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EFFECT OF MULTIPLE RANGE RINGS VS. A SINGLE RANGE RING ON PILOT PERCEPTION OF VERTICAL SEPARATION ON A COCKPIT DISPLAY OF TRAFFIC INFORMATION

by

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Applied Aviation Sciences in Partial Fulfillment
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EFFECT OF MULTIPLE RANGE RINGS VS. A SINGLE RANGE RING ON PILOT PERCEPTION OF VERTICAL SEPARATION ON A COCKPIT DISPLAY OF TRAFFIC INFORMATION

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Abstract

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<u>Institution</u>: Embry-Riddle Aeronautical University

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The purpose of this study was to determine the effectiveness of both a two and four mile range ring versus a single three mile range ring on pilot's perception of future vertical separation as viewed on a cockpit display of traffic information. The subjects consisted of 30 volunteer pilots from Embry-Riddle Aeronautical University and the surrounding Daytona Beach, Florida area.

The simulation of a cockpit display of traffic information was generated using SuperCard® Version 1.6 software and a Macintosh IIx® personal computer. Eighty unique scenarios were monitored by the pilots in which they determined, as early as possible, what the vertical miss distance would be when a single intruder passed the subject's aircraft (ownship). The pilots' perceived vertical miss distance (error) and decision time were compiled for each scenario. The use of multiple range rings required significantly more time for the pilots' to choose a vertical miss distance versus a single range ring. The use of multiple range rings had no significant effect on error versus the single range ring.

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Introduction

The National Aeronautics and Space Administration (NASA) began research in the 1970's on the Cockpit Display of Traffic Information (CDTI) which has since developed into the current traffic alert and collision avoidance system (TCAS) status display (Abbott, Moen, Person, Keyser, Yenni, & Garren, 1980). CDTI presents the pilot with a certain volume of airspace around their aircraft and displays both "non-threatening [and threatening intruding] aircraft that could affect piloting decisions" (Britt, Davis, Jackson, & McCellan, 1984). TCAS, TCAS II, and TCAS III display intruding aircraft based on computer predictions of intersecting flight paths, issue resolution advisories (RA) to the pilot, and, in the case of two aircraft equipped with TCAS III, communicate directly between their flight control systems.

According to Wickens, Carbonari, Merwin, Morphew, and O'Brien (1997) efforts to provide pilots with CDTI were terminated because of concerns regarding visual workload and air traffic control (ATC) authority. However, a concept called free flight, which is intended to reallocate some aspects of tactical conflict avoidance and strategic planning from ATC to the flight deck, has triggered renewed interest in CDTI (Planzer & Jenny, 1995).

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 intruding aircraft caused by the turning of the CDTI equipped aircraft (Palmer, Jago, Baty, & O'Conner, 1980). ATC displays present dynamic air traffic on a stationary map with a north-up orientation, whereas the CDTI depicts a dynamic traffic situation from a moving frame of reference (heading-up). This makes the aircraft interactions difficult to correctly perceive. CDTIs show the surrounding aircraft from a bird's-eye point of view (plan-view), which is similar to an ATC display. The plan-view format is two-dimensional, and therefore lacks a vertical component. This makes it difficult for the pilot to perceive the vertical separation of traffic when viewing a climbing or descending intruder. However, research by Wickens et al. (1997) "compared two-dimensional (coplanar) with three-dimensional (perspective) versions of a [CDTI}. The results revealed an advantage for the coplanar display, particularly when there was vertical intruder behavior." Despite poor presentation of vertical information, the plan-view format may be the most practical because of its ability to conform with other displays such as moving maps and weather radar. Wickens et al. (1997) found pilot performance to be better with the coplanar format versus the perspective format when weather data was either overlaid or displayed separately. The coplanar display provided the best pilot performance particularly when weather data was overlaid.

Literature that specifically includes vertical separation and vertical rates (Ellis, McGreevy, & Hitchcock, 1987; Hart & Loomis, 1980; Lester & Palmer, 1983; Palmer, 1983; Palmer & Ellis, 1983; Smith, Ellis, & Lee, 1982) concentrates on the effect of altitude coding and pilot maneuver responses. Wassell (1993) studied the effect of a singular range ring verse no range ring on a pilot's ability to correctly perceive vertical separation. "A range ring is defined as a circle which represents a fixed distance placed around the pilot's own aircraft on the CDTI display" (Wassell, 1993).

The plan-view format appears to be the most practical display format in use and will most likely remain dominant for some years. The ability to judge aircraft separation in the vertical plane is equally important as judging separation in the horizontal plane, but not as visually obvious. Because intruder vertical separation is more difficult to determine, this factor must be fully understood to realize the full potential of the CDTI. By understanding the methods pilots use to determine vertical separation and the effects of different range ring placements on a CDTI, a better understanding of how pilots form a three-dimensional view of the surrounding airspace using the vertical information on a two-dimensional display will be developed. If a CDTI is to compliment the automated ATC system and assist the implementation of the free flight concept, a clear understanding of how pilots perceive two-dimensional vertical information is needed. 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 both a two and four mile range ring versus a single three mile range ring on a pilot's perception of future vertical separation while viewing a cockpit display of traffic information. 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.

Providing pilots with the ability to monitor the surrounding traffic environment is an idea which began as early as the 1940's. Research was conducted at the RCA Princeton Electronic Laboratories which placed a televised image of the ATC ground controller's radar display in an aircraft cockpit. 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. The researchers used top view or "plan-view" display format while investigating such factors 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). Throughout the late 1970's and 1980's NASA research centers focused on the development of traffic display formats and how they were perceived by pilots. These studies used displays with a heading or track-up orientation which would constantly change to coincide with the heading of ownship. Three areas of significant research which investigated pilots use of CDTI displays for traffic separation are: (1) pilots' ability to maintain separation, (2) pilots' maneuver responses, and (3) pilots' perception of separation.

Separation maintenance studies employed approaches and departures to a terminal area to study pilots' ability to use the display to maintain spacing during terminal sequences. 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 NASA studies involved dynamic cockpit displays and were done as a series of experiments that built upon the results of previous experiments.

Throughout the 1990's, a gradual evolution of the CDTI has occurred through the continuing advancement of aircraft computer technology. This evolution brought about TCAS which, in conjunction with concerns of pilot visual workload and ATC authority, temporarily terminated efforts to provide pilots with a larger displayed region around ownship. However, interest has been revived thanks to free flight, a concept which is intended to reallocate some aspects of conflict avoidance and strategic planning from ATC to the cockpit (Wickens et al., 1997).

Pilot Avoidance Maneuvers.

A pilot's direct response to a displayed conflict is dependent on many factors including training, fatigue, display effectiveness, etc. Several studies have been conducted to determine not only pilots conflict awareness, but what action 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 deviated beyond 500 ft. vertical and 1.5 NM horizontal of the original flight course. The pilots' maneuvers avoided 80% of all the positive collision advisories, but often exceeded 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 in the encounters 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. The pattern of the pilots' actual maneuver selections did "exhibit substantial regularities across all subjects" (Smith et al., 1982). It was further inferred by Smith et al. (1982) 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 inherent 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.

Pilots displayed a tendency to 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 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.

Separation Maintenance.

Cockpit traffic displays have become increasingly refined with the advances in computer graphics, digital communications, and satellite-based navigation systems. Specifically, the TCAS status display has become integrated with the high resolution Horizontal Situation Indicator in some aircraft and is now being evaluated as a status display for conflict avoidance (Wickens et al., 1997).

A traffic display study was performed using curved descending approaches based on the microwave landing system (MLS), to investigate 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).

The time between each successive aircraft as they crossed the inner marker was termed the "intercrossing time" (Kreifeldt & Wempe, 1973). There were no significant differences in average intercrossing times for the two conditions. The distributed dispersion time was half that of centralized. Verbal workload was shown to decrease for the controller and remain constant for the distributed condition. Interestingly, controllers expressed a preference for the distributed condition whereas a preference for the centralized condition 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.

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 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.

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.

Anderson, Curry, Weiss, Simpson, Connelly, and Imrich (1971) performed an experiment in which the objective was to pilot a 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.

CDTI Design Elements.

Display size. Advances in computer technology has made the integration of the CDTI and other cathode-ray tube displayed information (i.e., weather radar, horizontal situation indicator, moving map displays, etc.) possible in current transport aircraft. Although these displays and their location may (or may not) be optimized for their primary task, with little thought given to the uniqueness of the mission of a CDTI, many previous studies have addressed display effectiveness in relation to the CDTI.

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.

Anderson et al. (1971) attempted to determine the effect of display size 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 5 in. x 7 in. display. This may have been more the result of the geometry of the intruding aircraft's path rather than display size. All intruders approached 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 used most frequently.

Display Type. Early displays of airborne traffic information were limited to a two-dimensional (planview) representation. However, the increasing role of computers in the designing of cockpit displays has brought about the development of a three-dimensional (perspective) traffic display. Research regarding a perspective display is ongoing and has, thus far, yielded inconclusive results.

Ellis, McGreevy, and Hitchcock (1987) examined the perspective display of 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 1). 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.

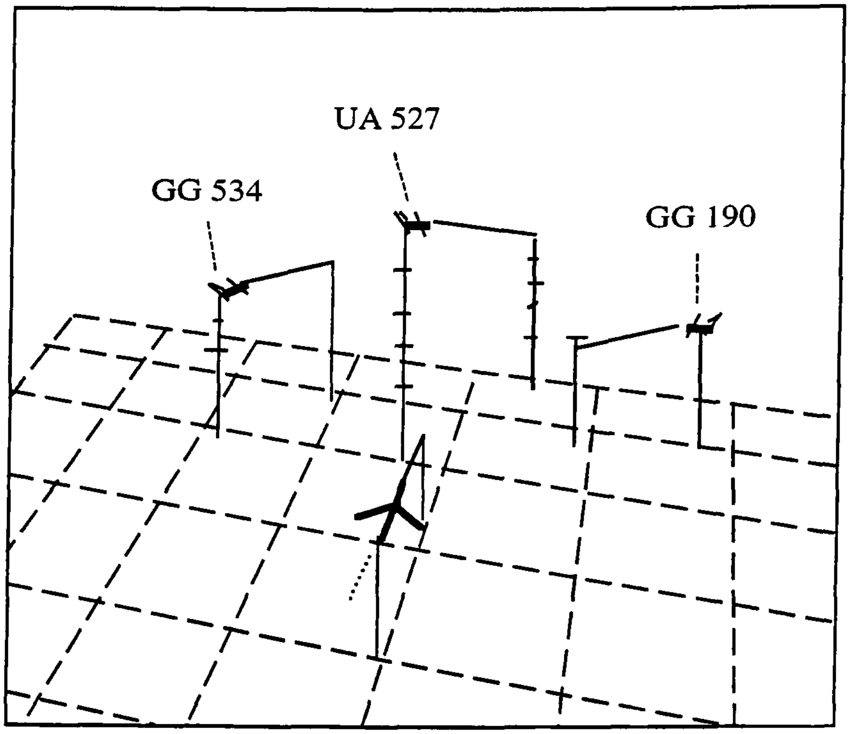


Figure 1. Perspective traffic display (adapted from Ellis, McGreevy, and Hitchcock, 1987).

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

Wickens et al. (1997) compared two-dimensional (coplanar) with three-dimensional (perspective) displays. A coplanar display combines a plan view (above) with a profile view (below) (Figure 2). The profile view was presented from a viewpoint behind ownship and presented the vertical component of the traffic environment. Pilots were instructed to fly to a waypoint, on the far side of the presented traffic, as directly as possible without creating any actual or predicted conflicts.

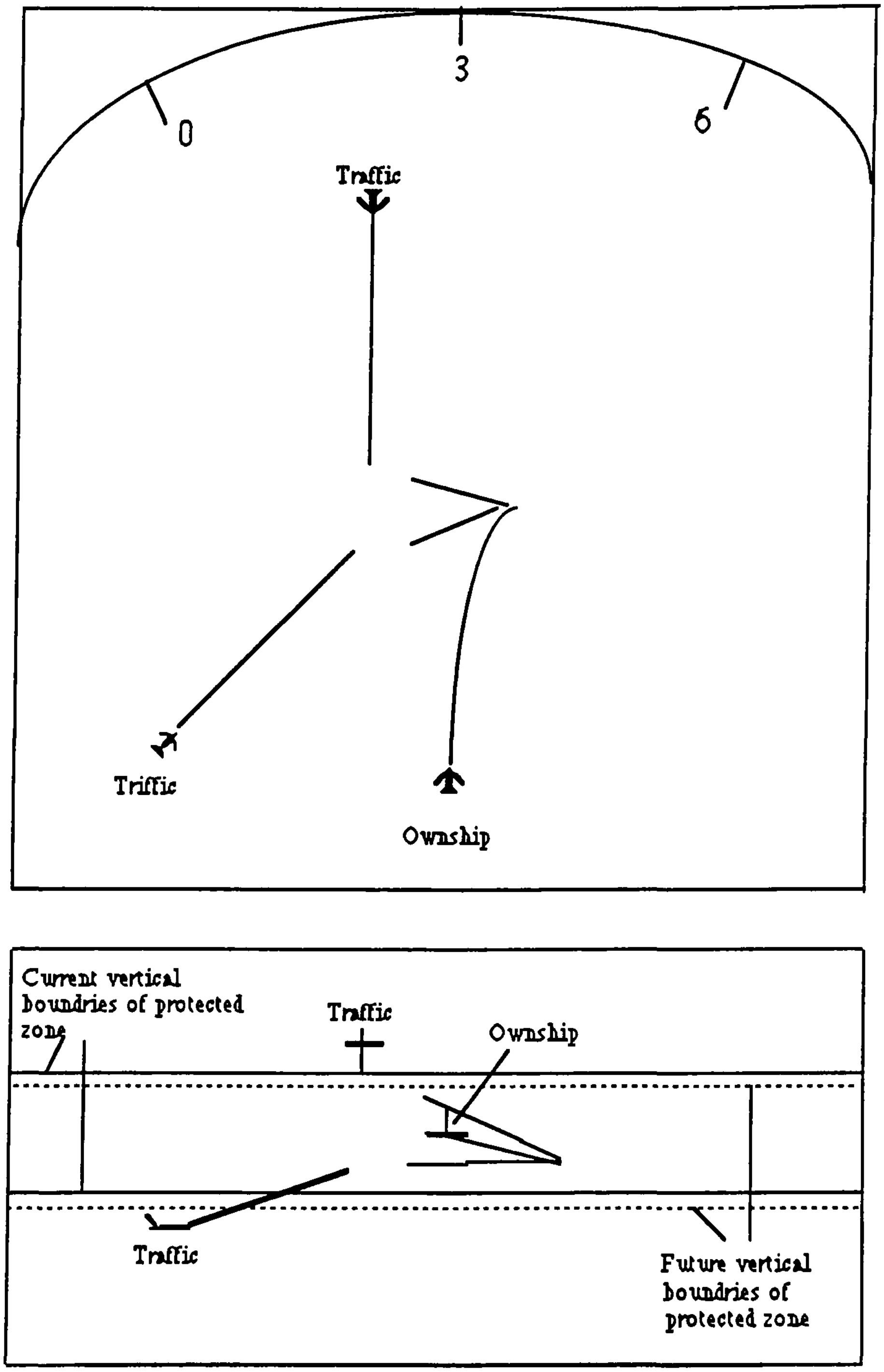


Figure 2. Coplanar traffic display
(adapted from Wickens et al.,(1997).

Wickens et al. (1997) found "that the coplanar display supported safer conflict resolution" versus the perspective display. Specifically, the perspective display showed a greater conflict rate when the primary traffic was descending or ascending which presented a more difficult perceptual problem. Pilots generally chose vertical maneuvers over lateral maneuvers regardless of display type. However, the coplanar display enhanced the tendency to chose vertical over lateral maneuvers (Wickens et al., 1997). Wickens et al. (1997) also found that pilots tended to move vertically in the opposite direction of the intruders vertical motion when using the coplanar display. Whereas pilots tended to maneuver in the same vertical direction as the intruder when using the perspective display. These findings show an effect opposite of those obtained by Ellis et al. (1987). Wickens et al. (1997) noted that the two-dimensional display of Ellis et al. (1987) "presented only symbolic and digital representation of the vertical axis", whereas the vertical was presented in a linear analog format on the coplanar display. Wickens et al. (1997) suggested the two-dimensional (uniplanar) display used by Ellis et al. (1987) may explain why less vertical maneuvering was encouraged within that study, whereas the two-dimensional (coplanar) display encouraged more vertical maneuvering within the Wickens et al. (1997) study.

Symbology. The method used to convey information on any visual display is the limiting factor to correct interpretation of that information. For CDTI to be an effective collision avoidance tool, a lucid depiction of intruder location relative to ownship is paramount. Several studies have investigated display background, aircraft symbols, altitude codes, datatags, history lines, and predictor lines.

Display backgrounds provide a frame of reference that enable a pilot to differentiate intruder movement relative to the ground from intruder movement relative to ownship. These background objects include: navigational fixes, airways, airports, and terrain. O'Conner, Jago, Baty, and Palmer (1980) examined the effects of a moving background image which was thought to assist the pilots in judging the ground speed of ownship. However, 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.

Jago, Baty, O'Conner, and Palmer (1981) examined the effects of a rectilinear grid background and no background at all. Although the subjects indicated a preference toward a background grid over no background, the results showed no significance between the two conditions and the ability of the subjects to accurately judge separation (Jago et al., 1981).

Research into the effectiveness of one or more range rings around ownship is very limited. 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. Neither of these studies examined the effectiveness of the range rings used, nor was there any consistency regarding its use. Chappell (1988) established a consensus on the use of range rings. This consensus stated that the range ring size should be standardized and suggested that a three nautical mile range ring should be used as standard. Rooney (1992) used a three mile range ring but did not directly analyze its effectiveness. However, upon debriefing the pilots at the end of the experiment, Rooney (1992) concluded that all the methods pilots used to arrive at their decisions can be reduced to the use of some fixed distance(s) from ownship. Rooney (1992) further states, "The most readily used distance was the three mile range ring."

Wassell (1993) examined the effect of a single three mile range ring and no range ring on pilot selection time and selection error. Wassell (1993) found that "the subjects did not select a miss distance significantly faster or slower when the ring was not displayed." The results were similar in relation to subject miss distance error. However, Wassell (1997) reported a significant reduction in subject miss distance when the intruder approached from an angle of 50° with the ring displayed. 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.

Hart and Loomis (1980) evaluated different types of background symbology. A significant number of pilots responded that high terrain features, natural or man-made, should be graphically represented at pilot request or automatically if ownship were below minimum safe altitude. However, pilots also acknowledged that this information would not affect the primary task of traffic separation.

A subjective experiment on ownship and intruder symbols was performed by Hart and Loomis (1980). This study involved a group of general aviation and airline pilots who were shown pictures of a CDTI utilizing various combinations of symbols. The pilots were then asked to respond 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. Abbott, Moen, Person, Keyser, Yenni, and Garren (1980) compared 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. Intruder relative altitude, CDTI equipage, and ATC status were coded into the intruder's symbol (Figure 3). All of the experimental data was acquired through subjective questionnaires following the approaches.

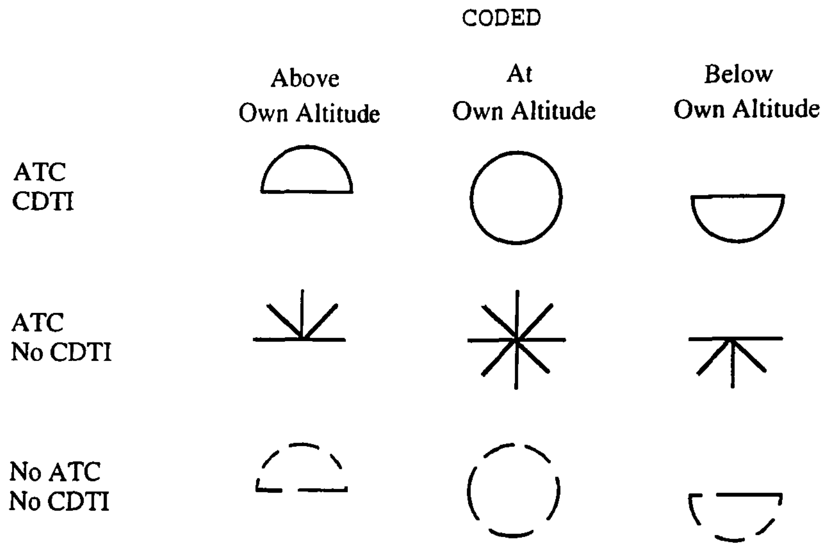


Figure 3. Traffic Symbology (adapted from Abbott, Moen, Person, Keyser, Yenni, & Garren, 1980)

The subjective assessment of 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 above or below 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 seem to 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 too much time with his/her head in the cockpit waiting for the coded symbol to change. The objective is to find a format that helps pilots make accurate and timely predictions of the future vertical separation of an intruding aircraft.

Research on datatag information and location was conducted to discover the most useful presentation for the cockpit environment. Lester and Palmer (1983) examined pilots use of vertical situation information presented in a datatag format. Pilots were presented with a traffic display in an aircraft simulator. The display employed three intruder datatag formats; normal, absolute, and relative. 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, though no significant differences were found between the two.

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 less accurate they were.

Anderson et al. (1971) examined datatag location relative to aircraft targets. 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.

The ability of pilots to properly assess the future horizontal position of the intruder relative to ownship through predictive and historical data has been researched. 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.

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. Pilot performance was significantly improved and response time reduced by the addition of either a curved or straight flight path predictors for curved and straight encounters 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 et al. (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.

Palmer (1983) also found the use of horizontal plane predictors coupled with the predictive relative altitude in the datatag, enabled pilots to avoid 90% of the positive advisory warnings as compared to 80% without the predictors displayed.

Conclusion.

The reviewed CDTI studies concentrated on how pilots perceived and responded to the information displayed. The areas of examination were: pilot conflict avoidance maneuvers, pilot self-spacing ability, and various CDTI design elements.

The studies have shown that experimental results of pilot performance rely heavily on display design presentation. Much of the current symbology was selected subjectively. Research has proven the advantage of a perspective display over a plan-view display to be inconclusive. However, the ease of adapting a plan-view display on to existing cockpit displays will most likely make the plan-view format the display of choice. The use of a coplanar display may prove advantageous considering its ability to display the vertical axis in a linear translation.

The use of coded information, such as relative altitude, lacked the accuracy required to resolve traffic conflicts. Other coded information such as whether an intruder is under ATC control was found unneeded. The use of predictor lines had a significant effect on the reduction of error rates. However, there has been little data to support the use of other background symbology.

Of the many studies incorporating the use of a range ring only one examined its effectiveness in reducing pilot error rates. While this study, conducted by Wassell (1993), showed no direct significance in reducing pilot error rates, there was a significant error reduction with the ring displayed and the intruder approaching from an angle of 50°. Further investigation on the effects of range ring placement and number of rings displayed is needed to create an effective and efficient presentation of the vertical plane on a plan-view display.

Statement of the Hypotheses

The use of CDTI technology requires a better understanding of how well pilots perceive and project intruder vertical information. It was felt that the use of both a two and four mile range ring would assist in the interpretation of intruder vertical separation information. Therefore, it was hypothesized that the use of both a two mile and four mile range ring, as compared to a single three mile range ring, on a seven nautical mile display, would reduce pilot selection time and selection error in predicting future aircraft vertical separation.

Method

Subjects

The subjects participating in this study were 30 volunteers from Embry-Riddle Aeronautical University (ERAU) and the surrounding Daytona Beach, Florida area. 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 56 with a mean of 26 (*SD* = 11). Total flight time for the subjects ranged from 45 to 10,000 hours with an average of 568 hours (*SD* = 683). Pilot certificates held by the subjects included 13 private, 16 commercial (5 certified flight instructors), and 1 airline transport pilot.

Instrument

A Macintosh IIx® personal computer and SuperCard® Version 1.6 software was used for this study. The actual design of the CDTI display was accomplished using Canvas® Version 2.0 graphics software and SuperCard software. The display elements created using Canvas graphics were transferred to SuperCard. A dynamic CDTI was constructed and simulated using SuperCard software. Experimental data (time, error, & scenario number) was sent to individual Excel® Version 5.0 text files and then compiled into one Excel spreadsheet for manipulation. The data was imported into a statistical software package (Statistica® Version 4.1) for analysis.

Subjects entered identity information (the last four digits of their social security number) through a keyboard and all other inputs through a mouse. Development of the simulation program was aided by graphics designed by Chng (1991), Rooney (1992), and Wassell (1993). The script (programming language, Appendix A) controlling the simulation was modified from that used by Wassell (1993).

Display Development.

A seven nautical mile display was used to more closely parallel the previous work of Chng (1991), Rooney (1992), and Wassell (1993) to avoid negatively influencing the ability of generalizing the results. However, there is some consensus that the display range should be 5, 10, and 20 miles (Chappell, 1988). The display size used in the experiment was 5 3/8 inches by 6 inches, the same size as used by Wassell (1993), and similar to the size used in earlier research (Abbott et al., 1980).

Pixel data is used by the software to determine intruder position. Therefore, pixel location was critical for proper scaling of the display. The pixel identifiers for each display range are shown in Appendix B.

The use of a three nautical mile range ring is consistent with previous research (Palmer, 1983; Chng, 1991; Rooney, 1992; Wassell, 1993) and, as stated by Chappell (1988), should be the standardized size. The three mile ring was used in this study for the singular ring display. The multiple ring display incorporated both a two and four mile ring. The two and four mile rings were used because it was felt that these distances best divided the seven nautical mile display.

The primary displays for the experiment were modified versions of Wassell's (1993) display and are presented in figures 4 and 5. The objects designed for the displays included the ownship symbol, range ring(s), intruder symbol, data tags, and the general instrument layout. A data tag was positioned next to the intruder symbol and moved in unison with the intruder symbol. The data tag contained the intruder's altitude relative to ownship. A positive value indicated the intruder was above ownship. The negative value indicated the intruder was below ownship. All graphics were either designed in Canvas and imported into SuperCard, or were designed using SuperCard software.

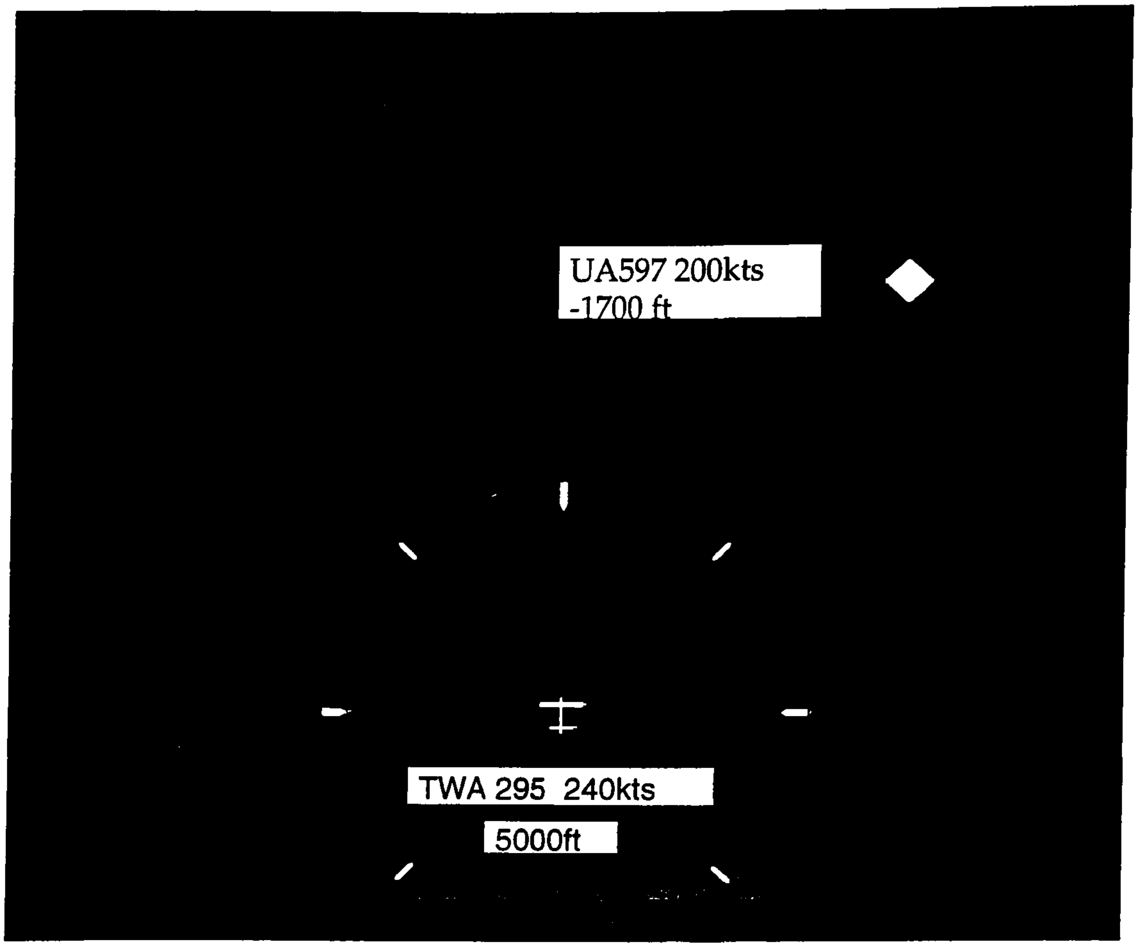


Figure 4. Single 3 NM range ring on the 7 NM primary display.

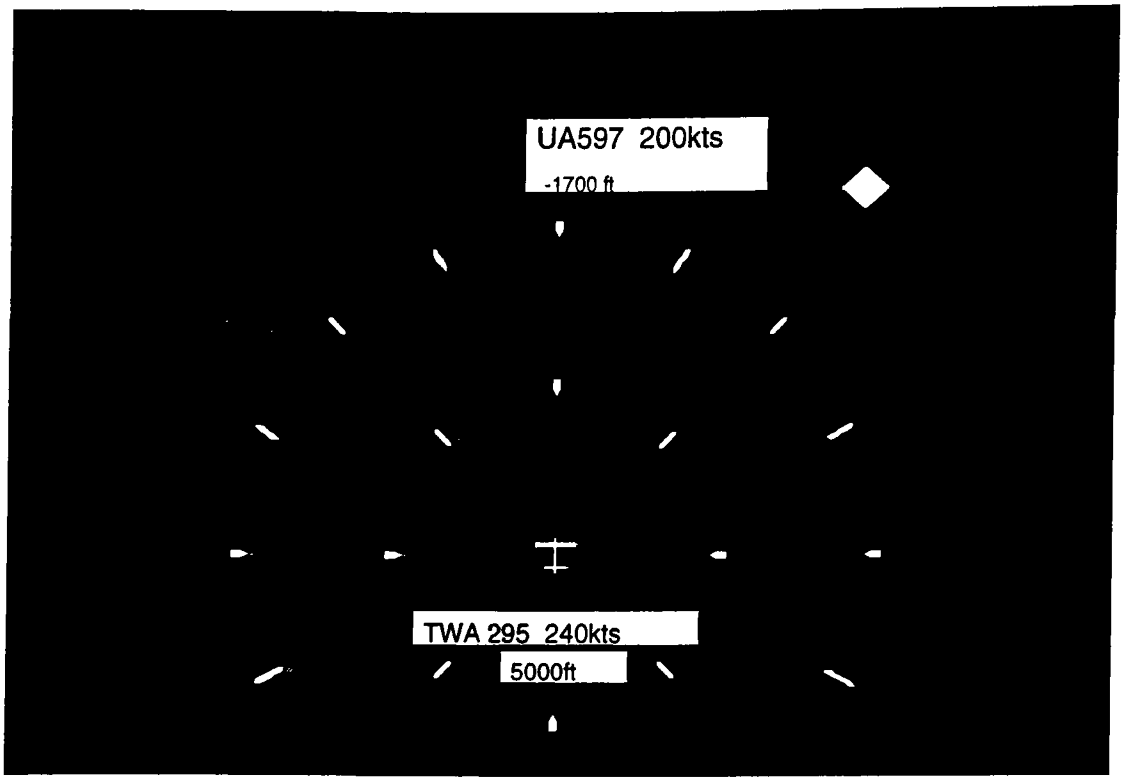
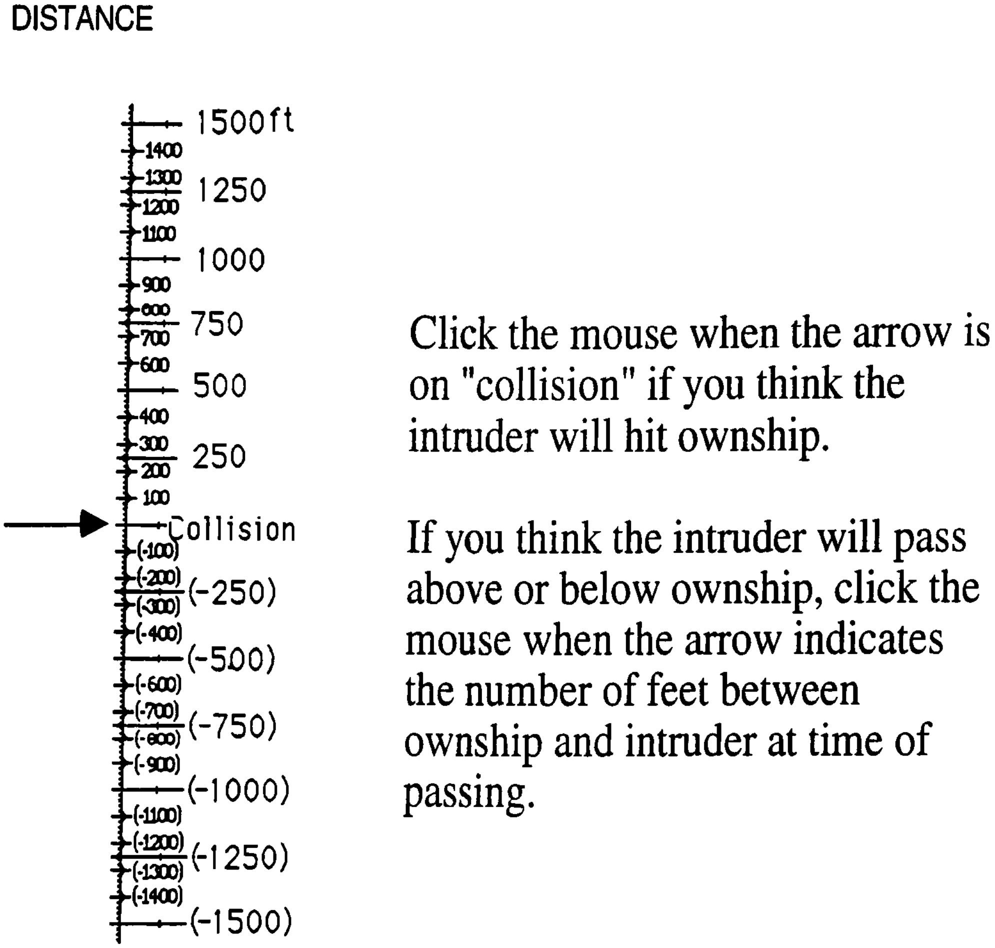


Figure 5. 2 NM and 4 NM range rings on the 7 NM primary display.

The secondary display in this experiment was a modified version of Wassell's (1993) secondary display and was presented when the mouse button was clicked. Clicking the mouse also halted the scenario indicating the subjects readiness to select a vertical miss distance. The mouse was used to move a pointer on a variable scale ranging from 1500 feet below ownship to 1500 feet above ownship. The increments were clearly marked to differentiate the below-ownship and above-ownship choices (Figure 6).



Click the mouse when the arrow is on "collision" if you think the intruder will hit ownship.

If you think the intruder will pass above or below ownship, click the mouse when the arrow indicates the number of feet between ownship and intruder at time of passing.

Figure 6. The secondary display with the vertical miss distance selection scale.

Simulation Software Development.

The SuperCard based application was originally designed by Rooney (1992), then highly modified by Wassell (1993), and further modified to fit the requirements of this study (see Appendix A). The application consisted of two parts, the script and the visual objects. The script was of a stacked design in which a card script was placed on top of, and sent information to, a background script which in turn was placed on top of, and sent information to, a window script.

Each scenario had its own card with a set of unique values for each of the dependent variables. These variables included vertical miss distance (feet), vertical rate (feet/second), approach angle (degrees), and number of range rings displayed (one or two). These values were sent to the background script as each scenario was run. There were no objects associated with the cards. The background script controlled the visual portion of the simulation. The background script used the card values to display the objects of the simulation in their respective initial positions and to update the object positions until the subject clicked the mouse button. Clicking the mouse indicated that the subject was ready to select a miss distance. The background script then displayed the vertical miss distance selection scale and pointer. The mouse operated pointer was moved by the subjects to indicate the desired vertical miss distance. When the mouse button was clicked by the subject to select the vertical miss distance, the background script sent the scenario number and experimental data to a text file, reset all the variables, and began the next scenario.

The window script randomized the 80 different scenarios so that each subject saw them in a different order. This randomization helped control carryover effects such as fatigue, learning, and boredom. The window script was also used to obtain the last four digits of the subject's social security number for identification at the beginning of each session. A pilot study was conducted to evaluate and improve the experimental simulation and training methods. Four licensed pilots having human factors research experience took part in the pilot study.

Mathematical Development of Intruder's Motion.

The mathematical relationships between the intruding aircraft and ownship were used to translate their motion in three-dimensional space to a two-dimensional display. The experiment was designed so that ownship always maintained a constant ground speed in straight and level flight. This configuration allowed ownship to move in one of three dimensions. The only motion which had to be described by the software was the intruder's motion relative to ownship. The following equations as expressed by Rooney (1992) and Wassell (1993) define this motion.

a = Ownship

b = Intruding Aircraft

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

where 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 V_b is the velocity 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 j-component of the intruder's relative velocity was the only component affected by the velocity of ownship. The intruder's other two relative velocity components, i and k, remained equal to the intruder's normal i and k velocity components. Figure 7 presents a description of the intruder's velocity in vector form.

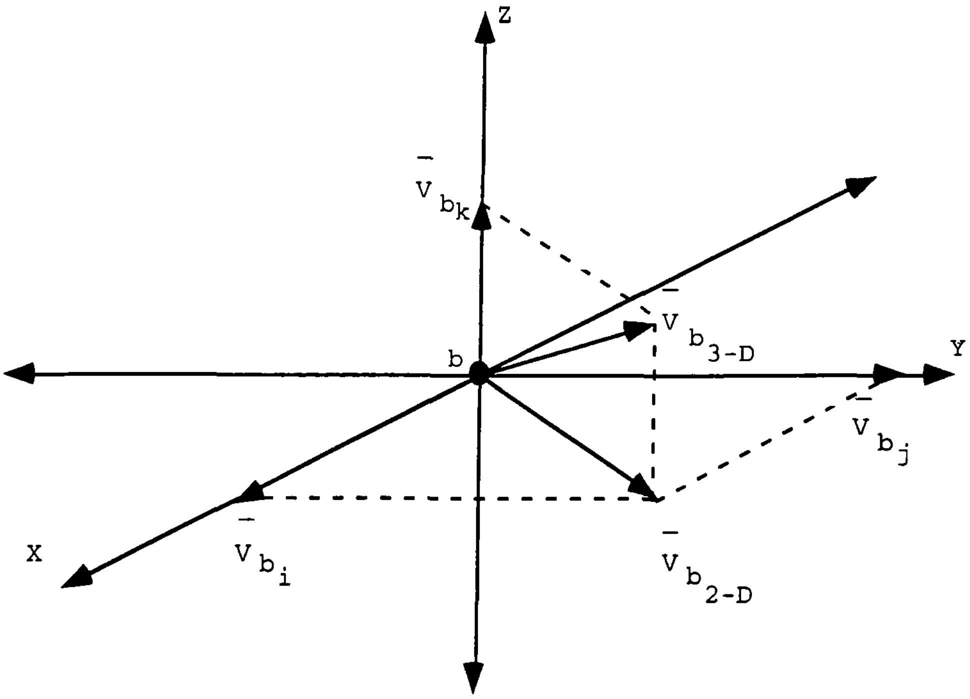


Figure 7. Description of intruder's ascending velocity in 3-D (adapted from Rooney, 1992)

To generate approaches from the left or right of ownship, the intruder's i-component of relative velocity was set at positive and negative values respectively. Figure 8 presents the two-dimensional depiction of intruder and ownship motion.

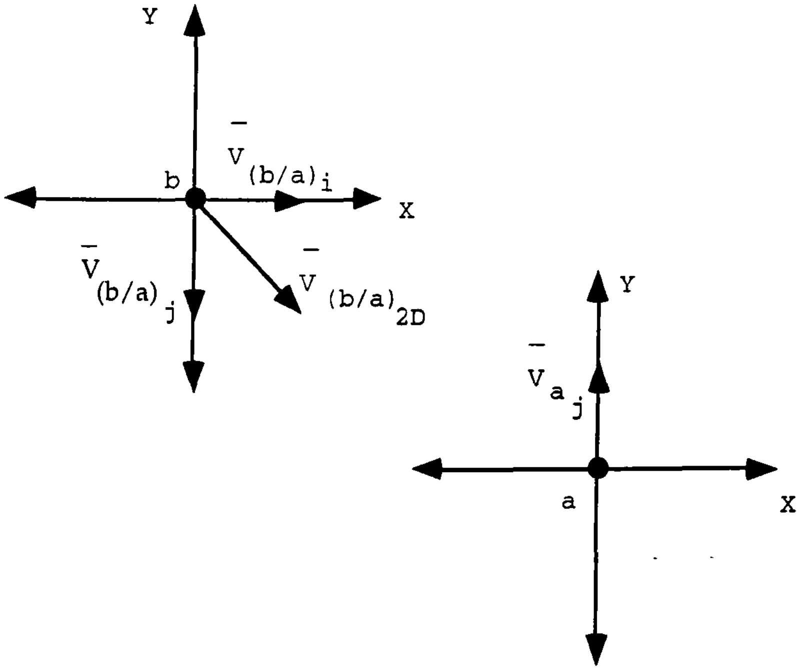


Figure 8. 2-D description of intruder's relative velocity with respect to ownship (left approach) (adapted from Rooney, 1992).

To describe each of the scenarios, a spread/sheet was generated by Rooney (1992) to determine all the necessary velocities. The following was the process used to determine the necessary velocities to describe each of the scenarios:

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

2) Use the 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 $5^{3/8}$ inch x 6 inch display. A three-dimensional closure rate of 350 knots and an ownship velocity were selected by Wassell (1993) as being representative of the speeds of aircraft flown in a terminal area, and are maintained in this study. The results of the above calculations are presented in Appendix C, and include all combinations of the independent variables.

Experimental Design

The experiment followed a 2 (approach angle) x 4 (vertical rate) x 5 (miss distance) x 2 (display) within-subjects repeated measure design. The independent variables in this experiment were the intruder's angle of approach, vertical rate, number of range rings displayed, and the vertical miss distance. Approach angles were either 0 or 50 degrees from the heading of ownship. Approaching from the left or right was considered symmetrical, so the 50° approaches were distributed evenly across the left and right portions of the screen. The intruder's vertical rate comprised the following four levels; 1000, 1500, 2000, and 2500 feet per minute. Although the vertical rates were varied between the scenarios, the rate remained constant throughout each scenario. The range ring variable consisted of two displays: (1) a single 3 NM range ring and (2) a multiple range ring display using both 2 NM and 4 NM range rings. The five levels of the vertical miss distance were -600, -300, 0, 300, and 600 feet relative to ownship. Climbing and descending flight paths appeared the same on the display and were considered symmetrical. Therefore, climbs and descents were evenly distributed across scenarios. The five levels of the vertical miss distance were evenly distributed throughout the scenarios, however they could not be considered symmetrical. The lack of symmetry resulted from some scenarios being crossovers and others not (Rooney, 1992;

Wassell, 1993). A crossover is 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). An equal number of crossover and non-crossover scenarios were used to control for this condition (Figure 9).

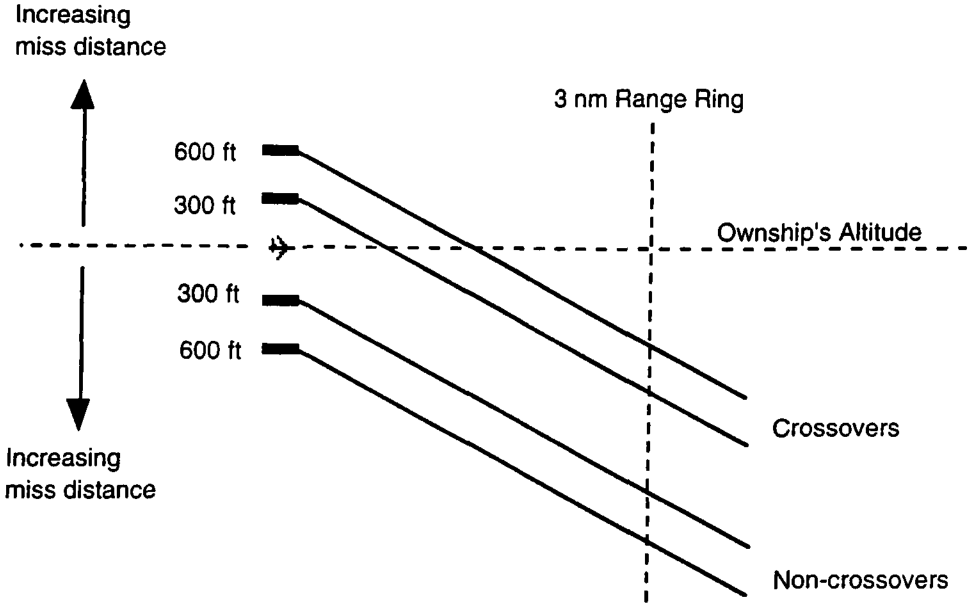


Figure 9. Crossovers and non-crossovers as viewed in the vertical plane (Wassell, 1993).

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

Procedure

Subjects were tested on the Macintosh IIx personal computer located in the Human Factors Laboratory at Embry Riddle Aeronautical University's (ERAU) Department of Human Factors and Systems. 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 in the same room as the subject during the training session to answer any questions the subject may have had. The researcher was not present in the same room during the experiment, but was available if the subject had any questions during the breaks.

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

To determine if subjects traded time for accuracy, the two dependent variables, TIME and ERROR, were analyzed using a pairwise Pearson correlation. This tradeoff would become apparent by the successful outcome of subjects waiting longer in order to make a more accurate determination of the vertical miss distance. The resulting correlation yielded a coefficient of r=-.336, n=30, p(.01) = .423. Therefore, the correlation is not significant (Figure 10).

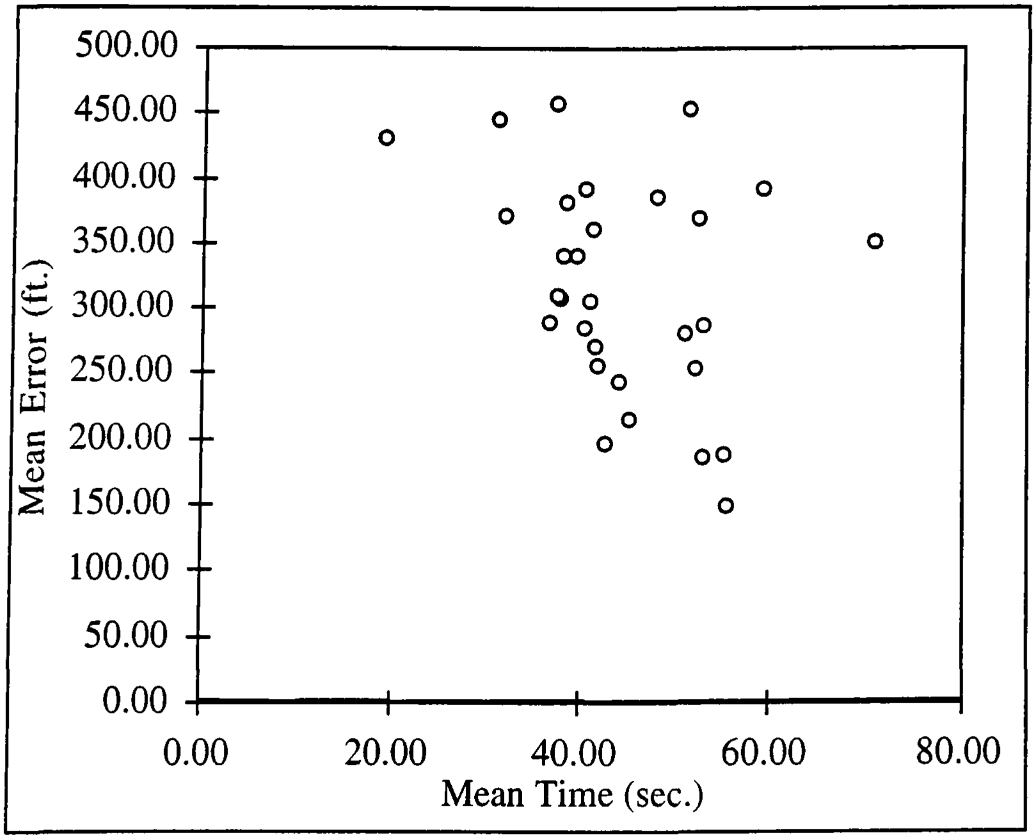


Figure 10. Scattergram showing dv ERROR versus dv TIME for 30 subjects.

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 2 (page 54) shows a summary of the results of the analysis of variance for the dv TIME.

A significant main effect was found for Ring F (1,29)=46.4, $p<0.000$. The subjects selected a miss distance significantly slower when two rings were displayed versus when only a single range ring was displayed. A Student Newman-Keuls (SNK) range test was performed on the two levels of ring using the following group means:

Number of Rings Displayed	*Group Means (TIME)*
1 Ring (3 NM)	40.67 (sec.)
2 Rings (2&4 NM)	48.34 (sec.)

Table 1

Student Newman-Keuls significance for ring on dv TIME

	1 Ring	2 Rings
1 Ring	■	<.01
2 Rings	<.01	■

TABLE 2 *Summary of ANOVA results for the dv TIME*

Source	*df*	*MS*	*F*	*p*
Error (Subjects)	29	2240		
Ring	1	35302	46.44	.000
Error (Subjects x Ring)	29	760		
Rate	3	1489	66.30	.000
Error (Subjects x Rate)	87	236		
Miss	4	189	1.10	.358
Error (Subjects x Miss)	116	172		
Angle	1	184	1.31	.263
Error (Subjects x Angle)	29	141		
Ring x Rate	3	362	2.02	.116
Error (Subjects x Ring x Rate)	87	179		
Ring x Miss	4	55	0.37	.829
Error (Subjects x Ring x Miss)	116	148		
Ring x Angle	1	17	0.11	.746
Error (Subjects x Ring x Angle)	29	162		
Rate x Miss	12	184	1.55	.103
Error (Subjects x Rate x Miss)	348	118		
Rate x Angle	3	68	0.56	.639
Error (Subjects x Rate x Angle)	87	121		
Miss x Angle	4	282	1.84	.125
Error (Subjects x Miss x Angle)	116	153		
Ring x Rate x Miss	12	91	0.68	.767
Error (Subjects x Ring x Rate x Miss)	348	134		
Ring x Rate x Angle	3	77	0.74	.528
Error (Subjects x Ring x Rate x Angle)	87	103		
Ring x Miss x Angle	4	53	0.37	.832
Error (Subjects x Ring x Miss x Angle)	116	144		
Rate x Miss x Angle	12	335	2.10	.016
Error (Subjects x Rate x Miss x Angle)	348	160		
Ring x Rate x Miss x Angle	12	90	0.76	.687
Error (Subjects x Ring x Rate x Miss x Angle)	348	117		
Total	2399			

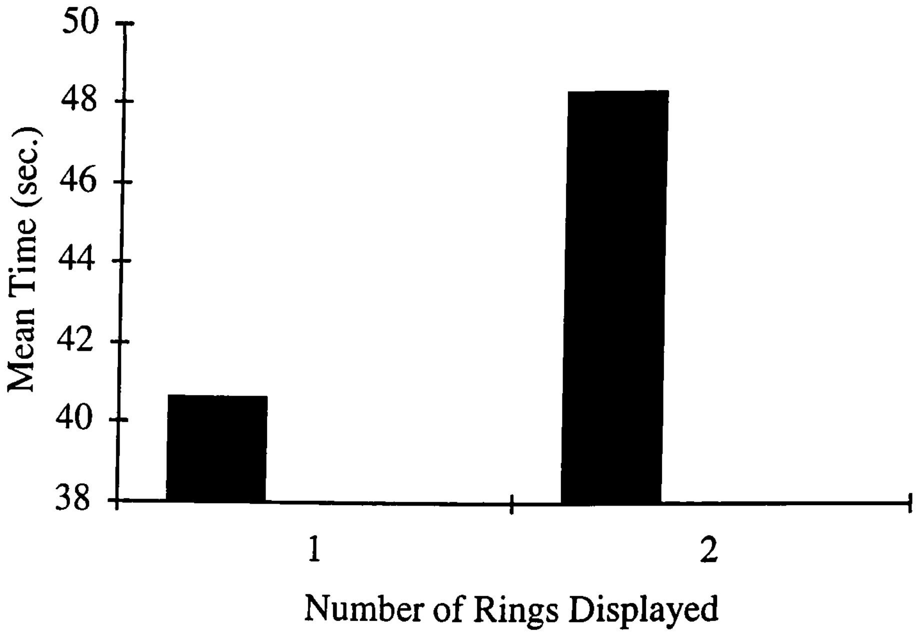


Figure 11. Mean Time taken to select vertical Miss by Ring.

The vertical rate of the intruder was also found to be significant for Time; F (3,87)=6.30, $p<0.000$. A SNK range test was performed using the following group means:

Rate	*Group Means (TIME)*
1000'/min.	43.53 (sec.)
1500'/min.	42.83 (sec.)
2000'/min.	46.17 (sec.)
2500'/min.	45.47 (sec.)

The result was a significantly faster response time for the 1000'/min. and 1500'/min. rates than for the 2000'/min. and 2500'/min. rates (Table 3). 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 12.

Table 3

Student Newman-Keuls significance for vertical rate on dv TIME

	1000'/min	1500'/min	2000'/min	2500'/min
1000'/min	■		0.011	0.032
1500'/min		■	0.002	0.011
2000'/min	0.011	0.002	■	
2500'/min	0.032	0.011		■

Empty cells indicate p levels greater than .05.

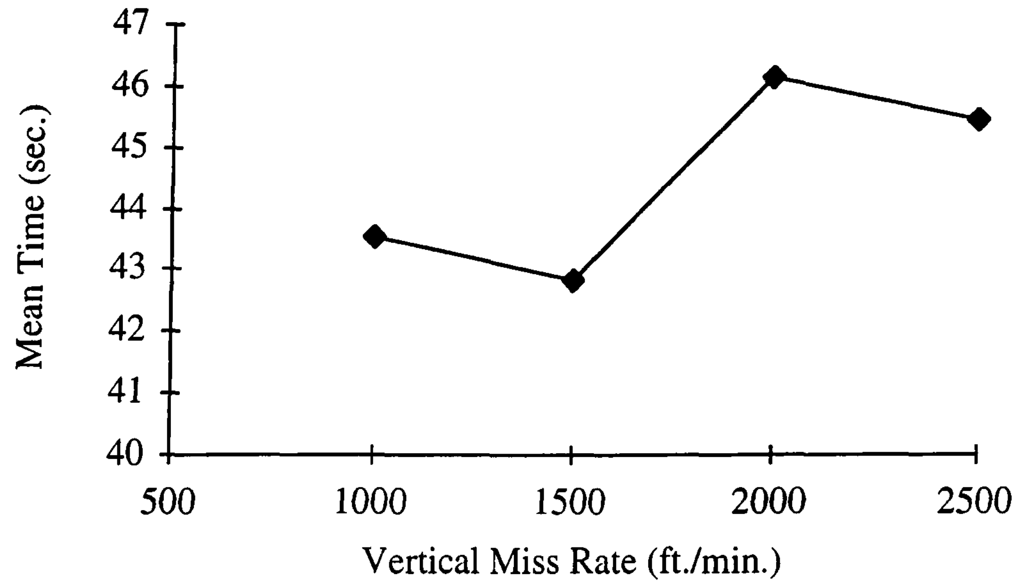


Figure 12. Mean Time taken to determine vertical Miss by vertical Rate.

No significant main effect was found for miss F (4,116)=1.104, p=.358. The subjects did not select a miss distance significantly faster or slower throughout the study. This insignificance remained regardless of the intruder's direction (above or below) or magnitude (feet from ownship) when passing ownship. The group means are listed below:

Miss Distance (ft.)	*Mean Time (sec.)*
-600	43.74
-300	45.22
0	44.90
+300	44.70
+600	43.97

There was also no significant main effect found for angle *F* (1,29)=1.31, *p*=0.262. The TIME used by the subjects to select a miss distance was not significantly different when the intruder approached at 0° (M=44.2 sec.) versus when the intruder approached at 50° (M=44.8 sec.).

The only significant interaction found for dv TIME was rate by miss by angle; *F* (12,348)=2.10, *p*=0.016. Of the forty combinations of interaction, only four interactions showed significance. A SNK range test was performed on all combinations of interaction however only the means of the significant interactions are shown below. A reference number is assigned to each interaction for clarity.

Reference #	*Rate*	*x*	*Miss*	*x*	*Angle*	*Mean (sec.)*
1	1000'/min.	x	-600 ft.	x	50°	40.23
2	1500'/min	x	-300 ft.	x	0°	40.17
3	1500'/min	x	-600 ft.	x	50°	39.95
4	2000'/min	x	300 ft.	x	50°	49.21

Table 4

Student Newman-Keuls significance for rate by miss by angle on TIME

	1000'/min. x -600 ft. x 50°	1500'/min. x -300 ft. x 0°	1500'/min. x -600 ft. x 50°	2000'/min. x 300 ft. x 50°
1000'/min. x -600 ft. x 50°				0.049
1500'/min. x -300 ft. x 0°				0.044
1500'/min. x -600 ft x 50°				0.032
2000'/min. x 300 ft. x 50°	0.049	0.044	0.032	

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

The results show that at Reference #4, as compared with all other interactions, the subjects required significantly more TIME to reach a decision (M=49.21 sec.), *p*=0.032. Given the equally distributed absolute miss distance among the four interactions (300 ft. and 600 ft.), and the lack of significance between means of the first three Reference numbers, the results show a significant increase in subject decision time at the 2000'/min. vs. the 1000 ft./min. and 1500 ft./min. rate. This result is similar to the main effect of rate (Figure 12). Figure 13 shows a plot of the means.

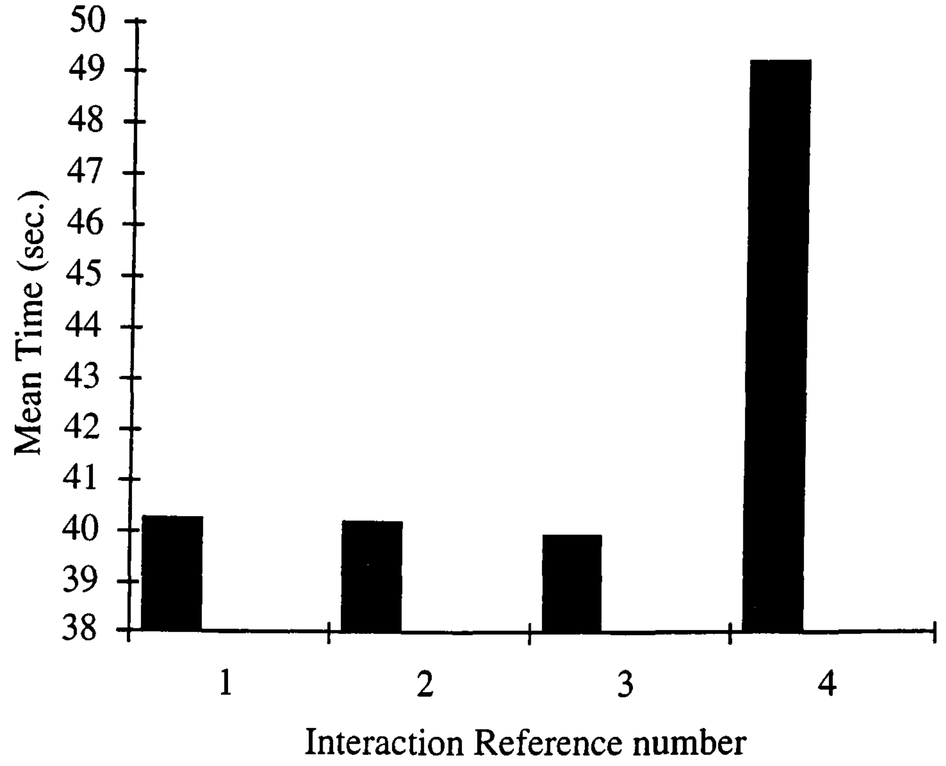


Figure 13. Interaction of Vertical Rate by Miss Distance by Angle versus TIME

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 the selected miss distance and the actual miss distance. A summary of the results of the analysis of variance for the dv ERROR are shown in Table 4.

There was no significant main effect found for ring *F* (1,29)=0.00, *p*=0.999. The subjects did not have significantly more ERROR when the single ring (3NM) was displayed (M = 255.8 ft.) versus when the two rings (2 & 4NM) were displayed (M = 272.6 ft.).

The vertical rate of the intruder was again found to be significant for ERROR; *F* (3,87)=22.28. *p*<0.000. A SNK range test was performed on the four levels of vertical rate using the following group means:

Rate	*Group Means (ERROR)*
1000'/min	229.3 (ft.)
1500'/min	280.2 (ft.)
2000'/min	337.4 (ft.)
2500'/min	416.4 (ft.)

Table 5 *Summary of ANOVA results for the dv ERROR*

Source	*df*	*MS*	*F*	*p*
Error (Subjects)	29	183890		
Ring	1	*	0.00	.999
Error (Subjects x Ring)	29	125391		
Rate	3	38666865	22.28	.000
Error (Subjects x Rate)	87	173562		
Miss	4	90838	29.74	.000
Error (Subjects x Miss)	116	2701300		
Angle	1	34503	2.61	.117
Error (Subjects x Angle)	29	89915		
Ring x Rate	3	59992	2.50	.065
Error (Subjects x Ring x Rate)	87	149771		
Ring x Miss	4	70208	0.87	.485
Error (Subjects x Ring x Miss)	116	660977		
Ring x Angle	1	63502	0.35	.558
Error (Subjects x Ring x Angle)	29	222665		
Rate x Miss	12	64889	0.41	.958
Error (Subjects x Rate x Miss)	348	26821		
Rate x Angle	3	47966	2.79	.045
Error (Subjects x Rate x Angle)	87	134027		
Miss x Angle	4	66810	0.52	.717
Error (Subjects x Miss x Angle)	116	35127		
Ring x Rate x Miss	12	56838	0.71	.767
Error (Subjects x Ring x Rate x Miss)	348	40493		
Ring x Rate x Angle	3	54950	0.17	.916
Error (Subjects x Ring x Rate x Angle)	87	9383		
Ring x Miss x Angle	4	66292	0.48	.753
Error (Subjects x Ring x Miss x Angle)	116	31555		
Rate x Miss x Angle	12	73636	1.39	.169
Error (Subjects x Rate x Miss x Angle)	348	102191		
Ring x Rate x Miss x Angle	12	61048	0.69	.758
Error (Subjects x Ring x Rate x Miss x Angle)	348	42308		
Total	2399			

* Note: Value lost during data transfer

The results show that vertical rate had a significant effect on ERROR. As vertical rate increased from 1000'/min. to 2500'/min., ERROR also increased in a near linear fashion. This relationship is shown in Figure 13. Significant ERROR resulted between each of the four vertical rates and is displayed in Table 6.

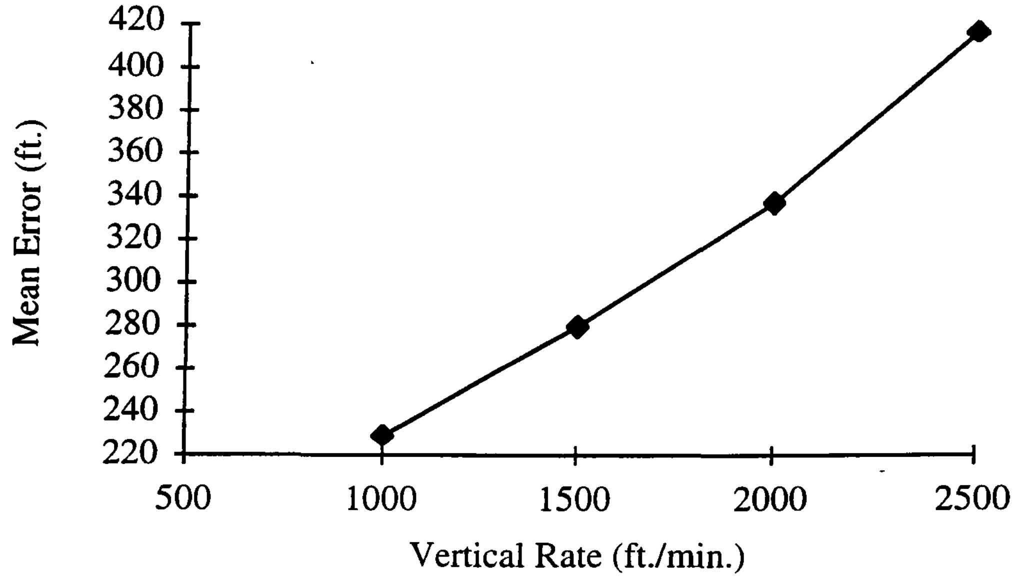


Figure 14. Mean Error versus vertical Rate

Table 6

Student Newman-Keuls significance for vertical rate on dv ERROR

	1000'/min	1500'/min	2000'/min	2500'/min
1000'/min		0.038	0.000	0.000
1500'/min	0.038		0.020	0.000
2000'/min	0.000	0.020		0.002
2500'/min	0.000	0.000	0.002	

Miss was also shown to have a significant effect on ERROR *F* (4,116)=29.74, $p<0.000$. The relationship between miss distance and ERROR was directly proportional to the absolute distance at which the intruder passed ownship. Subjects made the least amount of ERROR on the scenarios where the intruder would collide with ownship (0 ft.) (M=229.7 ft.). The greatest ERROR occurred on the scenarios where the intruder passed 600 ft. below ownship (M=411.8 ft.) (Figure 14).

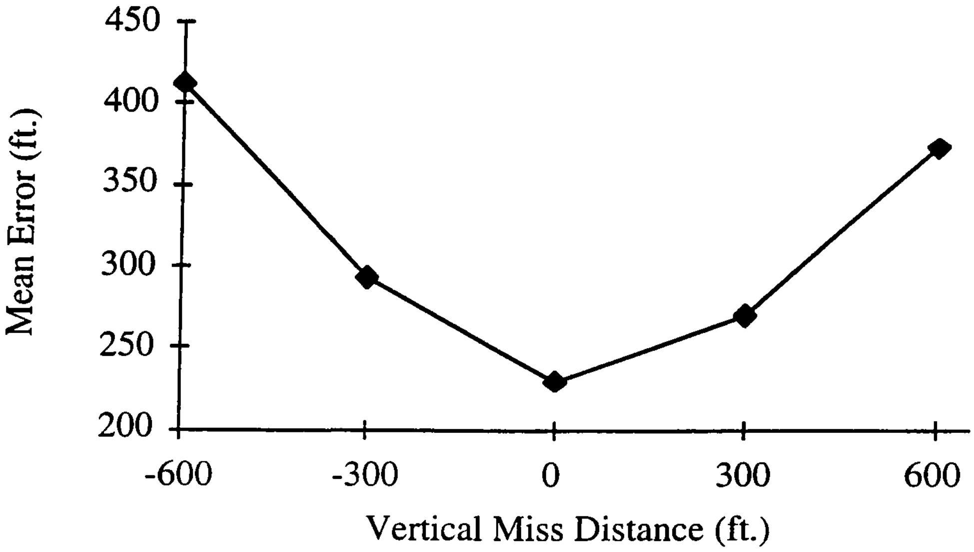


Figure 15. Mean Error versus vertical Miss

A SNK range test was performed on the five levels of the vertical miss distance (Table 7). The results show that the subjects experienced significantly more ERROR with miss distances -600 ft. and 600 ft.

respectively. The vertical miss was calculated using the following group means:

Miss Distance	*Group Mean (Error)*
-600 (ft.)	411.8 (ft.)
-300 (ft.)	294.0 (ft.)
0 (ft.)	229.7 (ft.)
+300 (ft.)	270.1 (ft.)
+600 (ft.)	373.5 (ft.)

Table 7

Student Newman-Keuls significance for vertical miss on dv ERROR

	-600	-300	0	300	600
-600	■	0.000	0.000	0.000	
-300	0.000	■	0.004		0.000
0	0.000	0.004	■	0.040	0.000
300	0.000		0.040	■	0.000
600		0.000	0.000	0.000	■

Empty cells indicate p levels greater than .05.

No significant main effect was found for angle F (1,29)=2.61, p=0.117. The subjects did not have significantly more ERROR when the intruder approach angle was 0° (head on) (M=309.7 ft.) as compared to an approach angle of 50° (M = 321.9 ft.).

The only significant interaction for dv ERROR was between rate and angle F (3,87)=2.79, p=0.045. A plot of the means (Figure 15) is similar to the plot for the main effect of rate (Figure 13). A SNK range test was performed using the following means:

Rate (ft./min.) by 0°	*Mean Error*	*Rate (ft./min.) by 50°*	*Mean Error*
2500	393.7 ft.	2500	439.1 ft.
2000	333.3 ft.	2000	341.5 ft.
1500	293.3 ft.	1500	267.1 ft.
1000	218.5 ft.	1000	240.2 ft.

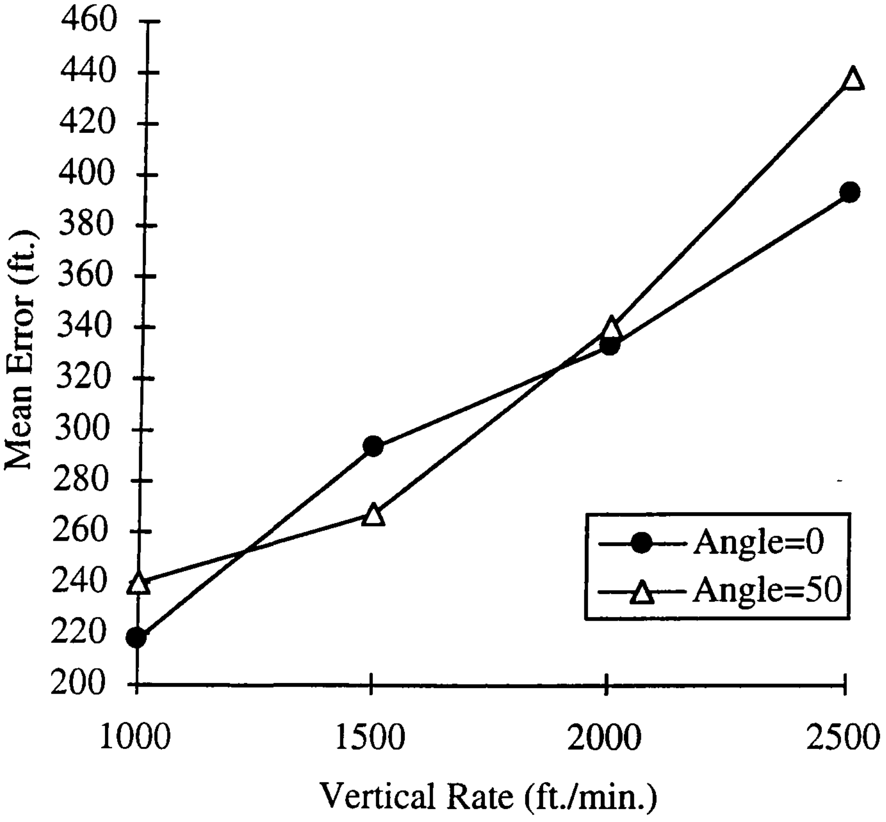


Figure 16. Mean Error versus Rate split by Angle

The results of the SNK range test showed that at an angle of 50°, 1000'/min had significantly less ERROR than 1500'/min (p<0.011), 2000'/min., and 2500'/min. (p<0.000). Also there was less ERROR between 1500'/min. and 2000'/min. (p=.028) than between 1000'/min. and

1500'/min (*p*<0.000) and between 2000'/min. and 2500'/min. (*p*=0.003). At the 0° angle, there was significantly more ERROR associated with 2500'/min. versus 1000'/min, 1500'/min., and 2000'/min. (*p*<0.000). There was no significant ERROR between 1000'/min. and 1500'/min.; however there was significant ERROR associated between 1500'/min. and 2000'/min. (*p*<0.000), and 2000'/min. and 2500'/min. (*p*<0.000).

Discussion

This study focused on the pilot's ability to quickly and accurately judge future vertical separation between a single intruding aircraft and ownship. The training instructions emphasized that decision time and accuracy were equally important factors in this research. Therefore, pilot's were to make their choice directly after determining a separation distance. They were not to build confidence in their selection by waiting. The lack of a correlation between TIME and ERROR reveals this aim was accomplished. The focus on equal importance for time and accuracy may have altered the methods pilots used to reach their decision. A different focus, such as increased accuracy at the expense of time, may have yielded very different results.

Upon completion of the research task, pilots were debriefed on their selection methods. Most pilots used some form of interpolation of intruder past progressions to determine future passing distance. These interpolations were made manifest through the use of either one or both of the displayed range rings. Pilots would use the three or four mile range ring (depending upon which was displayed) to determine the half-way point. The pilots would add or subtract the change in altitude of the intruder to the altitude at the half-way point to arrive at a miss distance.

One pilot occasionally allowed the intruder to fly within 1NM of ownship, thus halting the scenario. The pilot then calculated the number of updates required for the intruder to reach ownship. This method defeats the purpose of this study because it would not be a viable method in a real cockpit environment.

All of the above methods were based on the knowledge that the intruder would not deviate from its course and maintain a constant rate of climb/descent. This knowledge undoubtedly assisted the pilots in making more accurate decisions than if the intruder's intentions were unknown.

The subjects comprised a large range of experience. Total flight time for the subjects ranged from 45 to 10,000 hours (M=568 hours, SD = 683). Pilot certificates held by the subjects included 13 private, 11 commercial, 5 certified flight instructors, and 1 airline transport pilot. It was felt that the subject population represents the current users of CDTI because the task relies more on specific training and cognitive skills than flight hours.

The dependent variable for this study, TIME and ERROR, were analyzed using univariate ANOVAs (Table 8). The pairwise Pearson correlation yielded a coefficient of r=-.336, n=30, p(.01) = .423. Therefore, the correlation is not significant.

Table 8 *Summary of significance on dv TIME and dv ERROR*

TIME

Ring	$F(1,29)=46.4$, $p<0.000$ 3 NM Ring (faster) vs. 2 NM & 4 NM Rings
Rate	$F(3,87)=6.30$, $p<0.000$ 1000 ft./min. (faster) vs. 2000 ft./min & 2500 ft./min. 1500 ft./min. (faster) vs. 2000 ft./min. & 2500 ft./min.
Rate x Miss x Angle	$F(12,348)=2.10$, $p=0.016$ 2000 ft./min. x 300 ft. x 50° (slower) vs. all others

ERROR

Rate	$F(3.87)=22.28$, $p<0.000$ 2500 ft./min. (more error) vs. all others 2000 ft./min. (more error) vs. 1500 ft./min. 1500 ft./min. (more error) vs. 1000 ft./min.
Miss	$F(4,116)=29.74$, $p<0.000$ -600 ft. (more error) vs. all others +/-300 ft., +600 ft. (more error) vs. 0 ft. (collision)
Rate x Angle	$F(3,87)=2.79$, $p=0.045$ 2500 ft./min. @ 50° (more error) vs. 2500 ft./min. @0° 1500 ft./min. @ 0° (more error) vs. 1500 ft./min @ 50° 1500/2000/2500 ft./min. @ 50° (more error) vs. 1000 ft./min. @ 50° 1500/2000/2500 ft./min. @ 0° (more error) vs. 1000 ft./min. @ 0°

It was hypothesized that the use of both a two mile range ring and a four mile range ring, as compared to a single three mile range ring, would reduce pilot selection time and error. The use of both the two and four mile range rings required significantly more time for the subjects to choose a miss distance than using the single three mile range ring. The use of the two range rings had no significant effect on error versus the single range ring. Therefore, the research hypothesis is rejected. There are several possible reasons for this result. First, there was no standard ring distance maintained throughout the study. Had the three mile range ring been maintained with an additional ring placed around it, at possibly five or six miles from ownship, during the two ring scenario, this continuity of a standard or baseline ring may have aided in a more uniform perception pattern throughout the study. With the minimum ring distance from ownship randomly being changed, it is possible that a temporary disorientation may have occurred while the subjects adjusted to the new minimum ring distance from ownship. Second, the study incorporated a single task design which allowed the subjects to concentrate specifically on the display. Had a secondary or primary task been incorporated, the subjects may have studied the display for shorter periods thus yielding different results.

Additional research was conducted on vertical rate, miss distance, and angle of approach of the intruding aircraft. A direct relationship between vertical rate and error is strongly supported in the results and is clearly distinguished in Figure 13. The relationship between vertical rate and time displays a linear trend of direct proportionality Figure 12. The results indicate that as vertical rate increases, both error and time also increase. The results strongly support that an increase in vertical rate caused the subjects to wait longer in selecting a vertical miss distance and then, choosing a distance further from the actual distance. One possible reason for this may be the subjects inability to properly visualize a 3 dimensional traffic situation from the information given on the 2 dimensional display. This would arise from a lack of familiarity with CDTI displays and, although speculative, may have improved with further training.

Miss distance was found to be significant for error but not for time. The subjects had significantly less error at a 0 ft. miss distance (collision) than all other miss distances. The subjects displayed significantly more error at the -600 ft. and 600 ft. distances respectively. This indicates the subjects ability to identify when the intruder is on a near miss or collision course towards ownship. This is consistent with previous research by Wassell (1993), and suggests that vertical direction has an influence on accuracy. The last main effect was angle which resulted in no significance for time or error.

There were only two interactions which were found to be significant. The interaction for time involved rate, miss, and angle. Of the forty combinations of interaction only four were significant. Subjects took the longest time at the 2000 ft./min. x 300 ft. x 50° interaction vs. the other 39 interactions. The three remaining significant interactions have no significance between them (Table 4). However, further examination of the vertical rates of this interaction reveals a direct similarity to the main effect of rate on time.

The final interaction of significance was rate by angle on error. The plot of the means (Figure 15) reflects the main effect of rate on error. As vertical rate and angle increase, the error also increases. Although the mean for angle 0° at 1500 ft./min. is greater than the mean for 50° at 1500 ft./min. the difference is not significant revealing a linear trend.

Recommendations

The method used in this study to determine future vertical separation of an intruding aircraft is not very accurate and simply takes too much time. A realistic flight environment would require the subjects to divide their attention from total concentration of the CDTI to perform other tasks within the cockpit. A reduction in monitoring time of the CDTI would most likely result in higher levels of error associated with an increased workload. Pilot usage of the CDTI in an actual cockpit environment may be very different from the manner it was used in this study. Pilots may find that time constraints dictate the use of a CDTI as more of a quick reference tool in which avoidance decisions may be implemented long before an intruding aircraft becomes a threat. This suggests that the use of multiple range rings may be more beneficial in the field than in a research environment. Further research involving multiple range rings incorporating a standard minimum distance from ownship may provide a significant reduction in decision time and error. Incorporating an additional workload in future research will better represent a live cockpit environment that could add much insight into future development of the CDTI.

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Appendix A

Software Script

Window script

```
on openWindow
     global SSN, dist, ttime1, ttime2, relalt, VM, Vb3D, VR, pixel1,¬
  pixel2, h, v, locv, angle, cardnum, counter       -- global variables
  hide background field "datatag"                   -- initialize graphics
  hide background graphic "intruder"
  hide background graphic "screenscale"
  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 "rings"        -- two rings in this scenario
  put 1 into cardnum                     -- first scenario

  put 50 into angle                      -- intruder approaches from 50°
  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 291-pixel2 into y                      -- calculate distance to intruder
        put y^2 into y1
        put 253-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
                                               -- ownship & ownship alt (5000 ft)
   put "TWA 295   240kts" into background field "ownship"
   put "5000ft" into background field "ownalt"
   show background field "ownship"
   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 graphic "Intruder" at pixel1, pixel2
     if pixel1 < 253 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 2 second                          -- wait to update intruder position
    if the mouseclick then                     -- check again for mouse click
       beep
       exit repeat
   end if
   put 291-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
   send "startscale" to background graphic screenscale-- 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 1:CDTIstuff:PilotData:" & SSN
    write SSN & "," & cardnum & "," & angle & "," & VM & "," & VR
    & "," & pickedAlt & "," & dist & "," & relalt & "," & time &
    numToChar(13) after file "Caar 1:CDTIstuff:PilotData:" & SSN
  close file "Caar 1:CDTIstuff:PilotData:" & SSN
  set cursor to none
  hide background field "distance"       -- reset graphics for next scenario
  hide background field "screenscale"
  hide background graphic "intruder"
  hide background graphic "datatag"
  hide background graphic "ownship"
  hide background graphic "ownalt"
end bakscript
```

Object 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
    set cursor to danline                --cursor displayed as pointer
    set loc of cursor to 73, locV        --cursor locked horizontally
```

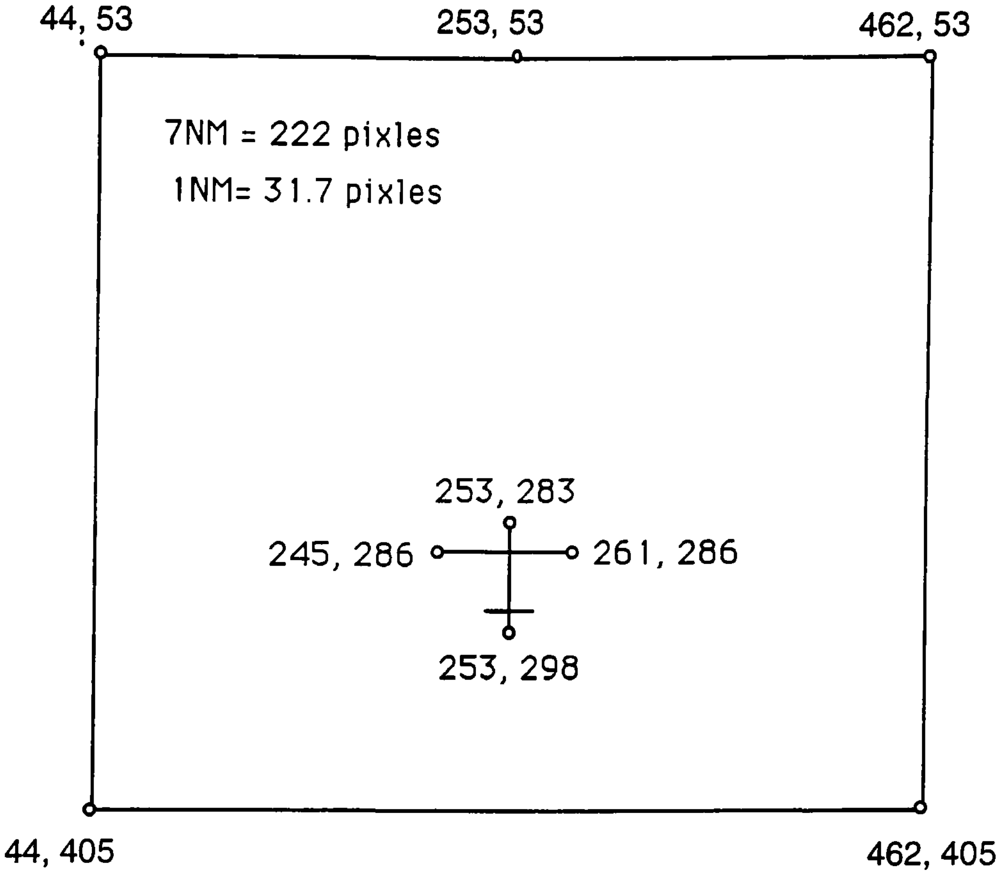
```
      show background graphic "distance"
      if the mouseclick then                  -- exit loop if mouse clicks
        beep
        exit repeat
      end if
    end repeat
  end startscale
```

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

	Rings	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	1	50.0	0	1000	350	240	15.1	268.4	268.6	16.7	-2.4	-2.0
2	1	0.0	0	-1000	350	240	-109.9	109.9	110.3	-16.7	0.0	-3.1
3	1	-50.0	300	1000	350	240	15.1	268.4	268.6	16.7	2.4	-2.0
4	1	0.0	300	-1000	350	240	-109.9	109.9	110.3	-16.7	0.0	-3.1
5	1	50.0	-300	1000	350	240	15.1	268.4	268.6	16.7	-2.4	-2.0
6	1	0.0	-300	-1000	350	240	-109.9	109.9	110.3	-16.7	0.0	-3.1
7	1	-50.0	600	-1000	350	240	15.1	268.4	268.6	-16.7	2.4	-2.0
8	1	0.0	600	1000	350	240	-109.9	109.9	110.3	16.7	0.0	-3.1
9	1	50.0	-600	-1000	350	240	15.1	268.4	268.6	-16.7	-2.4	-2.0
10	1	0.0	-600	1000	350	240	-109.9	109.9	110.3	16.7	0.0	-3.1
11	1	-50.0	0	-1500	350	240	15.2	268.3	268.7	-25.0	2.4	-2.0
12	1	0.0	0	1500	350	240	-109.7	109.7	110.7	25.0	0.0	-3.1
13	1	50.0	300	1500	350	240	15.2	268.3	268.7	25.0	-2.4	-2.0
14	1	0.0	300	-1500	350	240	-109.7	109.7	110.7	-25.0	0.0	-3.1
15	1	-50.0	-300	1500	350	240	15.2	268.3	268.7	25.0	2.4	-2.0
16	1	0.0	-300	-1500	350	240	-109.7	109.7	110.7	-25.0	0.0	-3.1
17	1	50.0	600	-1500	350	240	15.2	268.3	268.7	-25.0	-2.4	-2.0
18	1	0.0	600	1500	350	240	-109.7	109.7	110.7	25.0	0.0	-3.1
19	1	-50.0	-600	-1500	350	240	15.2	268.3	268.7	-25.0	2.4	-2.0
20	1	0.0	-600	1500	350	240	-109.7	109.7	110.7	25.0	0.0	-3.1
21	1	50.0	0	2000	350	240	15.4	268.1	268.9	33.3	-2.4	-2.0
22	1	0.0	0	-2000	350	240	-109.4	109.4	111.2	-33.3	0.0	-3.1
23	1	-50.0	300	2000	350	240	15.4	268.1	268.9	33.3	2.4	-2.0
24	1	0.0	300	-2000	350	240	-109.4	109.4	111.2	-33.3	0.0	-3.1
25	1	50.0	-300	2000	350	240	15.4	268.1	268.9	33.3	-2.4	-2.0
26	1	0.0	-300	-2000	350	240	-109.4	109.4	111.2	-33.3	0.0	-3.1
27	1	-50.0	600	-2000	350	240	15.4	268.1	268.9	-33.3	2.4	-2.0
28	1	0.0	600	2000	350	240	-109.4	109.4	111.2	33.3	0.0	-3.1
29	1	50.0	-600	-2000	350	240	15.4	268.1	268.9	-33.3	-2.4	-2.0
30	1	0.0	-600	2000	350	240	-109.4	109.4	111.2	33.3	0.0	-3.1
31	1	-50.0	0	-2500	350	240	15.6	267.9	269.0	-41.7	2.4	-2.0
32	1	0.0	0	2500	350	240	-109.1	109.1	111.9	41.7	0.0	-3.1
33	1	50.0	300	-2500	350	240	15.6	267.9	269.0	-41.7	-2.4	-2.0
34	1	0.0	300	2500	350	240	-109.1	109.1	111.9	41.7	0.0	-3.1
35	1	-50.0	-300	-2500	350	240	15.6	267.9	269.0	-41.7	2.4	-2.0
36	1	0.0	-300	2500	350	240	-109.1	109.1	111.9	41.7	0.0	-3.1
37	1	50.0	600	2500	350	240	15.6	267.9	269.0	41.7	-2.4	-2.0
38	1	0.0	600	-2500	350	240	-109.1	109.1	111.9	-41.7	0.0	-3.1
39	1	-50.0	-600	2500	350	240	15.6	267.9	269.0	41.7	2.4	-2.0
40	1	0.0	-600	-2500	350	240	-109.1	109.1	111.9	-41.7	0.0	-3.1

Note: The second 40 scenarios are identical to the above execpt the card script specifies that two rings are shown.

Appendix D

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 Daniel Rizzardi. 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 data tag. The data tag 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.

Click the mouse button when you feel you know what the vertical separation will be when the intruder and ownship pass. This will display a decision screen that 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 arrow 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.

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 software will halt the scenario and beep until you click the mouse button.

On the display, your aircraft will be centered in the lower third of the screen. In certain scenarios your aircraft will be inside a single three (3) mile range ring. In other scenarios, your aircraft will be inside two (2) range rings. These range rings are located two (2) and four(4) nautical miles from your aircraft. The display screen has a seven (7) nautical mile range. Your aircraft and the approaching aircraft are not scaled the same as the screen. The aircraft has 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 relative 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.

Appendix F

Means Table for all Scenarios

Rings	Rate	Miss	Angle	Mean Time (sec.)	SD Time	Mean Error (ft.)	SD Error
2	1000	0	50	46.41	18.76	189.00	218.73
2	1000	0	0	47.98	17.80	161.67	252.70
2	1000	300	50	47.88	20.75	183.67	170.71
2	1000	300	0	50.53	17.25	193.33	161.91
2	1000	-300	50	48.76	19.74	235.00	210.53
2	1000	-300	0	46.20	14.99	216.33	164.96
2	1000	600	50	50.96	15.67	284.00	265.90
2	1000	600	0	46.39	16.27	338.33	331.08
2	1000	-600	50	42.33	16.43	384.33	336.51
2	1000	-600	0	47.46	19.09	282.00	335.97
2	1500	0	50	46.15	18.69	199.67	290.50
2	1500	0	0	49.06	17.49	236.67	237.35
2	1500	300	50	44.34	16.80	249.33	178.59
2	1500	300	0	45.81	16.47	227.00	173.55
2	1500	-300	50	51.45	19.52	234.33	247.30
2	1500	-300	0	43.30	20.77	238.00	147.47
2	1500	600	50	45.51	14.88	309.67	224.37
2	1500	600	0	45.23	14.08	325.67	266.87
2	1500	-600	50	41.51	14.15	337.00	308.77
2	1500	-600	0	45.63	15.91	394.33	375.27
2	2000	0	50	49.63	17.48	263.33	225.04
2	2000	0	0	48.88	15.10	214.33	248.67
2	2000	300	50	51.75	16.94	356.33	238.83
2	2000	300	0	49.21	16.00	246.33	187.26
2	2000	-300	50	51.97	15.95	299.67	314.65
2	2000	-300	0	51.08	16.70	289.00	187.77
2	2000	600	50	48.35	16.41	401.67	391.72
2	2000	600	0	47.47	15.78	478.33	372.35
2	2000	-600	50	50.35	17.87	456.33	286.22
2	2000	-600	0	49.05	14.76	437.67	401.66
2	2500	0	50	51.83	13.93	255.00	243.99
2	2500	0	0	50.13	15.75	276.33	270.37
2	2500	300	50	47.33	16.35	428.33	337.28
2	2500	300	0	52.00	16.46	335.00	253.31
2	2500	-300	50	50.49	17.56	337.00	278.35
2	2500	-300	0	51.30	17.20	372.67	385.97
2	2500	600	50	50.17	17.99	553.33	331.44
2	2500	600	0	50.07	15.28	399.00	383.29
2	2500	-600	50	53.46	13.30	543.00	401.10
2	2500	-600	0	46.17	22.82	471.33	266.43

Rings	Rate	Miss	Angle	Mean Time (sec.)	SD Time	Mean Error (ft.)	SD Error
1	1000	0	50	42.25	13.79	130.00	221.48
1	1000	0	0	39.23	13.36	130.67	187.19
1	1000	300	50	39.23	16.16	167.00	108.12
1	1000	300	0	43.25	12.13	136.67	113.03
1	1000	-300	50	41.72	14.52	207.00	189.19
1	1000	-300	0	36.29	14.15	173.33	120.95
1	1000	600	50	40.74	13.35	242.33	212.08
1	1000	600	0	36.25	13.32	248.67	260.20
1	1000	-600	50	38.22	17.54	379.33	369.56
1	1000	-600	0	38.55	14.00	304.00	310.17
1	1500	0	50	38.99	14.34	152.33	216.63
1	1500	0	0	42.64	12.12	231.33	253.21
1	1500	300	50	38.47	14.38	268.67	172.82
1	1500	300	0	39.09	12.18	250.00	174.91
1	1500	-300	50	44.85	19.56	246.67	202.78
1	1500	-300	0	37.04	13.62	324.00	249.59
1	1500	600	50	38.88	12.64	295.33	208.34
1	1500	600	0	40.34	13.70	339.33	256.74
1	1500	-600	50	38.39	16.02	377.33	347.99
1	1500	-600	0	40.08	13.84	366.33	274.43
1	2000	0	50	47.62	13.59	213.00	199.95
1	2000	0	0	41.21	15.00	245.67	237.82
1	2000	300	50	46.66	17.56	287.00	185.23
1	2000	300	0	41.95	15.22	224.67	193.42
1	2000	-300	50	42.09	14.88	403.33	378.39
1	2000	-300	0	42.71	11.57	300.67	203.76
1	2000	600	50	39.65	15.98	341.67	326.19
1	2000	600	0	40.71	13.73	451.00	234.47
1	2000	-600	50	41.05	13.60	392.67	193.19
1	2000	-600	0	42.09	12.55	445.33	365.90
1	2500	0	50	38.39	12.80	395.33	368.62
1	2500	0	0	38.04	16.69	381.33	350.97
1	2500	300	50	38.11	15.33	343.67	336.95
1	2500	300	0	39.56	12.72	425.33	315.47
1	2500	-300	50	41.92	13.76	457.00	256.05
1	2500	-300	0	42.29	13.77	369.33	310.13
1	2500	600	50	41.45	15.84	557.00	285.71
1	2500	600	0	41.29	14.01	410.33	358.47
1	2500	-600	50	41.90	13.70	521.00	426.96
1	2500	-600	0	43.53	11.10	496.67	258.29

Appendix G

Means Table for all Subjects

Subject No.	Mean Time (sec.)	SD Time	Mean Error (ft.)	SD Error
1	55.86	3.89	148.25	233.75
2	40.70	19.80	391.38	359.80
3	52.48	12.03	252.63	256.88
4	52.61	12.68	368.75	299.16
5	48.20	16.81	385.50	312.00
6	37.07	13.31	288.25	183.90
7	45.35	7.47	214.13	198.28
8	42.80	6.69	196.38	220.24
9	32.14	12.36	371.38	289.22
10	41.35	19.49	304.00	218.61
11	38.22	14.93	307.50	254.95
12	38.58	15.41	340.38	280.90
13	38.83	23.23	380.13	353.57
14	41.44	8.39	360.75	288.57
15	31.31	5.04	443.75	336.72
16	41.83	8.26	269.00	218.32
17	44.18	10.70	243.25	241.79
18	19.15	6.36	430.13	325.06
19	55.60	11.13	186.88	233.72
20	39.84	9.85	339.75	317.53
21	71.15	10.38	350.25	288.02
22	51.21	15.49	280.38	234.09
23	53.16	5.46	286.25	216.46
24	51.53	16.39	453.63	417.08
25	40.60	3.92	283.25	313.49
26	37.81	14.37	309.63	261.43
27	37.73	10.68	457.50	353.86
28	59.28	17.55	391.50	317.43
29	41.96	9.66	255.38	181.91
30	53.15	16.28	184.75	204.21

	MEAN Time	SD Means	Mean Error	SD Means
All Subjects	44.50	9.96	315.82	84.07