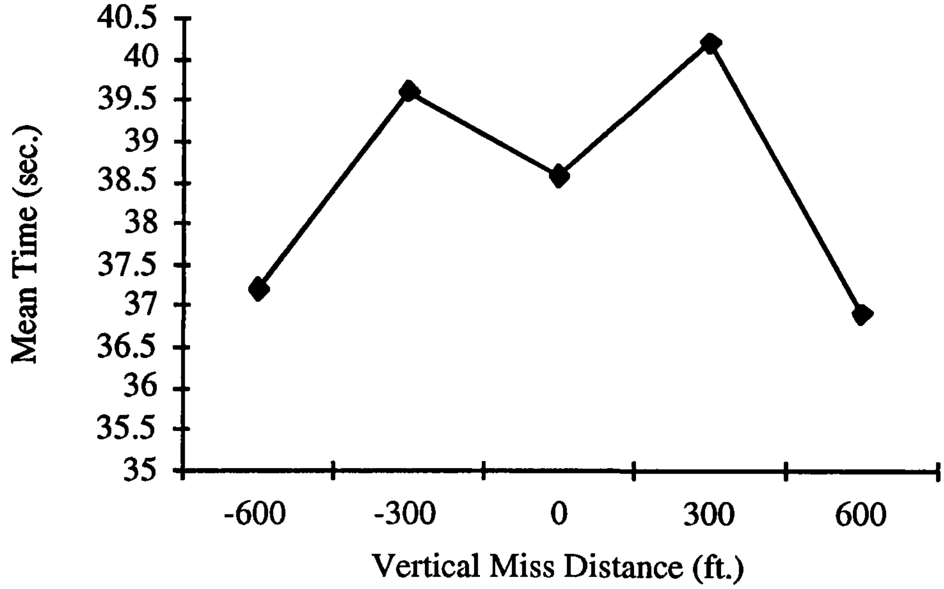

Figure 11. Mean Time taken to determine vertical Miss by vertical Miss.

Table 3

Student Newman-Keuls significance for vertical Miss on dv TIME

	-600 ft	-300 ft	0 ft	300 ft
-600 ft				
-300 ft	< .05			
0 ft				
300 ft	< .01			
600 ft		<.05		< .01

Empty cells indicate p levels greater than .05.

No significant main effect was found for Angle $F(1, 29)=0.29$, $p=0.595$. The TIME used by the subjects to select a Miss distance was not significantly different when the intruder approached at 0° ($M=38.7$ sec.) versus when the intruder approached at 50° ($M=38.3$ sec.).

The first order interaction of Miss by Angle was found to be significant for TIME; $F(4, 116)=6.26$, $p<0.001$. The plot of the Miss distances when broken out by Angle shows that there is now a lack of symmetry (i.e., direction has an effect) (Figure 12). This was confirmed by a test for simple effects which showed that Angle was significant at a Miss distance of -600 ft; $F(1, 29)=13.99$, $p<0.001$; and also at +600 feet; $F(1, 29)=7.43$, $p=0.007$. In the scenarios where the intruder passed over ownship at 600 feet, the subjects as a group were significantly faster when the intruder approached from 0° ($M=34.7$ sec.) then when it approached from 50° ($M=39.0$ sec.). This was reversed when the intruder passed 600 feet below ownship. During these scenarios, responses were significantly faster when the intruder approached from 50° ($M=34.3$) then from 0° ($M=40.2$ sec.).

The test for simple effects also showed that Miss distance was significant at 0°; $F(4, 29)=5.54$, $p<0.001$; and at 50°; $F(4, 29)=4.19$, $p=0.003$. A SNK range test was performed using the following group means:

Miss (ft.) by 0°	Mean Time	Miss (ft.) by 50°	Mean Time
+600	34.7 sec	+600	39.0 sec
+300	41.6 sec	+300	38.8 sec
0	37.9 sec	0	39.4 sec
-300	39.2 sec	-300	40.0 sec
-600	40.2 sec	-600	34.3 sec

The results when Angle was held constant at 0° showed that +600 foot Miss distance required significantly less time ($p<0.05$) to make a decision than all other Miss distances. Holding Angle constant at 50° resulted in significantly shorter response times ($p<0.05$) when Miss was -600 feet as compared to all other distances.

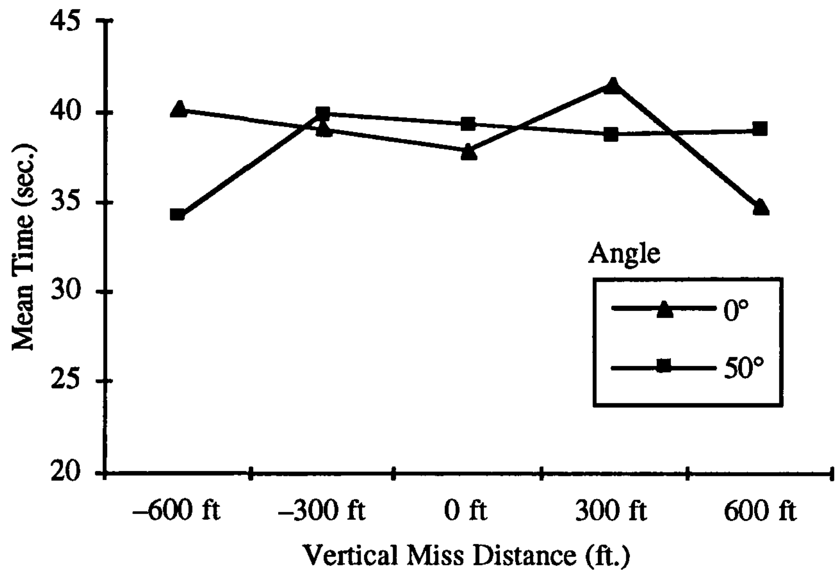

Figure 12. Mean Time versus Miss distance split by Angle.

Dependent Variable ERROR

A four-way within-subjects Analysis of Variance (ANOVA) was performed on the dependent variable ERROR using the factors: Ring (two levels), Rate (four levels), Miss (five levels), and Angle (two levels). ERROR refers to the absolute difference between selected Miss and actual Miss. Table 4 shows a summary of the results of the analysis of variance for the dv ERROR.

Table 4 Summary of ANOVA results for the dv ERROR

Source	df	SS	MS	F	p
Error (Subjects)	29	31033284	1070113		
Ring	1	79350	79350	1.99	.169
Error (Subjects x Ring)	29	1154773	39820		
Rate	3	5921934	1973978	8.85	.000
Error (Subjects x Rate)	87	19407043	223069		
Miss	4	7289292	1822323	16.62	.000
Error (Subjects x Miss)	116	12717153	109631		
Angle	1	892433	892433	9.40	.005
Error (Subjects x Angle)	29	2753640	94953		
Ring x Rate	3	231979	77326	1.59	.196
Error (Subjects x Ring x Rate)	87	4218829	48492		
Ring x Miss	4	129830	32458	.72	.578
Error (Subjects x Ring x Miss)	116	5203835	44861		
Ring x Angle	1	213948	213948	5.04	.033
Error (Subjects x Ring x Angle)	29	1231804	42476		
Rate x Miss	12	1424970	118748	1.81	.045
Error (Subjects x Rate x Miss)	348	22845265	65647		
Rate x Angle	3	1299859	433286	5.06	.003
Error (Subjects x Rate x Angle)	87	7456499	85707		
Miss x Angle	4	77280	19302	.27	.898
Error (Subjects x Miss x Angle)	116	6718176	57915		
Ring x Rate x Miss	12	511609	42634	.72	.727
Error (Subjects x Ring x Rate x Miss)	348	20465646	58809		
Ring x Rate x Angle	3	283861	60288	1.57	.203
Error (Subjects x Ring x Rate x Angle)	87	5245037	60288		
Ring x Miss x Angle	4	64795	16199	.28	.892
Error (Subjects x Ring x Miss x Angle)	116	6776590	58419		
Rate x Miss x Angle	12	1207630	100636	1.33	.201
Error (Subjects x Rate x Miss x Angle)	348	26398175	75857		
Ring x Rate x Miss x Angle	12	749141	62428	1.12	.345
Error (Subjects x Ring x Rate x Miss x Angle)	348	19442874	55870		
Total	2399	2.13E+08			

Again, no significant main effect was found for Ring $F(1, 29)=1.99$, $p=0.169$. The subjects did not have significantly more ERROR when the Ring was not displayed (M=344.1 ft.) versus when the ring was displayed (M=332.6 ft.).

The vertical Rate of the intruder was found to be significant for ERROR; $F(3, 87)=8.85$, $p<0.001$. Figure 13 shows a plot of the group means. A Student Newman-Keuls (SNK) range test was performed on the four levels of vertical Rate using the following group means:

Rate	Group Mean (Error)
1000 ft/min	308.6 ft
1500 ft/min	281.6 ft
2000 ft/min	350.0 ft
2500 ft/min	413.4 ft

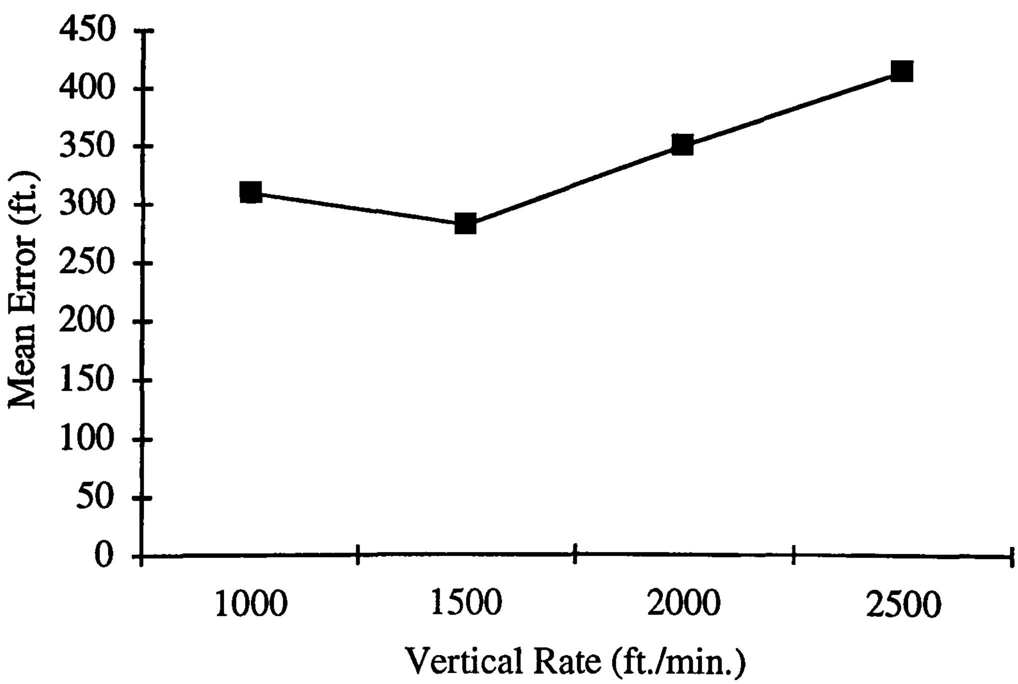

Figure 13. Mean Error versus vertical Rate.

The results show that when the intruder approached ownship at a vertical Rate of 2500 ft./min., the subjects experienced significantly higher ERROR when compared to all other vertical Rates. Additionally, there was significantly more ERROR associated with 2000 ft./min. than with 1500 ft./min. These results are shown in Table 5.

Table 5

Student Newman-Keuls significance for vertical Rate on dv ERROR

	1000 ft/min	1500 ft/min	2000 ft/min
1000 ft/min			
1500 ft/min			
2000 ft/min		<.05	
2500 ft/min	< .01	< .01	< .05

Empty cells indicate *p* levels greater than .05.

Miss was also shown to have a significant effect on ERROR $F(4, 116)=16.62$, $p<0.001$. The plot of mean group ERROR shows that subjects made the least amount of ERROR on the scenarios where the intruder would have collided with ownship (Figure 14). The magnitudes of the ERROR are less symmetrical around the vertical axis than was the case for dv TIME. A plot of the group ERROR versus the magnitude of the vertical Miss (disregarding 0 Miss) shows that there is an interaction due to direction (Figure 15). Namely, the difference in the amount of error between +/-600 feet is much greater than the difference between +/- 300 feet. The group means calculated for vertical Miss were as follows:

Miss	Group Mean (Error)
+600 ft.	358.3 ft.
+300 ft.	330.8 ft.
0 ft.	245.8 ft.
-300 ft.	340.2 ft.
-600 ft.	416.9 ft.

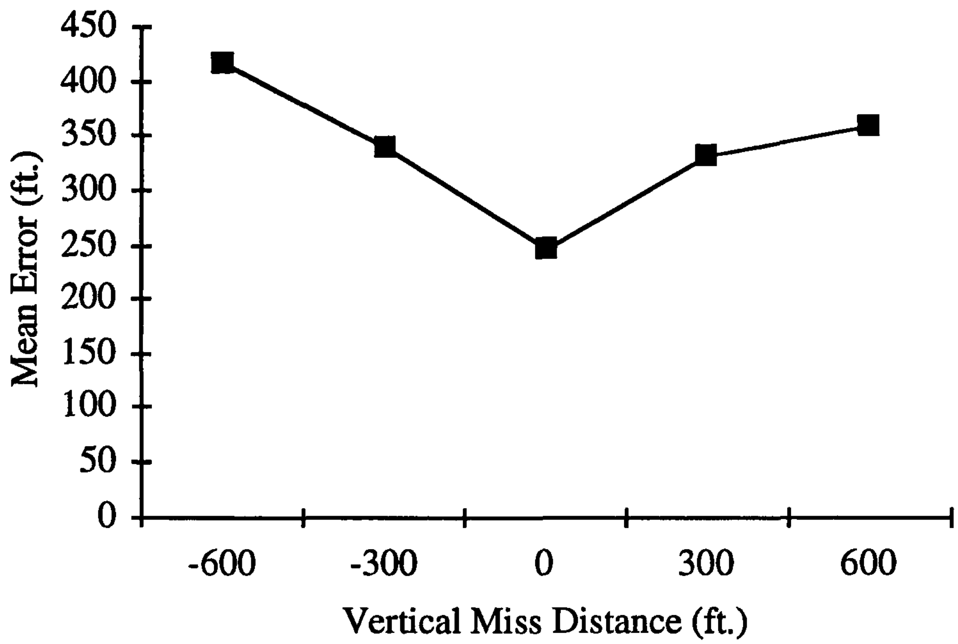

Figure 14. Mean Error versus vertical Miss.

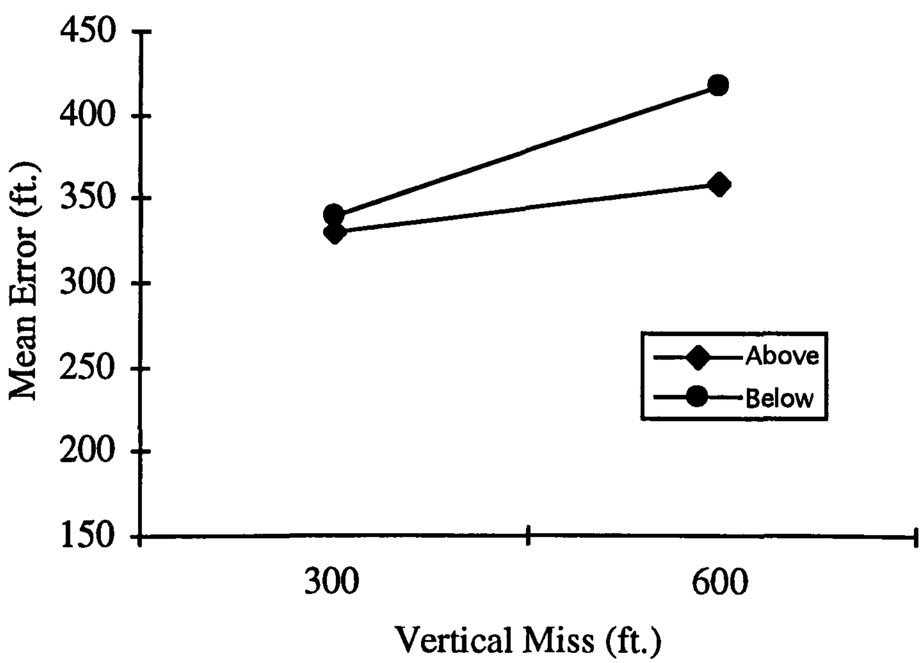

Figure 15. Mean Error versus Miss distance split by direction.

The Student Newman-Keuls range test showed that the -600 foot Miss distance was associated with significantly more error than all other Miss distances. Additionally, the -300 foot, +300 foot, and +600 foot levels were all significantly worse than the 0 Miss distance (collision). These results are shown in Table 6.

Table 6

Student Newman-Keuls significance for vertical Miss on dv ERROR

	-600 ft	-300 ft	0 ft	300 ft
-600 ft				
-300 ft	<.01			
0 ft	<.01	<.01		
300 ft	<.01		<.01	
600 ft	<.01		<.01	

Empty cells indicate *p* levels greater than .05.

The approach Angle of the intruder was also found to be significant. The mean group Error when the Angle was 0° (head on) was 319.1 feet. The group Error increased to 357.7 feet when the intruder's approach Angle was 50°. The subjects had significantly more error in determining a Miss distance when the intruder approached from the side.

The Ring by Angle first order interaction was found to be significant; $F(1, 29)=5.04$, $p=0.033$. Figure 16 shows the strong interaction. A test for simple effects was performed using the following group means:

Ring by Angle	Mean Error
no Ring/0°	315.4 ft
no Ring/50°	372.9 ft
Ring/0°	322.8 ft
Ring/50°	342.5 ft

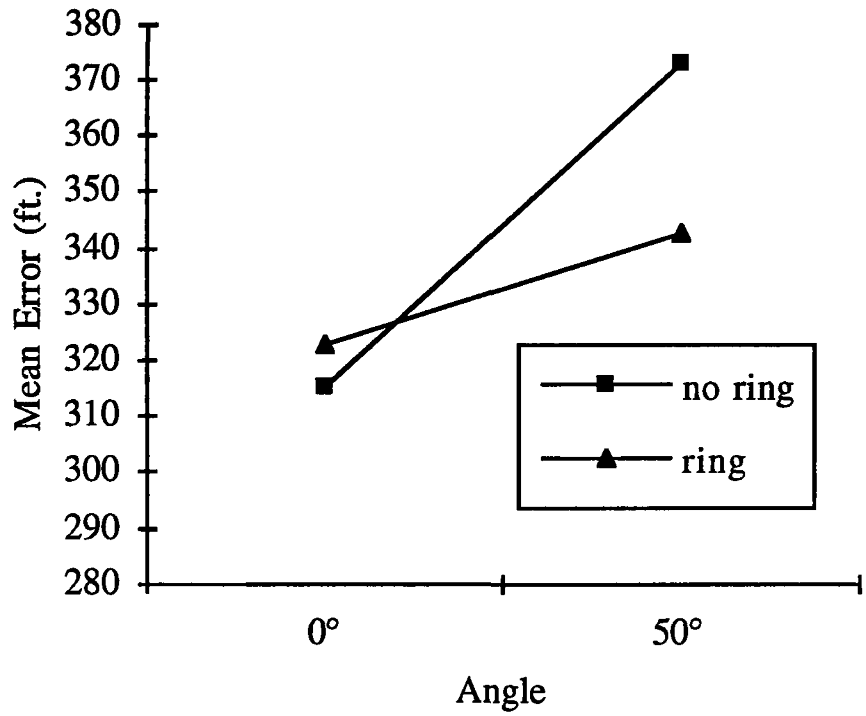

Figure 16. Mean Error versus Angle split by Ring/No Ring

The results showed that with no Ring displayed, an Angle of 0° resulted in significantly less ERROR then an approach Angle of 50°; $F(1, 29)=23.35$, $p<0.001$. At an Angle of 50°, no Ring resulted in significantly more ERROR than when the Ring was displayed ; $F(1, 29)=6.53$, $p=0.016$.

The first order interaction, Rate by Miss, was found to have a significant Mauchly sphericity test. The application of Box's Epsilon correction (e = 0.61) for a possible violation of the assumption of compound symmetry resulted in a nonsignificant interaction; $F(8, 212)=1.81$, $p>0.05$. No further action was taken on this interaction.

The final significant interaction was Rate by Angle; $F(3, 87)=5.06$, $p=0.003$. A plot of the means shows roughly the same shape as for the main effect of Rate (Figure 17). A test for simple effects used the following group means:

Rate (ft./min.) by 0°	Mean Error	Rate (ft./min.) by 50°	Mean Error
2500	355.9 ft.	2500	470.9 ft.
2000	340.3 ft.	2000	359.6 ft.
1500	266.4 ft.	1500	296.9 ft.
1000	313.8 ft.	1000	303.4 ft.

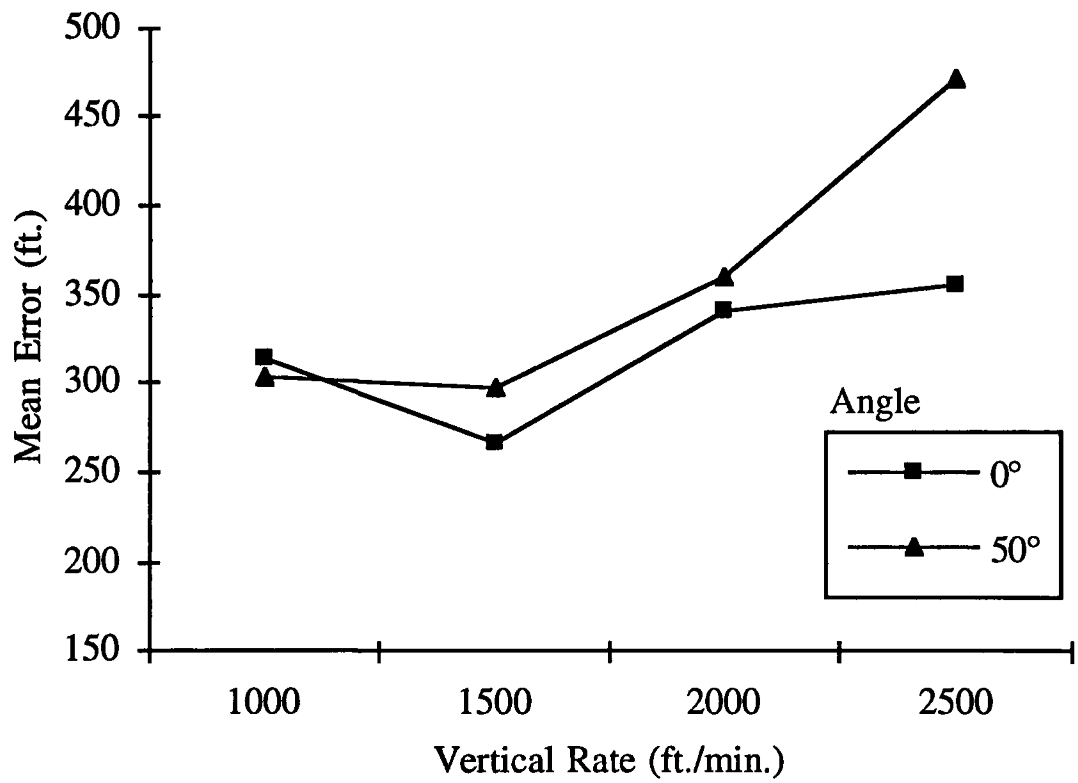

Figure 17. Mean Error versus Rate split by Angle.

The results of the test for simple effects showed that the ERROR associated with a Rate of 2500 ft./min. was significantly greater at 50°

(*M*=470.9 ft.) then it was at 0° (*M*=355.9 ft.); $F(1, 29)=23.15$, $p<0.001$. These findings are similar to the main effect of Angle on ERROR and the interaction of Miss and Angle on the dv TIME.

The results also showed that Rate was significant at 0°; $F(3, 87)=5.38$, $p=0.002$; and at 50°; $F(3, 87)=22.71$, $p<0.001$. A SNK range test was done at each level of Angle. At an Angle of 0°, 1500 ft./min. was found to have significantly less ERROR than 2000 ft./min. and 2500 ft./min. ($p<0.05$). At an Angle of 50°, the 2500 ft./min. Rate had significantly more ERROR than 1000 ft./min., 1500 ft./min., and 2000 ft./min. ($p<0.001$). Also at 50°, there was significantly less ERROR associated with 1500 ft./min. versus 2000 ft./min. ($p<0.05$) and between 1000 ft./min. and 2000 ft./min. ($p<0.05$).

Discussion

This study focused on the pilots' ability to quickly judge future vertical separation between ownship and a single intruder. It was emphasized in the training instructions that the time required to make a decision and the accuracy of that decision were equally important. Therefore, pilots were to make their choice as soon as they determined a separation distance. They were not to wait and build confidence in their determination. The correlation between TIME and ERROR showed that there was a tradeoff of time for accuracy. This is to be expected because as time increases, the difference between the present intruder vertical distance and the Miss distance becomes smaller and thus, easier to judge. The focus on equal importance for time and accuracy may have altered the methods used by pilots to make their decisions. A different focus, such as stressing the need for accuracy by letting the intruder fly in closer, may have resulted in a different outcome.

Pilots were asked during the debrief what methods they used to arrive at a decision. Pilots stated several methods that were based on determining the vertical change of the intruder over a fixed distance. The most readily used distance was the 3.5 nm. point (half-way). Several of the subjects said they used the Ring, when displayed, to make a more accurate determination of the half-way point. Another popular method was to let the intruder fly for three nautical miles and determine the altitude change, then add/ subtract this number from the relative altitude when the aircraft reached three nautical miles from ownship (the range Ring if displayed). One subject stated he used this method because, for him, accuracy was more important than horizontal separation and this was a good compromise.

All the above methods depended upon the intruder not deviating from its course. Changes in the intruder flight path will plague the effectiveness of any display that requires the operator to make predictions. Subjects knew the intruder would not deviate from its path, that it would pass directly over ownship, and that it would climb/descend at a constant Rate. This knowledge undoubtedly assisted the pilots in making more accurate decisions because when an intruder deviates from its original course, there is no longer a linear relationship between time, horizontal distance, and vertical separation.

There was one pilot who tried to "beat the test." This pilot let the first couple intruders fly toward ownship until the software halted them, then he would use the average number of updates to calculate a Miss distance for subsequent scenarios. Although no explicit instructions were given to the subjects on how to complete the objective, this method defeats the purpose of the study because it would not be a viable method in a real cockpit environment.

The subjects, for the most part, were comprised of low time (65 to 4000 hours, M=433 hours, SD=756) general aviation pilots with little knowledge of cockpit displays of traffic information. It was felt that the subject population represents the present users of CDTI because the task relies more on cognitive skills and specific training than flight hours.

The dependent variables for this study, TIME and ERROR were analyzed using univariate ANOVAs (Table 7). This was done despite the argument that a significant correlation between the dependent variables

(r=-0.639, n=30, p<0.01) should necessitate the use of multivariate statistics.

Table 7 Summary of significance on dv TIME and dv ERROR

TIME	
Rate	$F(3, 87)=8.39, p<0.001$
	1000 ft./min. (faster) vs. 2000 ft./min. & 2500 ft./min. 1500 ft./min. (faster) vs. 2000 ft./min. & 2500 ft./min.
Miss	$F(4, 116)=4.67, p=0.002$ +/-600 ft. (faster) vs. +/-300 ft.
Miss x Angle	$F(4, 116)=6.26, p<0.001$ +600 ft. @ 0° (faster) vs. +600 ft. @ 50° -600 ft. @ 50° (faster) vs. -600 ft. @ 0° +600 ft. @ 0° (faster) vs. all others @ 0° -600 ft. @ 50° (faster) vs. all others @ 50°
ERROR	
Rate	$F(3, 87)=8.85, p<0.001$ 2500 ft./min. (more error) vs. all others 2000 ft./min. (more error) vs. 1500 ft./min.
Miss	$F(4, 116)=16.62, p<0.001$ -600 ft. (more error) vs. all others +/-300 ft., +600 ft. (more error) vs. 0 Miss
Angle	$F(1, 29)=9.40, p=0.005$ 50° (more error) vs. 0°
Ring x Angle	$F(1, 29)=5.04, p=0.033$ no Ring @ 50° (more error) vs. no Ring @ 0° no Ring @ 50° (more error) vs. Ring @ 50°
Rate x Angle	$F(3, 87)=5.06, p=0.003$ 2500 ft./min. @ 50° (more error) vs. 2500 ft./min. @0° 2000/2500 ft./min. @0° (more error) vs. 1500 ft./min. @ 0° 2500 ft./min. @ 50° (more error) vs. 1000/ 1500/2000 ft./min. @ 50° 2000 ft./min. @ 50° (more error) vs. 1000/ 1500 ft./min. @ 50°

Although most of the subjects said they used the three mile range Ring to determine future separation, there was no main effect for the range

Ring with regard to TIME or ERROR. Therefore, the research hypothesis that a 3-mile range Ring will reduce the time and error associated with the selection of vertical Miss distances is rejected. There are several possible reasons for this result. One is that this was a single task simulation which allowed the subject to concentrate on a point on the display and/or use a finger to mark the half-way point. This might negate the usefulness of the displayed range Ring by constructing an "artificial" range. Another possible explanation is that time was not a limiting factor during the scenario. The range Ring may have had more of an effect if the subjects were given a short amount of time to judge the horizontal distance before determining a vertical separation.

There was a first order interaction of Ring x Angle on the dependent variable ERROR suggesting that there may be instances where a range ring is useful. Past research has shown that as approach Angle increases, it becomes harder to correctly interpret the flightpath interactions (Hart & Loomis, 1980). Thus, the Ring may have been used to resolve the more complicated conflicts.

The second research hypothesis that intruder vertical Rate would increase the amount of time to make a decision and also increase the amount of error of that decision, is accepted. There is strong evidence to show that an increase in the vertical Rate resulted in the subjects waiting longer to make a decision and then, being further from the actual distance. One possible explanation for the significance in TIME and ERROR with respect to vertical Rate is that the subjects were not used to being involved with aircraft capable of climbing at 2000+ feet/minute due to their general aviation background (general aviation aircraft typically climb at less than 1000 ft./min.). The fact that Rate was found to be significant is more likely due to the process the subjects used to calculate a Miss distance rather than to their past flying experiences. The task for each scenario involved calculating a Miss distance by watching the relative altitude in the intruder's datatag and projecting what this value would read when intruder passed ownship. The subjects may have required more time and had more error at the higher vertical rates because the relative altitude in the datatag made larger changes. This seems logical when the 1500 ft./min. Rate is examined closely. The relative altitude in the datatag changed 100 feet every time the intruder/datatag updated ((1500 ft./min.) / (60 sec./min.) * (4 sec. update rate) =100 foot change). The ease with which the subjects could predict what the successive relative altitudes possibly explains why the 1500 ft./min. Rate was significant for ERROR and TIME. If the change had been 99 feet or 101 feet, the change would not have been as obvious and the outcome may have been different.

Exploratory research was performed on vertical Miss and approach Angle. Miss distance was found to be significant for both TIME and ERROR. Subjects clicked the mouse to select a Miss distance significantly faster when the correct Miss was +/-600 compared to +/- 300. This may be due to the subjects realizing the intruder would not pass close to ownship in which case they answered quickly. When the subjects thought the intruder would be close to ownship (i.e., +/-300 feet), they waited to be more accurate. The subjects made faster decisions (relative to +/-300 ft.) when the intruder would collide with ownship, although this was not significantly so. This implies that the subjects could determine that the intruder was on a collision course faster then when it would pass close. A look at the ERROR for vertical Miss shows that 0 Miss was associated with significantly less ERROR then all other Miss distances. Thus, on scenarios that would have resulted in a collision, the subjects made relatively quick, accurate decisions. There was significantly more ERROR associated with -600 feet that with all other Miss distances. This suggests that direction has an influence on accuracy.

The last main effect was Angle. The intruders that approached from 50° had significantly more ERROR than those that approached from 0°. This is consistent with previous research which found significant increases in error as intruder approach Angle increased. This is hard to explain because the intruder still flies straight at ownship.

There were two other first-order interactions which were significant. Since the interactions are harder to interpret than the main effects, tests of simple effects were performed to make sense of these results. Miss by Angle was the only significant interaction for TIME. Like the main effect, the 600 and -600 foot Miss distances were the fastest, but Angle had an interesting interaction in that +600 feet was significantly faster at 0° and -600 feet was significantly faster at 50°. There is no easy explanation for this.

The final significant interaction was Rate by Angle. This is a compilation of the main effects of Rate and Angle, namely high vertical Rates and the 50° approach Angle result in the most ERROR. The Angle seems have the most effect at 2500 ft./min. The 1500 ft./min. Rate may also have been affected by the fact that the change in relative altitude was easy to project. This would explain why 1500 ft./min. ERROR was less than the ERROR for 1000 ft./min.

Recommendations

The methods used by subjects in this study to determine future vertical separation of an intruding aircraft take too long and are not very accurate. While the subjects in this experiment could concentrate on the simulation, pilots in a real flight environment would not have time to focus their attention on the display and would probably do much worse, all other things being equal. This calls into question the methods used by pilots to project future separation in a real cockpit environment. Pilots in a real cockpit environment might use the display totally differently, such as making decisions about intruders when they are farther out (10 nm., 20 nm., etc.) so that fewer decisions have to be made about closely passing aircraft. The pilots would most likely make decisions based on looking at the display for shorter amounts of time then the subjects did in the experiment. This suggests that display objects such as the range Ring may have a positive effect in the field even though it was not needed in this experiment. It may be that multiple range Rings around ownship provide more horizontal information in a limited amount of time. Further studies should examine whether multiple range Rings provide a significant advantage in TIME and ERROR. It is further suggested that future CDTI experiments be conducted as a secondary task, which is similar to how it would be used in real life. A simple PC-based flight simulator could provide the primary task without much additional effort.

It was determined that intruder vertical Rate had a significant negative effect on subject estimates of future vertical separation. This is important because pilots need to be able to accurately determine vertical passing as soon as possible. It might prove interesting to include vertical rate information in the datatag, or in a coded symbol, to see if ERROR decreases.

More research must be conducted on how the vertical Miss distance between the intruder and ownship affects the selected distance. This is especially important because even though the subjects were more accurate at the 0 Miss condition, they took more time to arrive at a decision. It would also be interesting to look at the direction of the subjects' guesses for each passing distance. This was not accomplished during this experiment but might provide interesting results.

Cockpit displays of traffic information have the ability to provide an important function as a backup to pilots and controllers for traffic separation. There is also work being done on lowering separation standards for aircraft equipped with CDTI. Both of these roles rely on the correct interpretation of the display by the pilots. Additional research will allow the cockpit display of traffic information to reach its full potential.

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Appendix A

Script

Identification and randomization script

```
on openWindow
     global SSN, dist, ttime1, ttime2, relalt, VM, Vb3D, VR, pixel1,¬
    pixel2, h, v, locv, angle, cardnum, counter      -- global variables
  hide background graphic "line"                     -- initialize graphics
  hide background field "datatag"
  hide background field "Ownship"
  hide background graphic "intruder"
  hide background graphic "screenscale"
  hide background graphic "border"
  repeat                        -- obtain identification
    ask "Please type in the last four digits of your SSN."
    put it into SSN
    ask "Is " & SSN & " correct? (Type y/n)"
    if it is "y" then exit repeat
  end repeat
  set cursor to none
  go card 81                    -- these are the 4 practice scenarios
  go card 82
  go card 83
  go card 84
  Put 1 into counter            -- initialize variables for randomization
  Put 81 into start
  Put 1 into N
  Put 1 into value1             -- initialize dummy variable for 80 scenarios
  Put 2 into value2
  Put 3 into value3
          •
          •
          •
  Put 78 into value78
  Put 79 into value79
  Put 80 into value80

  repeat with counter = 1 to 79         -- loop for scenario selection
    if counter = 28 then go card 85 -- break after 28th and 56th scenario
    if counter = 56 then go card 85
    Put random(start - counter) into rand  -- scenario selected at random
    if rand = value1 then              -- checks if random number = scenario
      go card 1                        -- if so, run that scenario
      put start + counter into value1  -- change dummy variable if
    end if                -- scenario is used so it will not be selected again
```

```
if rand = value2 then
   go card 2
   put start + counter into value2
end if
if rand = value3 then
   go card 3
   put start + counter into value3
end if
      •
      •
      •
if rand = value78 then
   go card 78
   put start + counter into value78
end if
if rand = value79 then
   go card 79
   put start + counter into value79
end if
if rand = value80 then
   go card 80
   put start + counter into value80
end if

if value1 <= 80 then            -- reduce by 1, the dummy variable
   Put N into value1            -- associated with all scenarios greater
   put N + 1 into N             -- than the one selected. this results in
end if                          -- continuous numbering for scenarios
if value2 <= 80 then            -- that have not been selected yet.
   Put N into value2
   put N + 1 into N
end if
if value3 <= 80 then
   Put N into value3
   put N + 1 into N
end if
      •
      •
      •
if value78 <= 80 then
   Put N into value78
   put N + 1 into N
end if
```

```
    if value79 <= 80 then
      Put N into value79
      put N + 1 into N
    end if
    if value80 <= 80 then
      Put N into value80
      put N + 1 into N
    end if

    put 1 into N
  end repeat                          -- loop until 79 scenarios are shown

  if value1 = 1 then go card 1        -- check for last scenario and run
  if value2 = 1 then go card 2
  if value3 = 1 then go card 3
         •
         •
         •
  if value78 = 1 then go card 78
  if value79 = 1 then go card 79
  if value80 = 1 then go card 80
  go card 85                          -- go to "Thank You" message
end openWindow
```

Card script

```
on openCard
  global SSN, dist, ttime1, ttime2, relalt, VM, Vb3D, VR, pixel1,¬
    pixel2, h, v, locv, angle, cardnum   -- global variables
  show background graphic "ringless"     -- no ring in this scenario
  put 1 into cardnum                     -- first scenario
  put 50 into angle                      -- intruder approaches from 50º
  put 268 into Vb3D                      -- intruder groundspeed
  put 16.67 into VR                      -- intruder vert rate (ft/sec)
  put 424 into pixel1                    -- intruder hor start position
  put 140 into pixel2                    -- intruder vert start position
  put -2.4 into H                        -- hor distance every 4 sec
  put 2.0 into V                         -- vert distance every 4 sec
  put 0 into VM                          -- vert miss when a/c pass
  send "bakscript" to background         -- send command to start scenario
end openCard
```

Background script

```
on bakscript
     global SSN, dist, time, relalt, VM, Vb3D, VR, pixel1,¬
   pixel2, h, v, locv, pickedAlt, cardnum, angle       -- global variables
  put 276-pixel2 into y                    -- calculate distance to intruder
     put y^2 into y1
     put 259-pixel1 into x
     put x^2 into x1
     put (sqrt(y1+x1))/31.71 into D
     put D*4583.3333 into Ds
     put sqrt(H^2+V^2) into Vi
     put Vi*138.28 into Vis
 put (Ds/Vis*VR) into startalt             -- calculate intruder start alt using
 put (5000-startalt)+VM into alt           -- vert miss, vert rate, distance to
 show background field "ownship"           -- ownship & ownship alt (5000 ft)
 put the ticks into time1                  -- record start time
 repeat for 200 times                      -- loop to update intruder
   put alt-5000 into relalt                -- calculate intruder relative alt
   show background grc "Intruder" at pixel1,pixel2
   if pixel1 < 254 then                    -- position datatag on open side
     show background field "datatag" at pixel1+70, pixel2
     else show background field "datatag" at pixel1-70, pixel2
   set numberformat to "000"               -- fill intruder datatag
   put "UA597    " & Vb3D & "kts" & numtochar(13) & "      " into
   background field "datatag"
   set numberformat to "0000"
   put relalt & " ft" after last character of background field "datatag"
   if the mouseclick then                  -- check if subject clicked mouse
     beep                                  -- indicating ready to select vert
     exit repeat                           -- miss, if so, exit loop
   end if
   wait for 4 second                       -- wait to update intruder position
   if the mouseclick then                  -- check again for mouse click
     beep
     exit repeat
  end if
   put 283-pixel2 into y                   -- calculate intruder distance from
   put y^2 into y1                         -- ownship
   put 254-pixel1 into x
   put x^2 into x1
   put (sqrt(y1+x1))/31.71 into dist
   if dist <= 1 then exit repeat           -- exit loop if intruder w/in 1nm
```

```
    add 4*vr to alt                    -- update intruder position
    add 4*H to pixel1
    add 4*V to pixel2
     end repeat

  put the ticks into time2            -- record ending time
  put (time2 - time1) / 60 into time  -- calculate time spent on scenario
  show background graphic "screenscale"  -- show graphic w/ vert miss
                                         -- scale
  show background graphic "border"       -- show graphic of border
  send "startscale" to background graphic border  -- send command to
                                      --start script in graphic border
  put -(locV-220)*10 into pickedAlt   -- calculate alt corresponding to
  set numberformat to "0.#"           -- pointer position at mouse click
     put "      " into background field "datatag"
  open file "Caar 2 HD:Paul's Folder:Thesis:PilotData:" & SSN
    write SSN & "," & cardnum & "," & angle & "," & VM & "," & VR
    & "," & pickedAlt & "," & dist & "," & relalt & "," & time &
    numToChar(13) after file "Caar 2 HD:Paul's Folder:Thesis:
    PilotData:" & SSN
  close file "Caar 2 HD:Paul's Folder:Thesis:PilotData:" & SSN
  hide background field "datatag"     -- reset graphics for next scenario
  hide background field "Ownship"
  hide background graphic "intruder"
  hide background graphic "line"
  hide background graphic "border"
  hide background graphic "screenscale"
end bakscript
```

Border script

```
on startscale
  global SSN, dist, ttime1, ttime2, relalt, VM, Vb3D, vr, pixel1, pixel2,¬
    h, v, hm, locv, scaleAlt          -- global variables
  repeat forever                -- waiting for subject to select vert miss
    put the mouseV into locV    -- mouse location into dummy variable
    if locV > 370 then put 370 into locV -- limit "travel" of mouse to
    if locV < 70 then put 70 into locV   -- keep within scale boundary
    show background graphic "line" at 100, locV      -- pointer follows
                                                     -- mouse location
    if the mouseclick then                 -- exit loop if mouse clicks
      beep
```

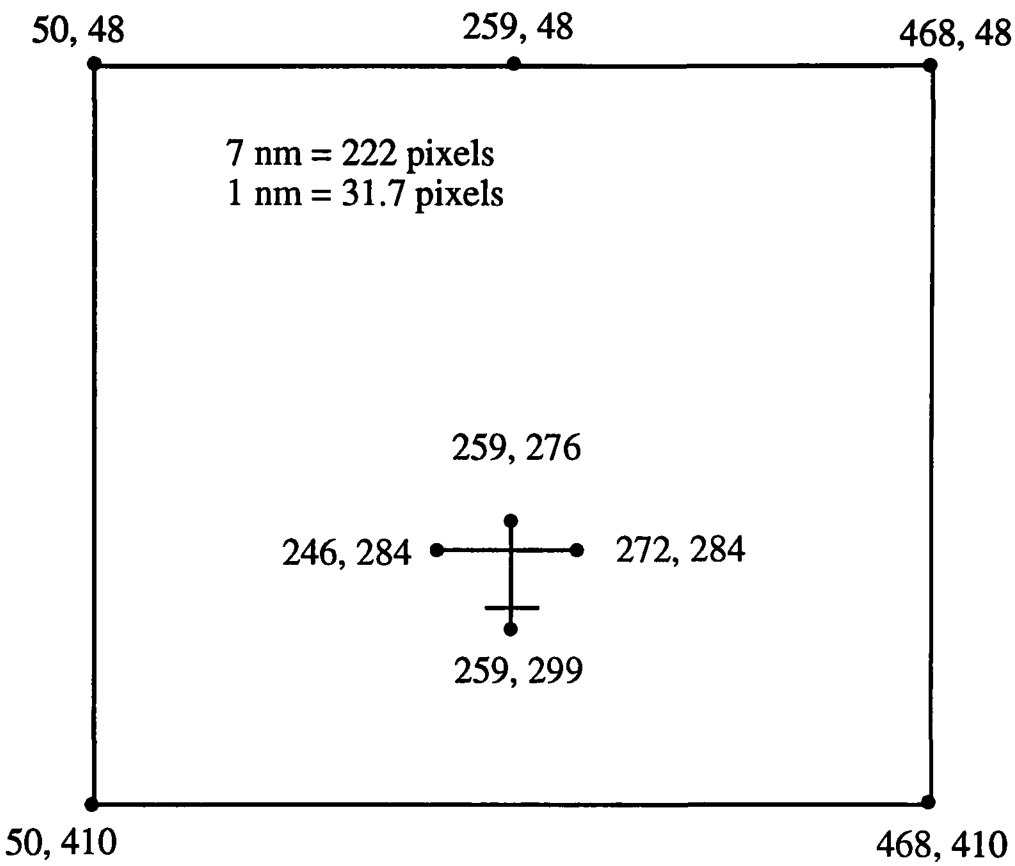
```
      exit repeat
    end if
  end repeat
end startscale
```

Break script

```
on openCard
  global SSN, dist, ttime1, ttime2, relalt, VM, Vb3D, VR, pixel1,¬
    pixel2, h, v, locv, angle, cardnum, counter      -- global variables
  set cursor to arrow                                 -- show pointer
  if counter = 79 then        -- show "Thank You" if experiment done
    show cd field "end"
    wait for 10 seconds
    hide cd field "end"
  else
    show cd field "break"     -- show break message until mouse click
    repeat forever
      if the mouseclick then exit repeat
    end repeat
  hide cd field "break"
  end if
  set cursor to none
end openCard
```

Appendix B

Display Information



7 Nautical Mile Screen

Screen and Ownship pixel locations on the SuperCard window.

Angle	X-Coord	Y-Coord
0 Degrees	254	61
50 Degrees	424	140
-50 Degrees	84	140

Pixel location for Intruder starting position.

Appendix C

Excel spreadsheet

	Angle	Vert. Miss	Vert. Rate	(V)b/a	(V)a j	(V)b j	(V)b 2D	(V)b 3D	VR (ft/s)	7 nm (Horz)	7 nm (Vert)
1	50.0	0	1000	350	240.0	15.1	268.4	268.6	16.7	-2.4	-2.0
2	0.0	0	-1000	350	240.0	-109.9	109.9	110.3	-16.7	0.0	-3.1
3	-50.0	300	1000	350	240.0	15.1	268.4	268.6	16.7	2.4	-2.0
4	0.0	300	-1000	350	240.0	-109.9	109.9	110.3	-16.7	0.0	-3.1
5	50.0	-300	1000	350	240.0	15.1	268.4	268.6	16.7	-2.4	-2.0
6	0.0	-300	-1000	350	240.0	-109.9	109.9	110.3	-16.7	0.0	-3.1
7	-50.0	600	-1000	350	240.0	15.1	268.4	268.6	-16.7	2.4	-2.0
8	0.0	600	1000	350	240.0	-109.9	109.9	110.3	16.7	0.0	-3.1
9	50.0	-600	-1000	350	240.0	15.1	268.4	268.6	-16.7	-2.4	-2.0
10	0.0	-600	1000	350	240.0	-109.9	109.9	110.3	16.7	0.0	-3.1
11	-50.0	0	-1500	350	240.0	15.2	268.3	268.7	-25.0	2.4	-2.0
12	0.0	0	1500	350	240.0	-109.7	109.7	110.7	25.0	0.0	-3.1
13	50.0	300	1500	350	240.0	15.2	268.3	268.7	25.0	-2.4	-2.0
14	0.0	300	-1500	350	240.0	-109.7	109.7	110.7	-25.0	0.0	-3.1
15	-50.0	-300	1500	350	240.0	15.2	268.3	268.7	25.0	2.4	-2.0
16	0.0	-300	-1500	350	240.0	-109.7	109.7	110.7	-25.0	0.0	-3.1
17	50.0	600	-1500	350	240.0	15.2	268.3	268.7	-25.0	-2.4	-2.0
18	0.0	600	1500	350	240.0	-109.7	109.7	110.7	25.0	0.0	-3.1
19	-50.0	-600	-1500	350	240.0	15.2	268.3	268.7	-25.0	2.4	-2.0
20	0.0	-600	1500	350	240.0	-109.7	109.7	110.7	25.0	0.0	-3.1
21	50.0	0	2000	350	240.0	15.4	268.1	268.9	33.3	-2.4	-2.0
22	0.0	0	-2000	350	240.0	-109.4	109.4	111.2	-33.3	0.0	-3.1
23	-50.0	300	2000	350	240.0	15.4	268.1	268.9	33.3	2.4	-2.0
24	0.0	300	-2000	350	240.0	-109.4	109.4	111.2	-33.3	0.0	-3.1
25	50.0	-300	2000	350	240.0	15.4	268.1	268.9	33.3	-2.4	-2.0
26	0.0	-300	-2000	350	240.0	-109.4	109.4	111.2	-33.3	0.0	-3.1
27	-50.0	600	-2000	350	240.0	15.4	268.1	268.9	-33.3	2.4	-2.0
28	0.0	600	2000	350	240.0	-109.4	109.4	111.2	33.3	0.0	-3.1
29	50.0	-600	-2000	350	240.0	15.4	268.1	268.9	-33.3	-2.4	-2.0
30	0.0	-600	2000	350	240.0	-109.4	109.4	111.2	33.3	0.0	-3.1
31	-50.0	0	-2500	350	240.0	15.6	267.9	269.0	-41.7	2.4	-2.0
32	0.0	0	2500	350	240.0	-109.1	109.1	111.9	41.7	0.0	-3.1
33	50.0	300	-2500	350	240.0	15.6	267.9	269.0	-41.7	-2.4	-2.0
34	0.0	300	2500	350	240.0	-109.1	109.1	111.9	41.7	0.0	-3.1
35	-50.0	-300	-2500	350	240.0	15.6	267.9	269.0	-41.7	2.4	-2.0
36	0.0	-300	2500	350	240.0	-109.1	109.1	111.9	41.7	0.0	-3.1
37	50.0	600	2500	350	240.0	15.6	267.9	269.0	41.7	-2.4	-2.0
38	0.0	600	-2500	350	240.0	-109.1	109.1	111.9	-41.7	0.0	-3.1
39	-50.0	-600	2500	350	240.0	15.6	267.9	269.0	41.7	2.4	-2.0
40	0.0	-600	-2500	350	240.0	-109.1	109.1	111.9	-41.7	0.0	-3.1

Note: The second 40 scenarios are identical to the above except the card script specifies that the ring is shown.

Appendix D

Informed Consent Form

INFORMED CONSENT FORM

I, ____________________________, agree to participate in a research experiment on the pilot's perception of aircraft separation utilizing a cockpit display of traffic information, which is being conducted by Paul Wassell. I understand that participation in this research project is entirely voluntary. I can withdraw my participation at any time and have the results of the participation returned to me, removed from the experimental records, or destroyed.

The following points have been explained to me:

1. The purpose of this research is to examine the ability of pilots to perceive aircraft separation as viewed on a cockpit display of traffic information. The benefits I may expect to obtain from my participation are experience with using cockpit traffic displays and experience with research in human factors.

2. I will participate in 84 trials (including 4 practice trials), each of which involves monitoring an intruding aircraft on a cockpit traffic display simulator for approximately one (1) minute. I will indicate I have determined how the intruder will pass my aircraft by clicking the mouse. Upon clicking the mouse I will be presented with a scale that indicates feet above and below ownship. I will then be required to move the mouse so that the indicator matches my perception of how the intruding aircraft would pass my aircraft. Clicking the mouse at this point records the passing altitude and begins the next scenario.

3. Participation will entail neither risk, discomfort, nor stress during the study.

4. The results of the study will be confidential and will not be released in any individually identifiable form without my prior consent unless required by law.

5. The researcher will answer any further questions about the study, upon request.

____________________________	____________________________
Signature of Researcher	Signature of Participant
____________________________	____________________________
Date	Date

PLEASE SIGN BOTH COPIES. KEEP ONE AND RETURN THE OTHER TO THE RESEARCHER.

Research at Embry-Riddle Aeronautical University that involves human participants is carried out under the oversight of the Center for Aviation/Aerospace Research. Questions or problems regarding these activities should be addressed to Dr. Richard Gibson, Director, CAAR, Embry-Riddle Aeronautical University, Daytona Beach, Florida 32114-3900 (904)226-6380.

Appendix E

Verbal Instructions

Cockpit Display of Traffic Information Study

You will be determining how an aircraft will pass by your own aircraft from monitoring the approaching aircraft's datatag. The datatag will include the approaching aircraft's identity, altitude relative to your aircraft, and relative ground speed. All the approaching aircraft will pass over, collide with, or pass below your aircraft. During each scenario the approaching aircraft will have a constant rate of descent or ascent and fly a straight course towards ownship. From the available data you must determine at what distance, above or below ownship, the approaching aircraft will pass.

Determining how the approaching aircraft will pass is only one part of how pilots will use this display. Pilots need time to make decisions about how to respond to approaching aircraft after they have judged how the aircraft will pass. Keep in mind that you are relying solely on the display to judge the approaching aircraft's passing distance. For this reason, take only the time you need to make your decision before clicking the mouse button. Do not click the mouse to display the scale and then determine the separation. The study is not examining nor is it interested in whether pilots follow FARs. If you let the approaching aircraft fly to within approximately 1 nautical mile of your aircraft, the decision screen will appear automatically.

Click the mouse button when you feel you know what the vertical separation will be when the intruder and ownship pass. This will activate a decision screen which has a scale for selecting passing distance above or below ownship. The range of the scale is 1500 feet above ownship to 1500 feet below ownship. The mouse is used to move the indicator on the scale. When the indicator shows what you feel to be the vertical separation at time of passing, click the mouse to record your decision and begin the next scenario.

On the display, your aircraft will be centered in the lower third of the screen. In certain scenarios your aircraft will be inside a three (3) mile range ring. Your aircraft and the approaching aircraft are not scaled the same as the screen. The aircraft have wings that are approximately .5 nautical miles in span. The screen and velocities of the aircraft are exactly scaled to present actual closure velocities of the real aircraft. Your ground speed and altitude will be displayed below your aircraft on the screen. The approaching aircraft's flight data will appear in a data tag beside the aircraft. The data tag will be updated every four (4) seconds giving you the new altitude of the approaching aircraft. Ground speed of the approaching aircraft will remain constant during each scenario, but will vary from scenario to scenario.

You will monitor 84 different scenarios that take approximately one (1) minute per scenario. The total experiment will last approximately one and a half hours. The first screen of Training, first screen of the Test, and the break screens must be initiated by clicking the mouse. All other screens will automatically start after you click the decision button from the previous scenario. Ignore the 12nm and 17nm buttons at the bottom of the screen as they do not affect this experiment.

Appendix F

Means Table for all Scenarios

Ring	Rate	Miss	Angle	Mean Time (sec.)	SD Time	Mean Error (ft.)	SD Error
no ring	1000	0	50	39.20	19.22	195.67	319.91
no ring	1000	0	0	35.93	20.21	187.00	312.50
no ring	1000	300	50	35.48	16.81	289.00	196.42
no ring	1000	300	0	36.27	18.85	279.00	163.78
no ring	1000	-300	50	42.78	20.77	271.67	224.67
no ring	1000	-300	0	34.97	18.66	373.00	376.18
no ring	1000	600	50	35.55	15.03	301.00	199.64
no ring	1000	600	0	29.42	15.12	342.00	402.84
no ring	1000	-600	50	31.20	15.41	391.33	308.01
no ring	1000	-600	0	37.08	16.63	365.33	271.12
no ring	1500	0	50	35.26	19.33	192.00	245.21
no ring	1500	0	0	31.17	18.52	165.00	214.97
no ring	1500	300	50	38.50	19.00	282.33	264.31
no ring	1500	300	0	38.12	20.82	285.33	239.16
no ring	1500	-300	50	39.07	18.03	279.33	322.76
no ring	1500	-300	0	34.95	20.76	271.67	285.72
no ring	1500	600	50	37.68	18.23	377.33	300.07
no ring	1500	600	0	29.82	16.38	302.00	270.81
no ring	1500	-600	50	31.57	13.68	384.33	277.63
no ring	1500	-600	0	36.98	15.90	309.67	252.66
no ring	2000	0	50	40.43	21.14	254.00	275.19
no ring	2000	0	0	43.22	20.32	249.00	288.11
no ring	2000	300	50	42.76	20.50	403.33	247.86
no ring	2000	300	0	45.19	20.47	308.00	253.37
no ring	2000	-300	50	35.97	14.33	457.33	431.70
no ring	2000	-300	0	43.26	22.86	277.00	226.69
no ring	2000	600	50	38.21	18.22	395.33	255.99
no ring	2000	600	0	38.31	17.26	400.67	250.54
no ring	2000	-600	50	37.57	16.28	464.00	278.35
no ring	2000	-600	0	42.89	19.54	412.00	264.11
no ring	2500	0	50	41.29	20.50	541.67	395.64
no ring	2500	0	0	41.16	17.90	320.00	325.32
no ring	2500	300	50	40.13	23.67	500.33	369.95
no ring	2500	300	0	44.12	18.58	328.00	272.11
no ring	2500	-300	50	42.15	22.00	528.00	392.84
no ring	2500	-300	0	43.21	20.78	341.33	292.82
no ring	2500	600	50	43.11	21.36	426.33	281.49
no ring	2500	600	0	39.54	17.42	283.00	168.71
no ring	2500	-600	50	35.56	18.47	523.00	366.34
no ring	2500	-600	0	42.05	17.88	509.33	305.08

Ring	Rate	Miss	Angle	Mean Time (sec.)	SD Time	Mean Error (ft.)	SD Error
ring	1000	0	50	37.03	16.81	240.00	365.99
ring	1000	0	0	33.41	16.52	152.67	255.31
ring	1000	300	50	33.28	16.69	287.33	278.55
ring	1000	300	0	43.51	18.08	317.67	252.80
ring	1000	-300	50	36.83	18.42	277.67	258.11
ring	1000	-300	0	33.57	17.22	343.00	300.33
ring	1000	600	50	45.80	42.23	379.00	299.00
ring	1000	600	0	27.77	14.91	343.67	280.74
ring	1000	-600	50	31.04	13.67	401.33	416.36
ring	1000	-600	0	37.82	20.31	434.33	315.55
ring	1500	0	50	39.90	22.29	133.00	181.64
ring	1500	0	0	39.57	19.54	98.33	160.60
ring	1500	300	50	34.97	20.25	365.33	352.73
ring	1500	300	0	39.85	21.05	279.00	148.24
ring	1500	-300	50	35.94	17.30	268.33	165.74
ring	1500	-300	0	39.59	15.29	273.33	300.98
ring	1500	600	50	37.11	17.45	357.33	422.15
ring	1500	600	0	33.25	16.19	288.00	235.29
ring	1500	-600	50	31.80	16.48	329.33	232.41
ring	1500	-600	0	38.03	19.55	391.67	306.03
ring	2000	0	50	43.02	21.41	209.33	230.64
ring	2000	0	0	39.80	19.35	317.33	403.47
ring	2000	300	50	42.30	19.56	329.67	160.18
ring	2000	300	0	41.44	20.53	299.00	247.36
ring	2000	-300	50	46.12	40.86	308.33	304.43
ring	2000	-300	0	41.57	21.62	347.67	253.92
ring	2000	600	50	36.65	16.17	337.67	271.05
ring	2000	600	0	39.25	19.43	386.00	259.86
ring	2000	-600	50	38.43	16.14	436.67	302.59
ring	2000	-600	0	43.40	24.83	406.67	338.44
ring	2500	0	50	38.93	19.18	428.00	340.43
ring	2500	0	0	38.97	21.76	250.00	304.46
ring	2500	300	50	43.10	19.48	343.00	297.84
ring	2500	300	0	44.13	23.14	396.33	207.09
ring	2500	-300	50	41.28	18.93	485.67	349.38
ring	2500	-300	0	42.54	23.51	340.33	270.70
ring	2500	600	50	38.09	15.20	444.00	262.11
ring	2500	600	0	40.54	19.09	368.67	226.86
ring	2500	-600	50	37.30	19.15	488.67	305.60
ring	2500	-600	0	43.07	19.96	422.33	344.08

Appendix G

Means Table for all Subjects

Subject No.	Mean Time (sec.)	SD Time	Mean Error (ft.)	SD Error
1	25.35	16.17	350.38	271.44
2	14.61	6.92	448.75	295.94
3	22.80	9.64	415.38	218.74
4	29.56	15.62	385.00	350.23
5	16.30	6.57	483.38	324.20
6	61.31	16.01	249.00	231.75
7	48.64	5.45	195.88	187.70
8	45.04	2.76	331.88	296.78
9	31.08	9.76	476.50	374.83
10	30.19	15.71	696.00	491.19
11	39.01	6.69	141.88	99.98
12	43.03	10.41	286.00	266.94
13	42.54	10.86	392.50	365.72
14	20.42	18.43	468.13	372.23
15	19.21	12.00	442.75	300.50
16	49.54	19.75	342.13	291.79
17	47.43	11.59	227.13	170.13
18	39.87	13.04	222.88	121.30
19	21.88	26.12	473.63	256.52
20	29.03	8.99	384.13	403.04
21	61.02	13.37	305.25	254.40
22	42.50	6.17	214.13	247.41
23	45.00	28.46	252.38	230.43
24	41.41	28.90	247.38	202.83
25	45.92	17.97	333.00	254.37
26	47.12	7.08	242.13	194.07
27	49.57	17.41	272.50	199.79
28	38.41	14.90	282.63	235.51
29	46.66	20.62	283.88	225.69
30	61.02	13.37	305.25	254.40

	Mean Time	SD Means	Mean Error	SD Means
All Subjects	38.51	13.21	338.39	115.66