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EFFECT OF INTRUDER VERTICAL RATE ON PILOT PERCEPTION OF SEPARATION ON A COCKPIT TRAFFIC DISPLAY

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of Graduate Studies and Research in partial
fulfillment of the requirements for the degree of
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EFFECT OF INTRUDER VERTICAL RATE ON PILOT PERCEPTION OF SEPARATION ON A COCKPIT TRAFFIC DISPLAY

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This thesis was prepared under the direction of the candidate's advisor,
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NOMENCLATURE

a	Indicates ownship
b	Indicates intruder
$\bar{V}_a$	Velocity vector for ownship
$\bar{V}_b$	Velocity vector for intruder
$\bar{V}_{(b/a)}$	Velocity vector of intruder relative to ownship
$\bar{V}_i$	The x-component of the indicated velocity vector
$\bar{V}_j$	The y-component of the indicated velocity vector
$\bar{V}_k$	The z-component of the indicated velocity vector
$V_{(b/a)\ 2D}$	Two dimensional velocity vector of intruder relative to ownship
$V_{(b/a)\ 3D}$	Three dimensional velocity vector of intruder relative to ownship

ABSTRACT

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The purpose of this study was to determine the effect of intruder vertical rate on pilots' perception of aircraft separation as viewed on a cockpit traffic display. A group of 20 student pilots from Embry-Riddle Aeronautical University participated as subjects. SuperCard® software and a Macintosh II® personal computer were employed to generate the simulation of a cockpit display of traffic information. Each pilot monitored 84 scenarios in which they had to perceive how far away a single intruder would pass over or under their own aircraft. The pilots' decision time, vertical and horizontal distance at decision time and percentage of correct/incorrect answers were determined from the experimental data. Vertical rate was found to significantly effect pilots' predictions of vertical separation at the passing point and that pilot error rates increased with increasing intruder vertical rate. This result must be weighed with the randomization error present during the experiment.

INTRODUCTION

A steady increase in airborne traffic has continued to stimulate study into viable methods of maintaining safe separation distances between aircraft. The ability of automated air traffic control (ATC) systems to safely handle projected capacities is a matter of concern. This concern has given rise to the possible use of cockpit display of traffic information (CDTI) technology as a means to assist the automated systems in maintaining safe separation. Traffic displays in the cockpit are already a mandated reality in the form of traffic alert and collision avoidance systems (TCAS). CDTI simply shows the aircraft present in a certain volume of airspace, whereas TCAS displays traffic, issues resolution advisories, and is concerned with predicting the intersection of flight paths. CDTI uses broader traffic selection criteria than TCAS so as to monitor a larger volume of airspace and "include non-threatening aircraft that could affect piloting decisions" (Britt, Davis, Jackson, McCellan, 1984).

CDTI is a more perceptually complex display than those used by air traffic controllers, due to the misleading apparent motion of the other aircraft caused by the turning of the CDTI equipped aircraft (Palmer, P., Jago, S., Baty, D., O'Conner, S., 1980). ATC displays present dynamic air traffic on a stationary map, where as CDTI depicts a dynamic traffic situation from a moving frame of reference. This fact makes the display difficult to correctly perceive. CDTI displays the surrounding traffic information from a bird's-eye point of view (plan-view). The plan-view format lacks vertical dimensionality making it difficult for the pilot to perceive, from the visual cues, if minimum separation will occur when viewing a climbing or descending intruder. Despite poor presentation of vertical information, the plan-view format is still the prime format in use today. Intruder altitude information, when available, is presented to the pilot in the form of a numerical value given in the intruder's data tag. The pilot must mentally process the information further to obtain the intruder's vertical rate by monitoring successive altitude readings.

Literature that specifically includes vertical separation and vertical rates (Hart, Loomis (1980); Lester, Palmer (1983); Palmer (1983); Palmer, Ellis (1983); Smith, Ellis, Lee (1982); & Ellis, McGreevy, Hitchcock (1987)) concentrated on the effect of altitude coding and pilot maneuver responses. The studies neglected to make specific determinations as to the effect of different vertical rates on pilots ability to correctly perceive vertical separation. Previous studies do lend some insight to pilots' perception of the vertical plane, but as Hart and Loomis (1980) stated, "additional research will be required to determine how to best inform pilots' about the vertical relationship between their own aircraft (ownship) and another aircraft." Studies such as Lester and Palmer (1983) display a computer projected vertical separation, at the closest point of approach, in the intruder's datatag. This is a very effective means of predicting vertical separation, but most of the current traffic displays now in use do not offer vertical information in that form. This prompted the question of how different vertical rates effect what the pilot perceives when monitoring a plan-view display that does not offer predictive vertical separation information. The plan-view format, as stated before, is the prime display format and will most likely remain a dominate one for some years. The ability to judge or predict aircraft separation in the vertical plane is as important as judging separation in the horizontal plane. If intruder vertical separation is the weak point in the information displayed, it seems logically that the weakest link be fully understood so as to realize the full potential of the display. A better understanding of how accurately pilots perceive and project the vertical information on a plan-view display will necessarily come by understanding the effects of different intruder vertical rates. If CDTI is to compliment the automated ATC system and better serve pilots, a clear understanding of how pilots perceive plan-view presented 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 an intruder's vertical rate on pilots' 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 surrounding aircraft positions and motion with respect to ownship.

Review of Related Literature

History

The idea of placing traffic information in the cockpit is a vintage concept that emerged from the RCA Princeton Electronic Laboratory in the early 1940's. The concept was to place a televised image of the ATC ground controller's radar display in the cockpit to increase the pilots awareness of their surroundings. The technological limitations of the day only allowed a constant north-up presentation, which meant the displayed information did not turn with the aircraft and was disorienting when flying directions other than north. The RATCA and TELERAN concepts explored the idea in the mid to early sixties. During the early 1970's, 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 display format depicted a top view or "plan-view" of the air traffic surrounding ownship (Anderson, R. E., Curry, R. E., Weiss, H. G., Simpson, R. W., Connelly, M. E., Imrich, T. (1971). During the late 1970's and through the 1980's NASA's Ames and Langley Research Centers focused on the display's format and how pilots perceived and reacted to it. These CDTI studies used heading or track-up displays that constantly changed orientation, so the displayed traffic information corresponded to ownship's real time heading. On current cockpit traffic displays, the data tag information is limited by radar sweep times and the transponder's interrogate/respond technology to a four second update rate. A data uplink between ground ATC and the aircraft and the use of global positioning satellites (GPS) are options being considered as an alternate CDTI information source.

The different studies performed by the NASA centers can be grouped under the one main topic of aircraft separation. Under the main topic, three subtopics emerged: pilots' ability to maintain separation, pilots' maneuver responses, and pilots' perception of separation. Separation maintenance studies all employed approaches and departures, to and from a terminal area, to study pilots' ability to use the display to maintain separation. Maneuver studies employed approach, departure, and and level flight scenarios to test how pilots would react to the information presented by the display. The methods utilized in perception studies, to better understand the information pilots receive from traffic displays, were flying simulated approaches, departures, level flight, and judging future positions of intruding aircraft.

These studies were the most recent and were done as a series of experiments that built upon the results of one another. Most studies conducted in the 1970's and 1980's involved dynamic cockpit displays and were the material focused on for this study. Some work done at MIT is absent from the review, though it was referenced in the studies performed at the NASA centers, which incorporated the main achievements of the MIT work.

Separation Maintenance

A study by Kreifeldt, Parkin, Rothschild, and Wempe (1976) examined how pilots, given the tactical task of maintaining self-separation when not all of them will have traffic displays, could maintain separation. Three pilots, two with CDTI and one without, had to merge their simulators among other aircraft that were two minutes apart and already on final approach. All aircraft were required to be descending on a six degree glide slope one nautical mile from the runway. Two conditions were analyzed: vectoring, where the ground controller was the only source of separation information; and non-vectoring, where the controller gave only sequencing information to the CDTI pilots and vectoring instructions to the non-CDTI pilot. A discriminate analysis of objective measures indicated a significant difference between the two conditions for half of the measures. The non-vectored CDTI flights showed "distinctly different measures" and for some measures, "enhanced performance" when compared to vectored flight measures (Kreifeldt et al., 1976). The lone non-CDTI aircraft also showed distinct differences when comparing the vectored to the non-vectored condition. An interesting, but somewhat expected result was that controllers' verbal workload was markedly reduced in the non-vectored condition. The non-CDTI pilot's workload increased considerably in the non-vectored condition. This could have resulted from the controller having more free time to deal with the sole non-CDTI pilot or the fact that the non-CDTI pilot required more assistance for that condition. Pilots' verbal workload remain the same for both conditions. Though performance for the non-vectored (distributed) condition was at least at par with the vectored (centralized or ground-based) condition, the experiment found that better results were realized for the vectored condition.

A major air traffic control (ATC) concern is how to deal with aircraft that have mixed performance capabilities. It is unclear if the aircraft simulated in the above study were of the same class or type. A more informative study could include a mix of transport and general aviation aircraft, as well as a CDTI, non-CDTI mix. Regardless of what system is utilized to create an efficient traffic flow, the mixed performance issue, that plagues even the current system, must be evaluated.

Williams and Wells (1986) looked at the mix of CDTI equiped and non-equiped 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 employed 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 Douglas 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 approach (ILS) 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 (Williams, Wells, 1986).

Checklist procedures were found to be unaffected by the use of 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 much time monitoring the display, drawing them away from their primary flight instruments. Williams and Wells (1986) felt this result was due to 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 concerns for situations in need of abrupt maneuvers.

The subjective estimates of the pilots found 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 found lower associated workload with the display added in the monitoring role and higher associated workload with the display added 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 CDTI. The difference between the with CDTI and without CDTI mean interarrival time was just over seven seconds. The standard deviation of the with CDTI arrival time dispersions was reduced just over six seconds from the without CDTI task. The monitoring condition degraded the mean interarrival time performance 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, where 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 between air and ground to identify specific conflicting traffic.

This suggests the need for proper development of departure procedures to deal with this issue.

The study shows the importance of developing CDTI procedures that will provide optimum self-spacing results. The CDTI self-spacing task does show an ability to increase ROR and reduce controllers' verbal workload. To what extent and to what significance ROR will be enhanced should be determined by actual flight tests.

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" (Williams, 1983). This raises the question of how will a trailing aircraft be selected by pilots or ground controllers in a terminal area where aircraft are continuously coming in and effectively obscuring the end of the "trail?" The delay criteria, essentially, has aircraft 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 Stapelton 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 being 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.

Pilots felt that the four second update rate and placement of the display out of the primary instrument scan caused an increase in the dwell time associated with the display. It was suggested that additional self-spacing information be presented on the display to reduce the workload associated.

Even if the 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, Abbott, 1984). Kelly and Abbott (1984) analyzed the in-trail spacing dynamics of aircraft utilizing CDTI displays to determine separation during a self-spacing task. A line or 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. Again, as in most other research, pilots flew the approach in Denver's terminal area. 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 makes it undesirable for this application" (Kelly, Abbott, 1984). No dynamic oscillations were found for the delay criteria and no slow-down tendency was found. The authors cautioned generalizing the result to actual operation. This was due to all the aircraft in the queue having the *same performance characteristics.* Another possible reason no oscillations were encountered is that the time between the pilot making a control input and realizing its effect generated a "very low frequency loop closure" (Kelly, Abbott, 1984). A study such as this, but incorporating aircraft of mixed performance and with/without traffic displays, would better represent the actual environment pilots deal with.

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. 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 established the order early" (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. Kreifeldt and Wempe (1973) found both distributed modes "perfectly workable," 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 transmitted by the pilot or controller during a scenario was labeled as verbal workload. The pilot's verbal workload remained constant over all three conditions, while the controller's verbal workload in the distributed conditions was half of that of the vectoring condition. The time between "each successive aircraft" as they crossed the inner marker was termed the "intercrossing time"(Kreifeldt, Wempe, 1973) The mean intercrossing times were not significantly different across the three conditions. The pilots did produce less variable control results in the distributed conditions, which means the dispersion of intercrossing times was smaller.

A traffic display study that removes pilots from their familiar landing procedures, to study pilot opinion of separation tasks, employed curved descending approaches that were based on use of a microwave landing system (MLS) (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 (distributed).

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

Chappell and Palmer (1983) conducted a study that analyzed the effect of sensor noise and communication on a CDTI separation tasks. Light twin engine aircraft simulators at NASA Ames Research Center were used. Subjects were to maintain two nautical miles of horizontal separation and 500 ft of vertical separation under the different test conditions. The 24 experimental flights were made under four conditions: with and without sensor noise in the traffic and with or without communications for traffic coordination (Chappell & Palmer, 1983). The study concluded that there was no significant difference in minimum separation due to the presence of communication or sensor noise. This study would have more significance if it was conducted with actual equipment or simulator error rates and magnitudes replicating that of current equipment.

Pilot Avoidance Maneuvers

Palmer (1983) used a wide bodied jet simulator to test pilots' ability to select a maneuver that would keep the aircraft from deviating to 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 pilots' maneuvers followed a strategy that would "uniformly increase the predicted separation between ownship and the intruder"(Palmer, 1983). Pilots' maneuvers avoided 80% of all the positive collision advisories, but often could not keep within the previously mentioned flight path restraints.

Ellis and Palmer (1982) studied the effects of intruders' minimum separation and time to minimum separation on the avoidance maneuvers selected by pilots. Pilots viewed photographs depicting CDTI conflict situations and ranked the stack of photos by degree of threat. Pilots chose an avoidance maneuver for each photo from a list of nine options. The maneuvers chosen were intended to maintain separation between ownship and the perceived threat (intruder). Analysis of maneuvers showed a tendencies 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, 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 factors varied 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. 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). Smith et al. (1982) inferred that pilots in the experiment adopted decision strategies sensitive to subjective aspects of the encounters (perceived threat or perceived miss distance), which varied from pilot to pilot. The study found 86% of the maneuvers occurred before 30 seconds to the minimum miss distance. This would have been in advance of any positive avoidance advisory.

Pilots made more horizontal avoidance maneuvers than vertical maneuvers. This was possibly due to poor representation of the vertical situation. 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 often turned towards an intruder during a potential 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 when threat was deemed low. Pilots tended to turn toward intruders approaching more from the front, due to pilots having a lower perceived threat in those cases. Intruders that started below ownship caused pilots to chose climbing maneuvers. The opposite tend was present but could not be supported across all subjects.

Ellis, McGreevy and Hitchcock (1987) examined a totally new approach to presenting traffic information in the cockpit. Capabilities of computers now make it possible to display a perspective view of traffic instead of the standard plan-view format. The display was a "correct-perspective view, from an eye point 30 kilometers behind ownship, looking down on ownship from an elevation angle of 30 degrees with a 50 degree field-of-view angle" (Ellis et al., 1987). 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 then asked to select an avoidance maneuver from one of nine maneuver options.

It was found, except for head-on traffic, that pilots' decision time was three to six second faster using the perspective than when using the plan-view display. Head-on traffic was obscured by ownship which explains the pilots' longer interpret time 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. Ellis et al. (1987) noted that the current Traffic-Alert and Collision Avoidance Systems (TCAS) only issue vertical maneuvers and that pilots have a horizontal maneuver bias when using a plan-view format. The difference in maneuver type between pilots and TCAS suggests that the plan-view format may not be compatible with current TCAS systems (Ellis et al., 1987).

Pilot Perception

Studies that dealt with perception were placed into the two following areas: horizontal symbology presentation and vertical symbology presentation. There are several studies that cover the horizontal plane, but relatively few that shed light on the symbology that supports the pilots' perception of the vertical plane.

Horizontal Symbology Presentation

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 display sizes considered ranged from three inches high by four inches wide to six and a half inches square. Six map scales were employed: one, two, four, eight, sixteen, and thirty-two nautical miles per inch.

Throughout the tests, the test subjects consistently used the smallest scale factor (greatest resolution) that would keep the lead aircraft within the viewing area of the CDTI display (Abbott, Moen, 1981). The larger map scales were used at one or two minute intervals and for periods less than ten seconds. 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 a significant effect on pilot performance. Hart and Loomis (1980) found that half of the general aviation pilots indicated a five inch display was the smallest acceptable display, whereas only one airline pilot was willing to accept a display smaller than seven inches.

The effect of length of viewing time, time to encounter, and practice on pilots' perception of aircraft separation were examined by O'Conner, Palmer, Baty, & Jago (1980). Subjects were given different viewing times and times to encounter for each test. Separation at the point of encounter was set at 3,000 ft and was not necessarily the point of closest approach. No scenario would result in a collision between ownship and the intruder. Pilots were allowed to view the display a set amount of time and then asked to make judgements as to whether the intruder would pass in front of or behind ownship. Viewing time did not significantly alter the ability of the subjects to accurately perceive an encounter situation (O'Conner et al., 1980). The amount of training was found to have more affect on encounter judgement than viewing time. It was determined that the greater the time to encounter the more difficult it was for the subjects to make accurate judgements.

A 1980 study by O'Conner, Jago, Baty, and Palmer centered on the effects of display backgrounds, update type & rate of the display, and predictor and history type on perception of aircraft separation. The moving display's background image assists the pilot in judging the ground speed of ownship. The different backgrounds tested included grid, none, and a RNAV route with runway symbols. The two update methods examined were rotating ownship (north-up) or rotating the map (heading-up). Predictor and history coding showed where they would be in the near future and where the aircraft had been, 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 dots. The rate choices at which the display could be updated were 0.1, 1.0, 2.0, & 4.0 seconds.

The pilots were allowed to monitor a CDTI and select the display symbology they felt optimal for use in actual flight (O'Conner, Jago, Baty, Palmer, 1980). A series of trials were conducted with the pilots monitoring a CDTI that used the symbology they selected. Trials were also run with individual pilots monitoring a display designed by another pilot. Pilot were required to judge, after a sixteen second viewing time , whether the intruder would pass in front or in back of ownship.

Results showed that pilots tended to make fewer errors on the displays they designed. All pilots preferred displays with a continuous rotation, translation, and update of ownship. Use of the predictor aided pilots in the perception of turning encounters. Displays employing curved predictors alone had a significantly lower error rate than those using ground-referenced history alone. Pilots expressed the need for a display with all the needed information, but cautioned against clutter. A strong statistical discussion of results was not made though Jago, Baty, O'Conner, & Palmer (1981) clearly state that update interval, update type, and background did not significantly effect pilot perceptual judgment. However, Abbott and Moen (1981) suggest that the traffic update rate affects the amount of time that the pilot's visual attention is away from his primary flight instruments when the CDTI is out of the primary visual scan pattern.

The 1971 MIT study by Anderson, Curry, Weiss, Simpson, Connelly, and Imrich looked at display formats as well as possible uses of the display. The study was one of the first performed in an aircraft simulator that incorporated a dynamic display. The first task was to watch the CDTI and identify a specific relative aircraft position, altitude, and ground speed before pressing a button to signify completion and record response times. Information was obtained from datatags that were stacked on the edge of the screen (condition one) and attached to the aircraft targets (condition two). The second task was to pilot the simulator through a series of maneuvers including; arriving at an assigned spacing behind another aircraft, following another aircraft through a turn, and maintaining separation during deceleration of the lead aircraft. Topics of interest in the second task were display orientation and methods of displaying traffic.

The datatags attached to depicted aircraft targets had response times 30 to 50 percent less than that of the stacked datatags. This is due to looking back and forth from the stacked datatags to the main screen to identify the datatag that corresponds to the aircraft of interest.

The majority of the data sets showed better t-test scores for the heading-up display orientation. The continuous traffic and continuous map display showed better side task performance than the jumping map and jumping traffic display.

Hart and Loomis (1980) evaluated several different types of symbology. Symbology discused included: terrain, ownship symbols, and traffic symbols. A group of general aviation and airline pilots were shown pictures of a CDTI utilizing various combinations of symbols and were asked to respond to questions concerning the displays. The second part studied the effect of intruder approach direction (right or left) and speed (faster or slower than ownship) on response time and accuracy. Pilots were given a set viewing time to monitor the CDTI and then asked to determine if the intruder would pass in front or behind ownship.

A significant number of pilots responded that significantly high terrain features, natural and man-made, should be graphically represented at pilot request or automatically if ownship were below minimum safe altitude. General aviation pilots tended to pick the airplane shape that closest matched a general aviation plane where airline pilots tended to pick the chevron shape. Most pilots felt that aircraft speed, altitude, and map scale should be included in the display, but altitude should be limited to within +/- 2000 ft of ownship. Most pilots preferred shape coding of intruders' relative altitude that depicted above, below or at ownship's altitude.

Twice as many errors were made for curved encounters as for straight encounters and the time pilots took to respond was significantly greater (Hart, Loomis, 1980). As angular separation increased from 45 to 135 degrees, both response time and error rate increased significantly.

Vertical Symbology Presentation

To better determine the affects of display symbology on pilot performance, a modified Boeing 737 was employed to fly 28 curved, decelerating approaches into the NASA's Wallops area (Abbott, Moen, Person, Keyser, Yenni, Garren, 1980). The topics of concern were display clutter, coded symbology, workload impact, and acceptance of below minimum separation. Much of the experimental data was acquired through subjective questionnaires.

Crews indicated that display clutter was a major concern and that the problem worsened when choosing a larger range or more than a few aircraft appeared. Pilots preferred to monitor the larger range scales to give them the largest possible lead time once an intruding aircraft was discovered. Datatags contributed greatly to the clutter problem but could be switched off when not needed (Abbott et. al.,1980).

The only coded symbols that were found useful by the pilots were aircraft displayed position, it's predictor, and the altitude. Though the altitude was encoded to show a certain shape when an intruding aircraft was at ownship's altitude, "pilots always used the vertical information in the datatag to assess potential conflicts" (Abbott et. al.,1980). Since datatags were selected during potential conflicts, it seems the form of altitude coding was not effective enough. The encoding considered an intruder at 1000 ft above or below ownship to be at ownship's altitude. This shows, even though a readily understandable symbol, that the altitude encoding lacks the accuracy needed by pilot to make decisions (Abbott et. al.,1980). The comparison to uncoded symbology was neglected possibly due to the questionnaire method of data collection. It is felt that a study of a more comparative and quantitative nature would be more revealing.

Pilots found the display to be somewhat distracting, but the task of monitoring traffic was not found to adversely alter their piloting task. Pilots readily accepted the separation of two and a half miles. This being an actual flight makes the last point interesting. Pilots would probably fly closer separation as long as they had confidences in the display. More studies using actual aircraft with reduced separation would be beneficial in determining the CDTI systems accuracy in terms of separation distance.

Hart and Loomis (1979, 1980) studied pilots' ability to judge whether an aircraft would pass above or below ownship at the closest point of encounter. The purpose was to study what information would help pilots make accurate and timely predictions of the future vertical separation of an intruding aircraft.

The analysis of vertical judgements found response times to be longer and errors more frequent than for horizontal judgements. A surprising finding was that speed and accuracy performance were not significantly improved by the addition of either relative altitude information or the climb/descend arrow presented in the data tag. The length of time that it took the intruder to climb/descend to within 500 ft of ownship altitude was significantly related to response time and percent error. The later in the encounter that the intruder came within 500 ft of ownship, the longer pilots waited to respond and the less accurate they were (Hart, Loomis, 1980). When intruders "crossed ownship's altitude immediately prior to the encounter point," the error rate in judging separation was more than 50%, as compared to 7% for similar trials not involving crossovers (Hart, Loomis, 1980).

The approach angle did not have a significant effect on pilot error as it did for the horizontal judgements. This is due to the fact that approach angle does not change how pilots sees datatags, which is where the pilot obtains information describing the intruder's vertical position. It was made clear that additional research into pilot perception of vertical relationships will be required for a better understanding.

The most enlightening study concerning pilots use of vertical situation information was performed by Lester and Palmer (1983). Pilots were presented with a traffic display in an aircraft simulator. The display employed three intruder datatag formats. The normal tag 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 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. A total of 216 trials were run where subjects had to judge whether the intruder would come within 1000 feet vertically of 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 difference were found between the two. Pilots did mention that they would rather have the vertical speed information with the relative information as a selectable option.

The fore mentioned Palmer (1983) study found that with horizontal plane predictors and the predictive relative altitude in the datatag pilots avoided 90% of the positive advisory warnings as compared to 80% on the display with no predictors and on the display with predictors, but sensor noise azimuth errors included.

Conclusion

The CDTI studies reviewed concentrated on how pilots perceived and responded to the information provided. The areas of concern were: pilots' ability to maintain separation, pilots' maneuver responses, and pilots' perception of separation. The most revealing studies were those examining pilots' perception and response to information describing the vertical plane situation. The few studies including vertical rate in the encounter geometry did not draw any specific conclusions on the effect of vertical rate on pilot perception. It was noted that judging vertical separation was a more difficult task than judging horizontal separation. This is due to the inadequate vertical information provided by plan-view CDTI. Basic research will be needed to understand pilots' ability to use the available vertical information if the plan-view format remains the prime display format. A better understanding will lead to a more effective and efficient presentation of plan-view information describing the vertical plane.

Statement of the Hypothesis

The ability of automated ATC systems to safely handle projected capacities is a matter of concern and has given rise to the possible use of CDTI technology as a means to assist the automated system in maintaining safe separation. While past CDTI studies have included vertical rate as a variable, they have not drawn specific conclusions as to the effect of intruder's vertical rate on pilot perception of aircraft vertical separation. In order to better understand pilots' capabilities with CDTI, clear knowledge of how well pilots perceive and project an intruder's vertical information is needed. The purpose of the present study was to investigate the influence intruder vertical rates have on pilot perceptions of aircraft separation as displayed on a CDTI. Therefore, it was hypothesized that as the intruder's vertical rate increased, pilot error, in perception of future vertical separation, would increase.

METHOD

Subjects

Subjects consisted of 20 student and staff volunteers from Embry-Riddle Aeronautical University (ERAU) who held at least a private pilots licence and satisfied FAA currency requirements. A sample size of 40 subjects was the goal, but the number of subjects was dependent on the number of volunteer pilots that come forth in the limited time available. Subjects ages were not recorded, but ages ranged from the late teens to the late thirties. The majority of subjects were in their late teens and early twenties. The pilots possessed a mean of 181, a median of 144, and a range of 65 to 490 flight hours. Certificates held included 13 private, one commercial/instrument, one single-engine CFII, three commercial/ multi/instrument, one Multi-engine CFI, and one Multi-engine CFII. A possible sample bias is that ERAU pilots, on average, will have substantially fewer flight hours and utilize the display in a different manner than the airline transport pilots (ATP) that use CDTI. This difference in usage is discused further in the development of the display.

Instrument

A Macintosh IIx® personal computer and SuperCard® software were employed for this study. Actual fabrication of the CDTI display and images were accomplished via Canvas® graphics software and transferred to SuperCard. SuperCard was implemented to construct and simulate a dynamic CDTI and send the experimental data to individual text files. The spreadsheet software Excel® was employed to collect the text files into one large text file where the data was organized so the Statview® statistical software could readily import the experimental data for analysis. Pilots entered information minimally via keyboard (identity), but primarily by mouse (decisions). Development of the simulation program initiated with drawing the necessary graphics needed. Script (programing language) controlling the simulation was written and an Excel spreadsheet was constructed to determine the initial values needed to drive the variables in the script. A pilot study involving three peers was conducted to evaluate and improve the training procedures and experiment simulation.

Display Development

The strategy ATP pilots employ when using CDTI varies from that of general aviation (GA) pilots due to the great differences in closing speeds and altitudes flown. When flying in and around terminal control areas (TCA), speeds and altitudes flown by transport and GA aircraft more closely match and pilots are more likely to use the display in the same manner when determining vertical separations. The display is of more service to a pilot in a TCA due to the larger volume of aircraft present. The altitude and velocity (5000 ft, 240 kts) ownship flew at were chosen to reflect typical TCA ground speeds and altitudes to minimize the difference between GA and ATP pilot use of the display.

The three displays originally constructed by the researcher were the 7, 12, and 17 nautical mile ranges. The later two, while complete, were not used due to the excessive length of time required to include them in the experiment. After the experiment had already begun it was found that a consensus on display range was achieved amongst a group of airlines and display manufactures (Chappell, 1988). They felt that "5, 10, and 20 mile ranges should be used" and that "ranges should be consistent from one installation to another" (Chappell, 1988). The original, basic displays generated by Chng (1991) had to be modified due to improper scaling of the aircraft and range rings with respect to the display range. The CDTI display size was a function of the Macintosh IIx screen size., so the final display size employed in the experiment was 5 3/8 x 6 inches. This display size is approximate to the size used in earlier research (Abbott, Moen, Person, Keyser, Yenni, Garren, 1980).

The pixels that identify the corners of each display range and other important display locations can be seen in Appendix E. The pixel location information was critical while building the display due to the need for proper scaling and the fact that the software employs pixel data to determine intruder distances. Should the screens be used or modified in the future, care must be taken to re-check the pixel locations and make sure any changes are reflected in the software. The pixel locations needed to display the intruder at a desired approach angle are given in Appendix E.

The range ring was set at three nautical miles from ownship to keep with its use in previous experiments (Chng, 1991; Palmer, 1983). The Chappell (1988) consensus stated that the range ring size should be standardized, that additional rings on larger displays would be useful, and suggested the three nautical mile ring as a standard. The intruder's datatag included identification, ground speed, and altitude relative to ownship. The final display generated for the experiment is presented in Figure 1. The display built to present vertical miss distance options to the pilot is shown in Figure 2. The choices were arranged in a manner to clearly separate the above and below choices.

Mathematical Description of Intruder's Motion Relative to Ownship

All the scenarios involved ownship and one intruding aircraft. What is depicted to the pilot by CDTI is the intruder's relative velocity with respect to ownship. The pilot sees the two aircraft closing directly on each other, even though the aircraft are not necessarily flying directly at each other. Since

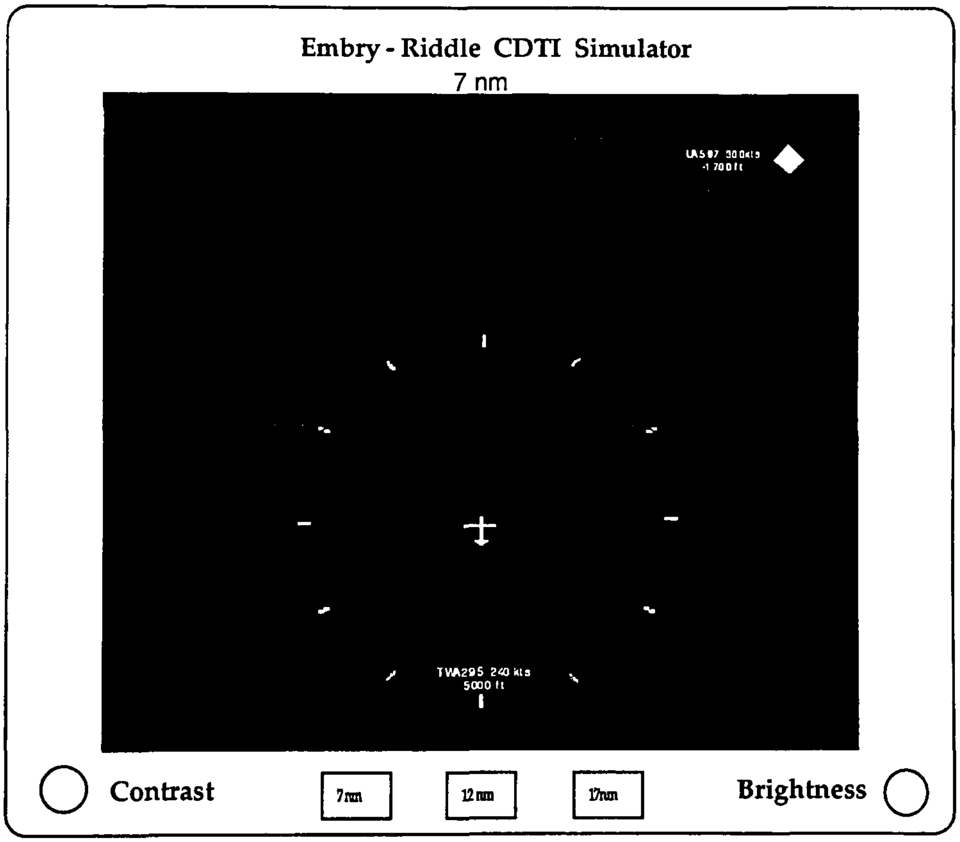

Figure 1. 7 nm range display employed in the experiment.

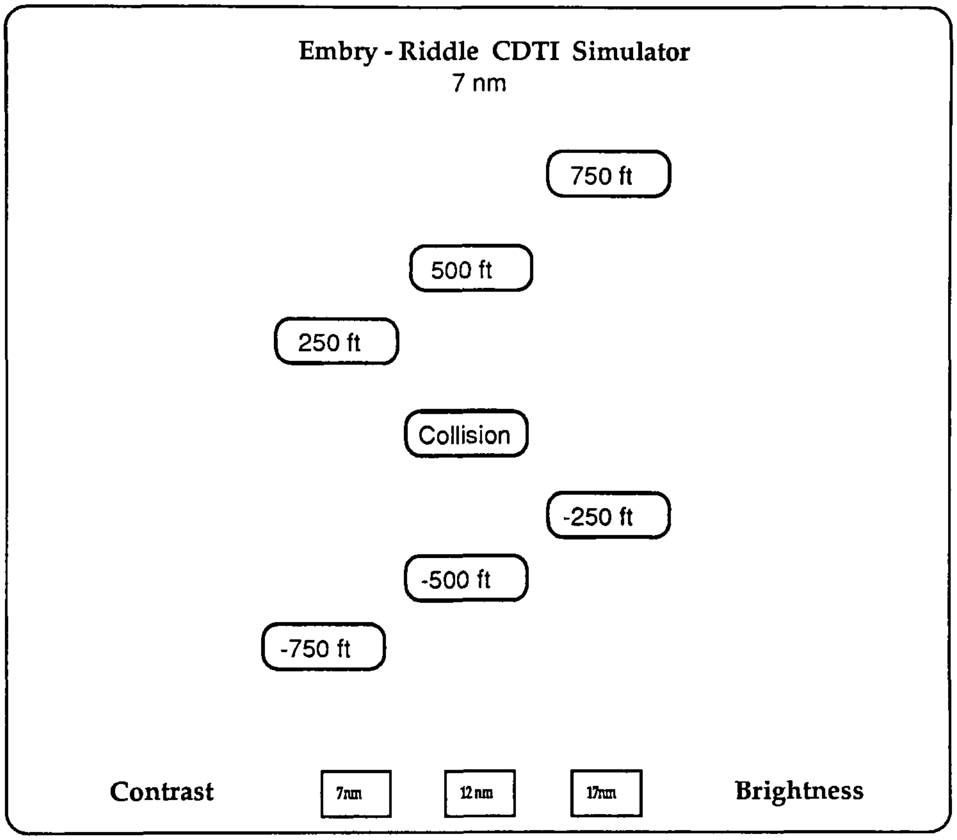

Figure 2. Display of vertical separation choices.

ownship remains stationary on the display, the only motion that must be described by the software is the intruder's motion relative to ownship. Assuming ownship always flies straight, level, and at a constant ground speed and the intruder only flies straight and at constant ground speed, we have the following:

b = Intruding aircraft

a = Ownship

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

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

From the relative velocity relationship;

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

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

So;

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

Therefore,

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

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

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

As can be seen above, the only component of the intruder's relative velocity that is affected by ownship's velocity is the y-component. The intruder's other two relative velocity components, x and z, are equal to the intruder's normal x and z velocity components. A description of the intruder's velocity in vector form is presented in Figure 3.

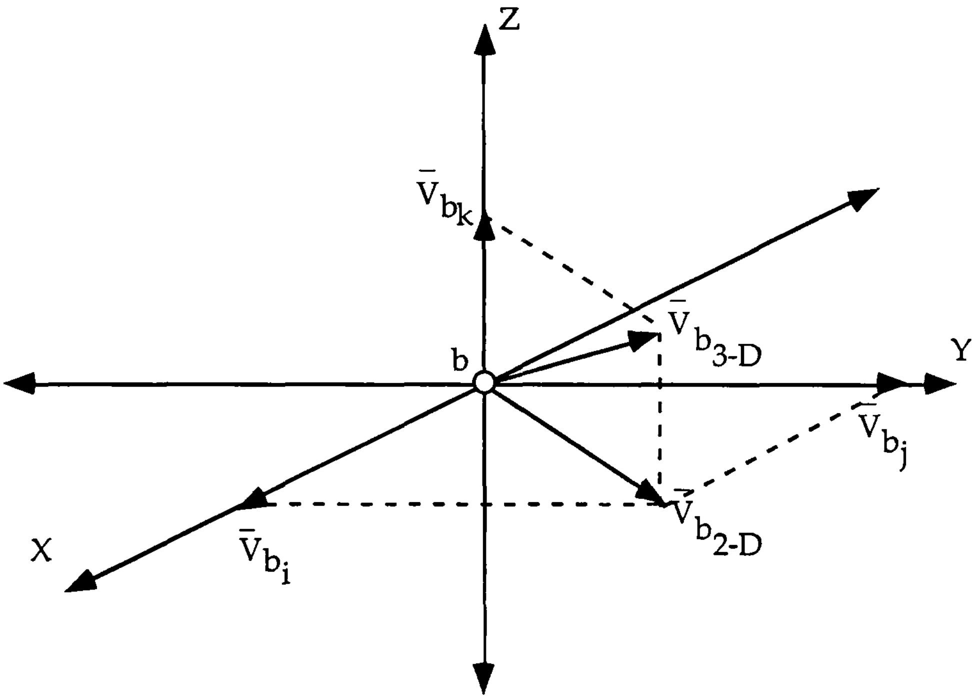

Figure 3. 3-D description of intruder's velocity.

The x-component of the intruder's relative velocity will switch back and forth from positive to negative to generate approaches from both the left or right of ownship, respectively. The intruder's x-y plane velocity, relative to ownship, and ownship's velocity are depicted in vector form in Figure 4. The y-component of the intruder's relative velocity can be positive or negative to reflect flying toward or away from ownship. If the intruders' y-component is positive, ownship's y-component must be large enough to overtake the intruder. Ownship's y-component will always remain positive and never possesses an x-component of velocity. An Excel spreadsheet, titled "RVcalc," was generated to determine all the necessary velocities needed to describe

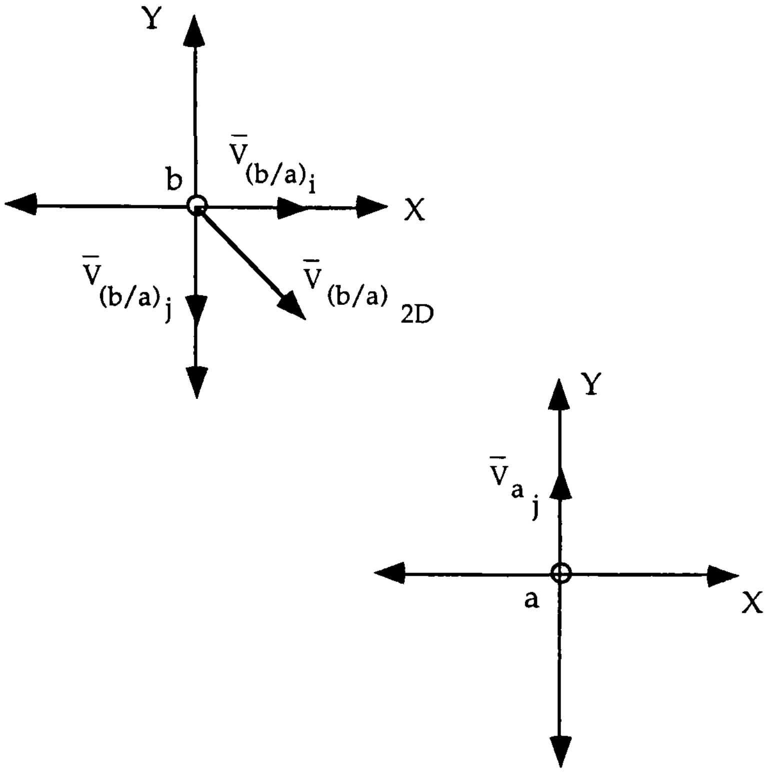

Figure 4. 2-D description of Intruder's relative velocity w.r.t. ownship (left approach).

each scenario. The process used in RVcalc to determine the necessary velocities is as follows:

1) Pick $V_{(b/a)_{3D}}$ (three dimensional closure rate)
2) Use vertical rate (knots) and $\overline{V}_{(b/a)_{3D}}$ to calculate $\overline{V}_{(b/a)_{2D}}$
3) Calculate $\overline{V}_{(b/a)_j}$ & $\overline{V}_{(b/a)_i}$ from $\overline{V}_{(b/a)_{2D}}$ & Approach angle
4) Pick $\overline{V}_{a_j}$ (ownship velocity)

If $\overline{V}_{a_j} > \overline{V}_{(b/a)_j}$; then intruder is flying in a direction away from ownship. This does not appear so on the display.

5) Calculate $\overline{V}_{b_j}$ from $\overline{V}_{(b/a)_j}$ & $\overline{V}_{a_j}$
6) Calculate $\overline{V}_{b_{2D}}$ from $\overline{V}_{b_j}$ & $\overline{V}_{b_i}$
7) Calculate $\overline{V}_{b_{3D}}$ from $\overline{V}_{b_{2D}}$ & $\overline{V}_{b_k}$

The results of the above calculations for all combinations of the variable levels are presented in "RVcalc" in Appendix D. The resulting velocities, expressed in knots, were converted to pixels/sec for the three original display ranges, though only the results for the seven nautical mile range were employed, and are displayed in Appendix D. The spreadsheet "RVcalc" relies on the researcher to choose the three dimensional closing velocity (velocity w.r.t. ownship) of the intruder and ownship's two dimensional airspeed. Once this has been chosen, the two velocities can be copied, so as the fill their respective columns, and the spreadsheet automatically determines all the data needed to load the variables of each scenario. Spreadsheet calculations are based on the variables placed in the first three columns and the two fore mentioned aircraft velocities. The velocities placed in the last columns of the spreadsheet are pastes of the first three columns to ease the variable loading workload. If variables are altered in the future, care must be taken that the units match and that the new set of variables are pasted on top of the old ones in the last columns. The later paste is only important if you copy the variable data from the Excel spreadsheet to a SuperCard text field to reduce data entry workload.

Development of the Simulation Software

The SuperCard project "NEWCDTI" was modified from the original experiment to reduce the number of display ranges from three to one in order to reduce the time needed to complete the experiment. The "NEWCDTI" project is separated into two windows titled "7nm" and " Training." The "7nm" window contains 84 experiment cards and "training " contains 12 training cards and a card with a text field for variable loading. The card graphics, stored in "Overlay," were built in Canvas and copied into the background of the "7nm" window. Once the script was written, the card was copied 84 times. The scenario (card) data was loaded from the "RVcalc" spreadsheet into the SuperCard text field mentioned above. The text field could be scrolled through to find the variable data for individual scenarios. A table of random numbers was employed to randomize the 84 scenarios. Each individual scenario on the randomized list, starting from the top, had variables loaded by scrolling the text field to the specific scenario (card) and typing the values shown into the scenario (card) script. Once the variables of each scenario were loaded, the values were rechecked to uncover any errors in data entry. The "NEWCDTI" project, which can be modified by SuperEdit®, was transformed into an application titled "ERAUSTAND" to reduce the possibility that the subjects could accidentally stop or harm the software. The application writes to the hard drive, folders, and file "SHD650:Bryan: PilotData:SSN," respectively. The project "NEWSTAND" can be modified by SuperEdit® and differs from "NEWCDTI" in that it writes to a disk, folder, and file titled "TRAVEL:DATA: SSN," respectively. The software is portable to other MACIIx's as long as a disk with the properly named volume and folder is used. The scripting, amply described in flowchart form and full script code, is presented in Appendix A.

The projects "OLDCDTI" and "OLDSTAND" were the original experiments and write to the same locations as the new counterparts, but include all three display ranges. These projects are split into three windows titled "7nm, 12nm, and 17nm." Each window contains one experiment card, which can be modified to meet experiment needs and then replicated.

The software was checked for proper functionality by running numerous scenarios with different variable values. Monitoring the intruder's motion and datatag information ensured that the expected scenario information was displayed to the pilot. One of the pilot study pilots was an ATP and was familiar with the traffic display employed by TCAS. He found the presentation of the display information to be a fair replica of those he has used.

Design

The research design employed was a 3 x 4 x 7 factorial design. The independent variables in this experiment were angle of approach, intruder vertical rate, and vertical miss distance. The vertical rates remained constant during each scenarios, but were varied between scenarios. The different levels of vertical rate employed were 1000, 1500, 2000, and 2500 feet per minute. The seven levels of vertical miss distance employed were -750, -500, -250, 0, 250, 500, and 750 feet. The approach angles employed were 0, 25, and 50 degrees from ownship heading. Climbing and descending flight paths appear the same on the display and were considered symmetrical, so climbs and descents were evenly distributed across scenarios. Approaching from the left or right was considered symmetrical, so the three levels of the variable were distributed evenly, across the right and left portions of the screen, throughout the scenarios. The seven levels of the vertical miss distance variable were evenly distributed throughout the scenarios. The vertical miss distances could not be considered symmetrical about ownship. This is due to some scenarios being crossovers and others not. A crossover (see Figure 10) is when the intruder flew through ownship's exact altitude before passing ownship and has been found to affect pilots' perception of the display in past studies (Hart, Loomis, 1980).

The dependent variable was the pilot's ability to project the vertical separation the intruder would have as it passed ownship by employing the information available in the datatag. The pilot's ability to perceive the display information and project an outcome was reflected by the number of correct vertical separations chosen. A correct choice was defined as picking the exact vertical separation that was defined for the scenario.

The scenarios variables were setup to keep the intruder exclusively within a 2-D vertical plane. The different approach angles were included to keep the pilot's task from becoming to routine. The intruding aircraft does not deviate from its starting flight path and always appears to fly directly at ownship.

Procedure

Subjects were tested on the Macintosh II personal computer located in the Human Factors Lab at ERAU's Center for Aviation/Aerospace Research. The software employed was a program called "ERAUstand" that was coded by the researcher in SuperCard script (see Appendix A). Upon arriving, each pilot read and signed an informed consent form (an example is presented in Appendix B). Each pilot was given a verbal training session where they read, and were read to, a written explanation of the task they would perform and what they needed to know to perform the task. The instructions used are presented in Appendix B and the pictures shown pilots during the verbal instruction are seen in Figures 2 & 3. This study was concerned with

The verbal instruction was followed by twelve different training scenarios on the simulator in order to familiarize the pilot with performance of the simulator task. The researcher was in the same room as the subject during the experiment, but in some sessions the researcher was not visible to the subject. Due to the limited space resources the experiments were conducted in three locations, always in a darkened room, and approximately the same monitor lighting settings.

Once the training scenarios were completed, the subject monitored 84 single intruder scenarios. The CDTI displayed a general aviation shaped ownship two-thirds from the display top, centered, and with a data tag. The datatag for ownship was added due to the lack of instruments for the pilot to monitor. The intruder was depicted by an diamond shape. The intruder data tag included altitude relative to ownship, ground speed, and identification. Each CDTI scenario displayed only one intruder, flying a linear course, and ownship. Throughout the scenarios the intruding aircraft appeared to come from different directions in front of ownship, were ascending or descending at a constant rate and had a predetermined passing geometry. The passing distances were (+/-) 750, 500, 250, and 0 feet vertically. The four vertical rates, ascending and descending, were : 1000, 1500, 2000, and 2500 feet per minute. The display range employed in the study was the seven nautical mile range. The passing geometries and vertical rate for each intruder were counterbalanced to cover all possible combinations of the variables. The pilot was given the intruder's altitude data, relative to ownship, by means of a numerical data tag. A negative sign (-) was placed on the datatag's relative altitude information to indicate the intruder was below ownship. The absence of the negative sign indicated the intruder was above ownship.

Upon determining how the intruding aircraft would pass ownship, the pilot immediately clicked the mouse button to halt the scenario and display seven vertical miss options of which one was chosen. Once the pilot selected an option, the computer passed the scenario and decision data to a text file for storage. The seven vertical miss options the pilot chose from were discused earlier. Selection of a vertical miss option resulted in blanking of the display followed by display of a new scenario. The new intruder would appear one second after the appearance of the new scenario. Subjects were given a break after every 27 scenarios which came to a total of two breaks. Pilots could take the break if they chose to or could continue if the so desired.

Upon completing the experiment, pilots were asked what strategy or method they used to make their separation determinations. Due to the researcher determining late to collect pilot responses, only half of the subjects were questioned about their method. Finally, pilots were shown a comparison between their responses and the correct responses and any further questions answered.

ANALYSIS

Data Analysis Procedures

The data from each pilot was compiled into one Excel text file, so scenario identifying information could be appended. During the compilation of the data into the Excel spreadsheet file, a trend in the raw data was noticed that was not apparent in the original text files. The trend was examined further and it was realized that somehow the researcher's method of loading the scenario variables was faulty and the randomized scenarios were systematically reordered. This meant that the subjects were presented the variables in a non-random, highly organized fashion. The progression of variables can be seen in "RVcalc" (as shown in Appendix D). The same loading scheme was employed to check the accuracy of the variables loaded, which means the check itself would not have uncovered the flaw. The trend was not noticed in the original pilot study data due to the unstructured format of the text file. By loading the raw data from the text file to the structured columns of an Excel spreadsheet file, the trend is easily noticed. The decision was made to continue with the analysis, but not before understanding the effect the structured variable presentation had on pilots' decisions. The only unusual verbal feedback came from a couple of pilots who mentioned that scenarios displaying a even jump in altitude during updating were the easiest miss distances to determine. This did not and still does not suggest to the researcher that pilots had realized the actual progression of variable levels. Pilots' comments are covered more in a later section.

Analysis of Variables by Order of Presentation

An analysis of pilots' mean decisions as they progressed through the experiment should show possible trends that arose from a non-random presentation of variables. Training affects should decrease pilots' mean error and boredom/fatigue affects should decrease pilots' mean decision time as the scenarios progress. The pilots' mean error in determining vertical separation, mean time to make a decision, mean distance away from ownship at decision, and mean altitude away at decision were calculated for each of the 84 scenarios. Graphs were generated with means as the dependent variable and the order of scenario presentation as the independent variable.

The graph of mean error verses scenario number is shown in Figure 5. The standard deviation appears to stay within a small range and only seems to increase noticeably with increasing vertical miss distance. The mean error in estimating the vertical miss distance increased from 100 ft to

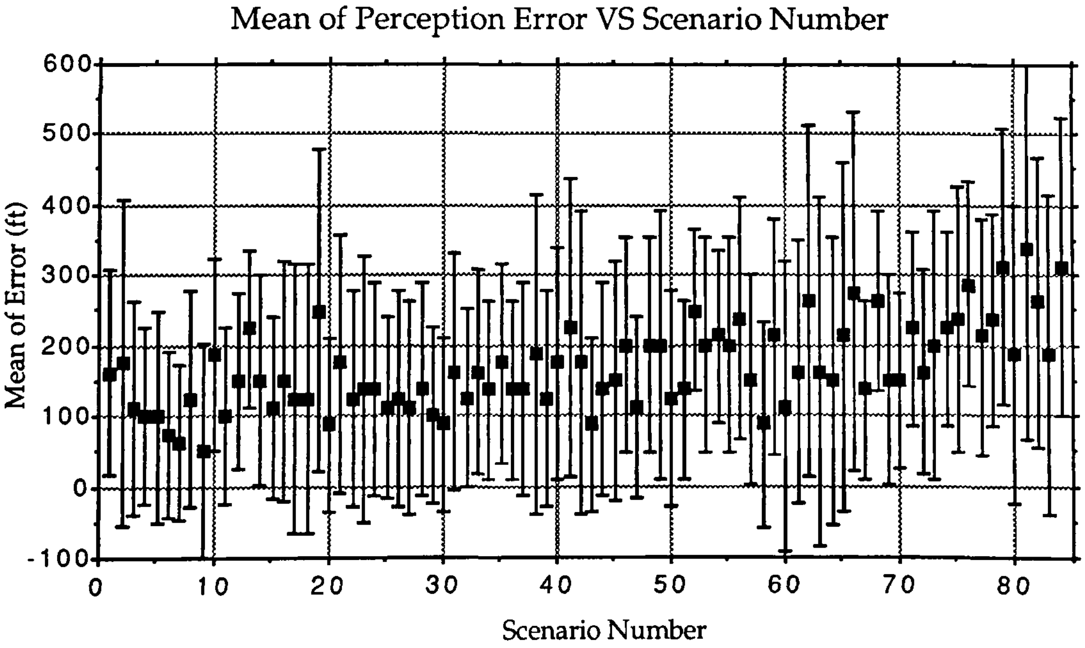

Figure 5. Pilots' mean perception error vs order of scenario presentation.

approximately 225 ft. This 125 ft increase in error could occur for two reasons. The increasing vertical rate made it more difficult to perceive and project the intruder's vertical separation at passing, or the pilots became bored or fatigued during the two hour long experiment. Two breaks were evenly spaced during the experiment to reduce the effects of boredom and fatigue. The effect of training or "figuring out the experiment" should produce less error in the later scenarios, which does not develop. This means either the effects of training are minimal, or training assisted in *reducing the error* to the level found.

The graph of mean decision time verses scenario number shows the mean time decreasing five seconds as scenarios proceed (see Figure 6). The decrease amounts to reaching a decision one intruder update earlier than the number of updates watched at the experiment start. It would seem that if

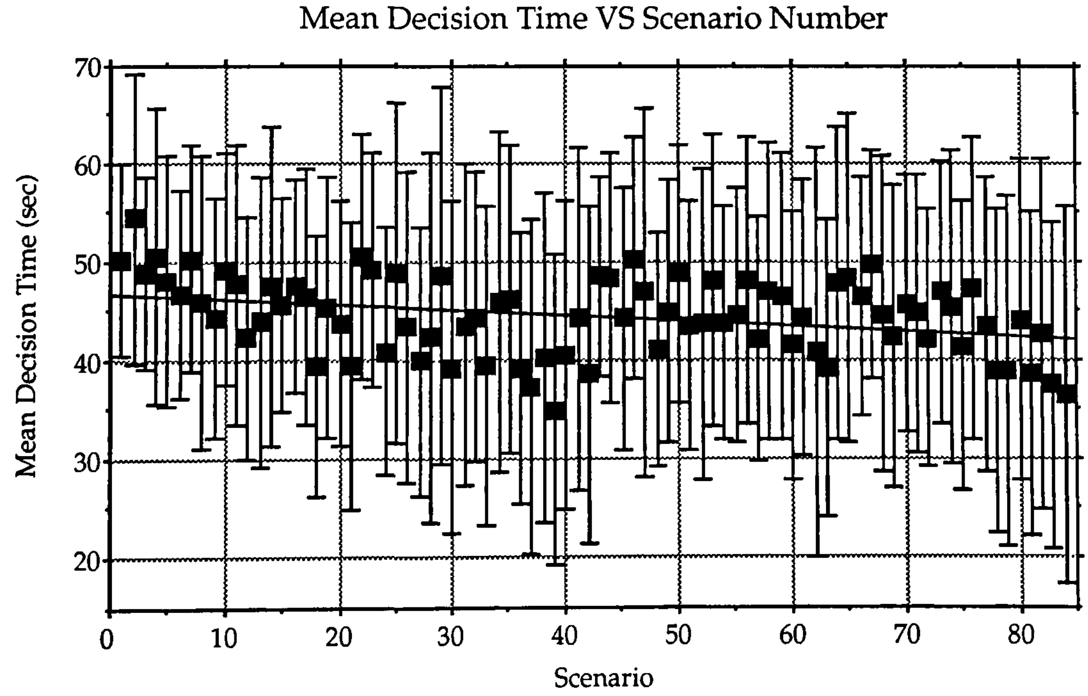

Figure 6 Mean decision time vs order of scenario presentation

subjects were affected by fatigue or boredom that their mean decision time would have decreased much more than five seconds out of a mean of approximately 45 seconds. It is possible that the 125 ft increase in the mean error was the result of not waiting the additional five second, which would allow another datatag update to occur. The standard deviation appears to increase noticeably with increasing vertical miss distance (repeating every 27 scenarios) and slightly with increasing vertical rate (increasing every 27 scenarios). The progression of variables with the scenarios can be seen in Appendix D. These results make it difficult to dismiss boredom/fatigue as a possible cause of the increase in error.

As expected, the mean distance away from ownship at decision increases slightly from 3.1 nm to 3.5 nm (see Figure 7). This is approximately the distance covered by the intruder in one update. This follows the mean decision time results.

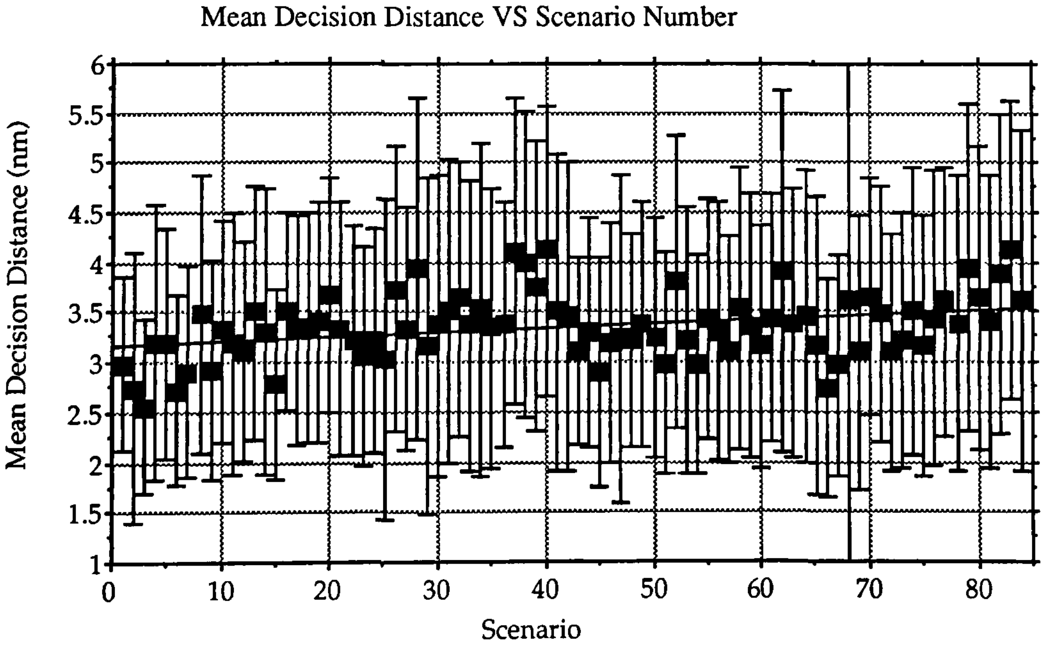

Figure 7. Mean distance away from ownship at decision vs order of scenario presentation

The most interesting findings were found on the mean altitude away from ownship verses scenario graph (see Figure 8). The mean altitude increased as the scenarios and vertical rate advanced and increased, respectively. The mean altitude increase is expected since the mean decision distance increased with the scenario sequence. The collision scenarios followed the mean decision altitude line through the progression of the scenarios. The decision altitudes for the crossover scenarios were consistently below the mean line and decreased, within a vertical rate level, and with increasing vertical separation (miss distance). Decision altitudes for the non-crossover scenarios were consistently above the mean line and increased, within a vertical rate level, with increasing vertical miss distance. These results seemed quite odd, until the general decision method used by most pilots was considered in combination with viewing scenario flight paths from the vertical plane (see Figure 9). Pilots' used the three nautical mile range

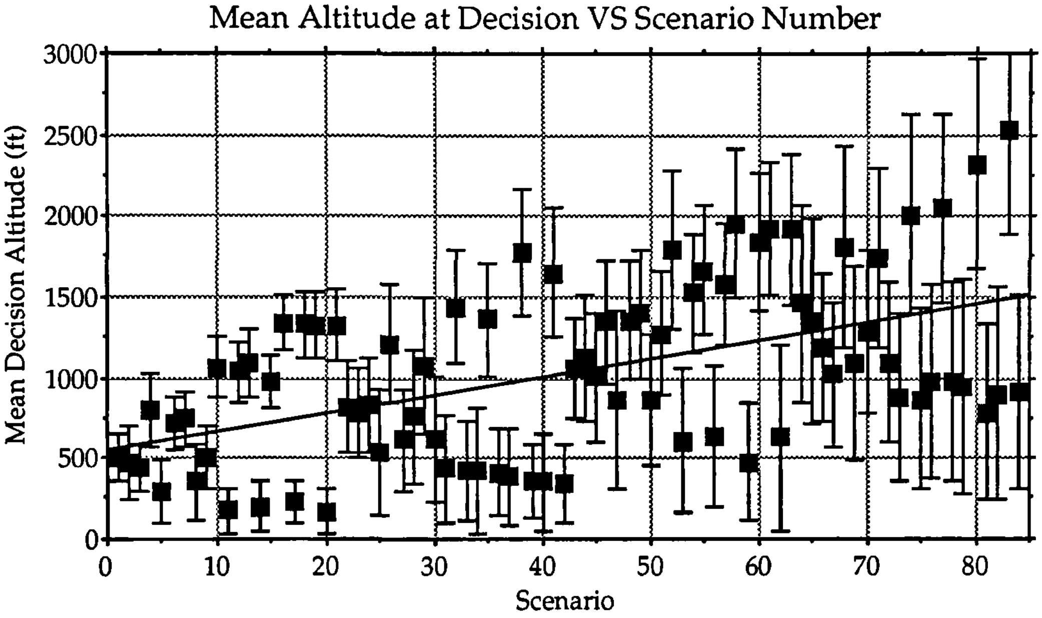

Figure 8. Mean altitude away from ownship at decision vs order of scenario presentation.

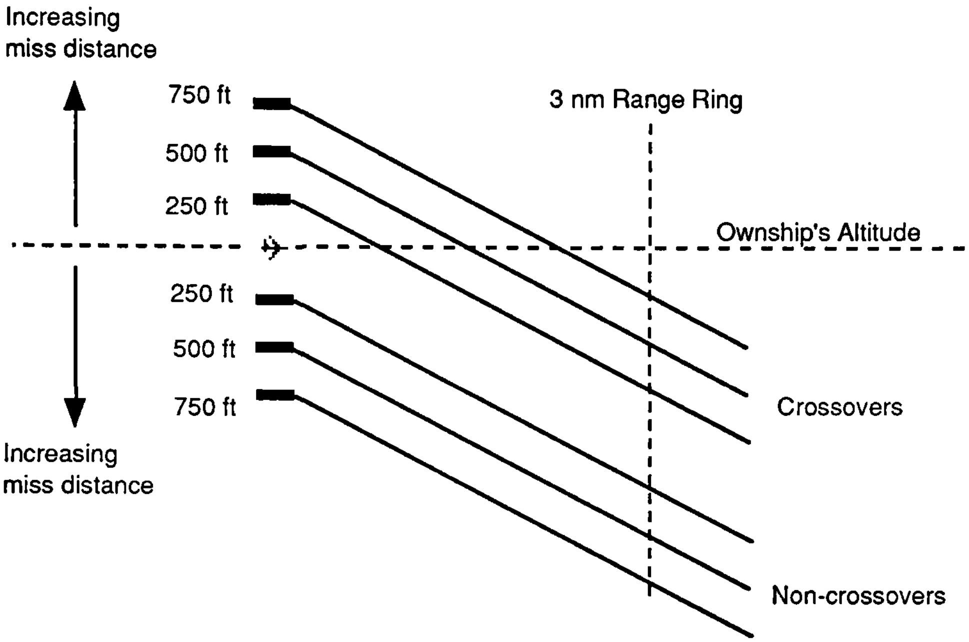

Figure 9. Crossover and Non-crossovers as viewed in the vertical plane

ring as a key element in making their miss distance choice. As a result, most decisions were made *around the range ring.* The method pilots used in making their miss distance determinations is discused later. Figure 9 shows intruder altitudes in terms of *magnitude* away from ownship. A graph that considers the mean decision altitudes in terms of vertical rate and miss distance, but does not differentiate between crossovers and noncrossovers, is discused later in the main analyses.

Having analyzed the effects of the structured variable presentation, it is felt that even if training was present that it would only increase the error rates present if accounted for. Boredom and/or fatigue may have effected the results by slightly decreasing the time pilots used to monitor the scenario and make their decision. Taking less time to make a determination could have caused the increase in error. This leaves open the question whether the vertical rate or boredom/fatigue caused the pilots' error in determining vertical miss distance to increase by 125 ft. It is felt that a five second decrease in monitoring time could not have generated all the error present if training effects are assumed to have decreased the error. It is felt that a combination of the intruder's vertical rate and separation caused a change in the pilot error rate. Whether the change was a statistically significant one is debatable.

Means Analysis

There simply is no way to be sure whether boredom/fatigue or vertical rate was the sole cause of the error increase. Had the scenarios been successfully randomized for each pilot, the above question would not be a factor. Since there is no way to "separate out" the possible affects of boredom and/or fatigue, an analysis will be carried out assuming the affects to be minimal. Any results derived from the analysis must take into consideration the possibility that significant fatigue and/or boredom affects do exist.

The means of the different experimental measures were grouped together on graphs, so that trends could be noticed and the results of the ANOVA and T-tests could be readily observed. The measures included pilots' time to make a decision, pilots' distance from the intruder at decision, pilots' altitude relative to the intruder at decision, and pilots' vertical miss distance decision. The graphs display experimental measures as the dependent variable and vertical rate as the independent variable. The measures were grouped by vertical miss distance, which generated seven different curves per graph.

Pilots' mean decision time is depicted in Figure 10. The mean decision time shows a decreasing trend as vertical rate increases. Some vertical miss distances (VMD) show larger changes, but the majority of the VMDs fluctuate only five seconds. A trend of decreasing decision time with increasing VMD can be seen. The wild fluctuation at 750 ft VMD, 1500 ft/min. is not readily explicable.

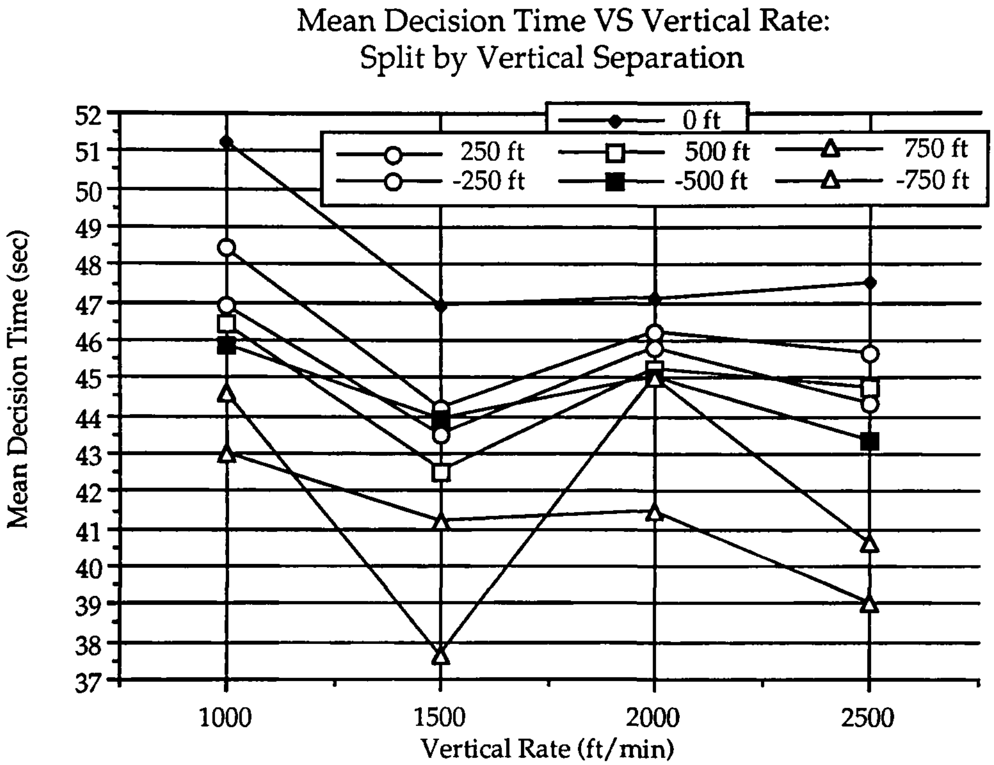

Figure 10. Mean decision time by vertical rate and vertical miss distance.

The graph of mean distance at decision time inverts the results of the mean decision time graph (see Figure 11). The trend depicts intruders flying closer to ownship as the VMD decreases. Possibly, when pilots determined the separation was close, they waited slightly longer, though instructed not to do so, to make a closer determination.

The mean altitude relative to the intruder at decision time (Figure 12) shows some of the interesting points made early. Due to the alternating signs on the vertical rate variable, coupled with the way the vertical miss

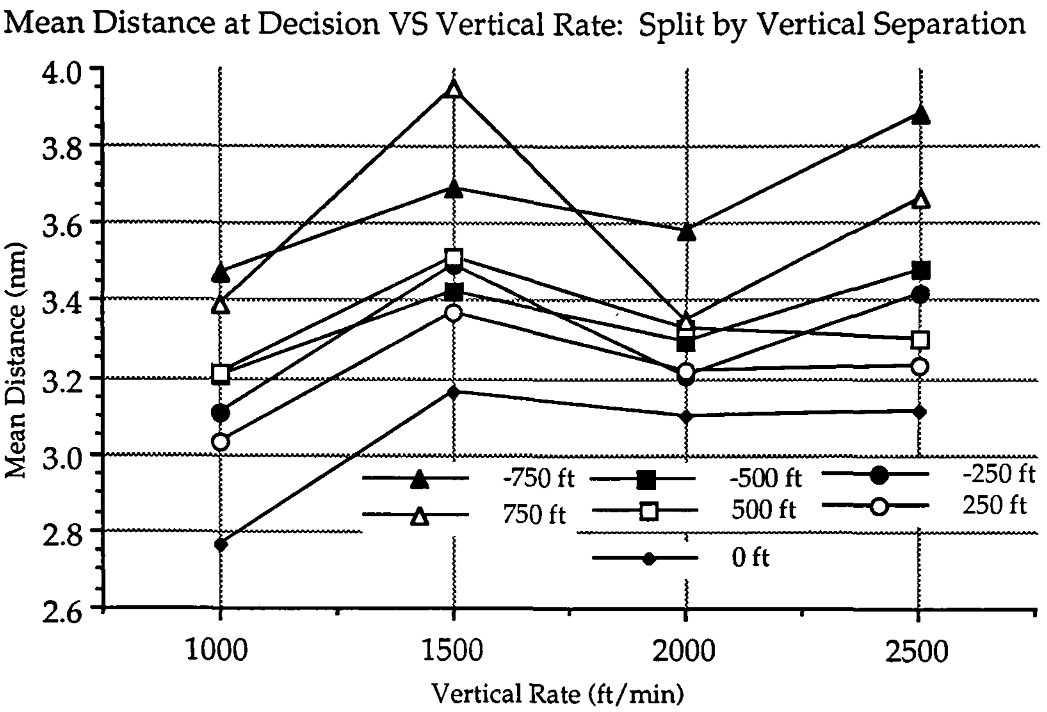

Figure 11. Mean intruder distance from ownship at decision time shown by vertical rate and separation

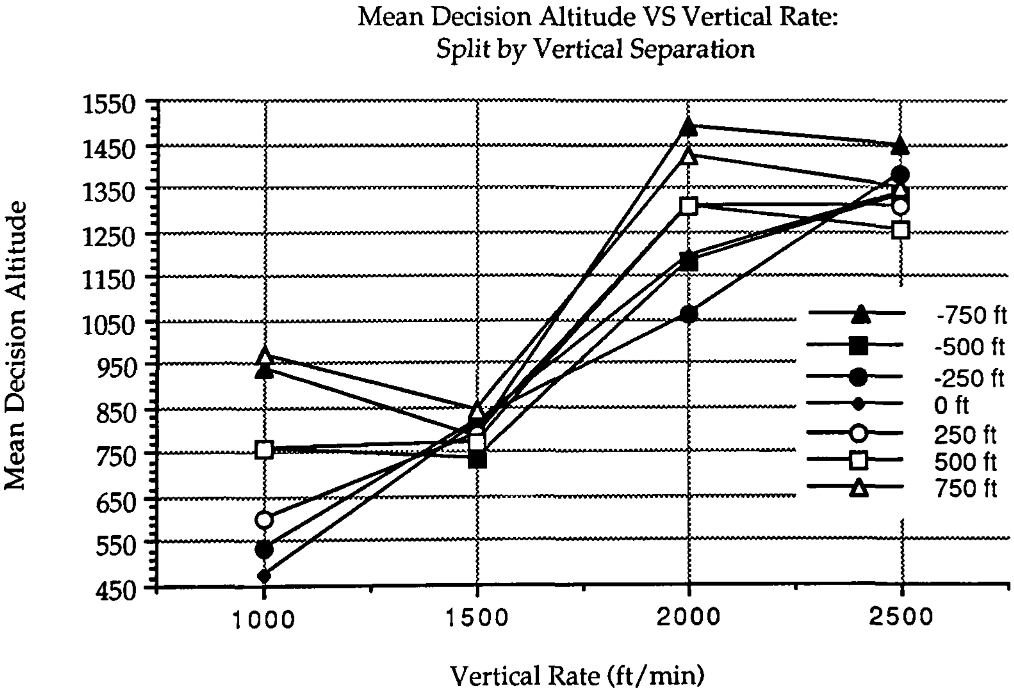

Figure 12. Mean relative altitude of intruder at decision time shown by vertical rate and separation.

distances were distributed, there were many more crossovers in the 1500 ft/min and 2500 ft/min scenarios. As was seen in Figure 9, crossover scenarios will be closer to ownship's altitude at decision time than non-crossovers when pilots make their determinations around the three mile range ring.. The 1500 ft/min. and 2500 ft/min. scenarios reflect the trend expected from the crossover dominated scenarios, where the increase in mean decision altitude, with increasing vertical rate, is kept to a minimum by the dominance of smaller crossover decision altitudes. As the vertical miss distance decreases, the difference between crossover and noncrossover decision altitudes, for *one miss distance magnitude,* become smaller until no difference and no crossovers exist. As vertical miss distance decreases to zero, the previous trend disappears as expected, since no crossovers occur at 0 ft VMD. When decisions are based upon the intruder reaching a specific distance from ownship, the intruder's altitude at decision time will increase in a direction away from ownship with increasing vertical rate and miss distance. This trend is present in Figure 12. If crossover scenarios cross before the specific distance, the intruder's altitude at decision time will decrease with increasing vertical rate. The majority of crossovers in this experiment were before the three mile range ring which caused the mean decision altitudes of the large vertical miss distances to actually decrease when crossover scenarios dominated. Again, the trends present are the result of the pilots' method of determining vertical separation.The graph does not separate the crossover and noncrossover scenarios as their effect was shown earlier in Figure 9.

Occasionally, pilots forgot whether the intruder would pass above or below ownship because they were concentrating on determining a separation magnitude. This means pilots could make unusually large errors by guessing the wrong direction of separation. The fact that pilots forgot the direction draws attention to the method they employed to reach their decision. This will be discused further in the frequency analysis section. To negate the direction errors made by pilots, the absolute value was taken of the pilots' separation decisions and of the actual separations employed in the scenario. The two values were then subtracted and the absolute value taken again to obtain a *pure magnitude expression.* That expression was termed the absolute error.

An analysis of variance (ANOVA) was conducted on the absolute error. Vertical rate was found to significantly effect the absolute error made by pilots when determining vertical miss distance ($p = .0001$, $F = 25.3$). Vertical miss distance was found to significantly effect the absolute error made by pilots when determining vertical miss distance ($p = .0001$, $F = 6.1$). Approach angle was not found to significantly effect the error made by pilots. This differs from the result found for the horizontal plane where approach angle significantly effected pilot ability to judge whether an aircraft would pass in front or behind them (Hart, Loomis, 1980). The approach angle result replicates the vertical plane approach angle findings of Hart and Loomis (1980). The result stems from the fact that the approach angle does not vary the presentation of datatag information, which pilots rely heavily on when making judgements on intruder's vertical situation.

Comparing absolute error means by performing T-tests found significance at 95% for all but the 1000 vs 1500 ft/min and 1500 vs 2000 ft/min comparisons. T-test results for vertical miss distance established significance at $P=.05$ in eight out of the twenty-three comparisons. T-tests showing significance are shown in Table 1 and the complete set of T-tests and ANOVAS are given in Appendix C.

Table 1:

Results of Vertical Rate and Miss Distance T-tests.

Vertical Miss Distance (ft) (d*f*=6)

Comparison	Paired t Value
-750 VS -250	4.42
-750 VS 0	2.68
-750 VS 250	3.87
-500 VS -250	4.74
-500 VS 250	3.89
-250 VS 500	4.5
-250 VS 750	2.85
2500 VS 500	3.78

Vertical Rate (ft/min.) (d*f*=3)

Comparison	Paired t Value
1000 VS 2500	7.83
1000 VS 2000	3.56
1500 VS 2500	7.72
2000 VS 2500	4.24

The different absolute error means are more readily seen in Figure 13 where mean error is split by vertical rate and separation. Error for the +/-250 ft. VMD's show a well behaved increase in error as vertical rate increases. The +/-500 ft. VMD's follow the increasing trend, but do not follow one another as closely as the +/-250 ft. VMD's. The +/-750 ft. VMD's follow one another to some extent, but do not totally support the trend of more error with increasing VMD as the +/-250 ft. and +/-500 ft. VMD's do. The 750 ft. VMD's

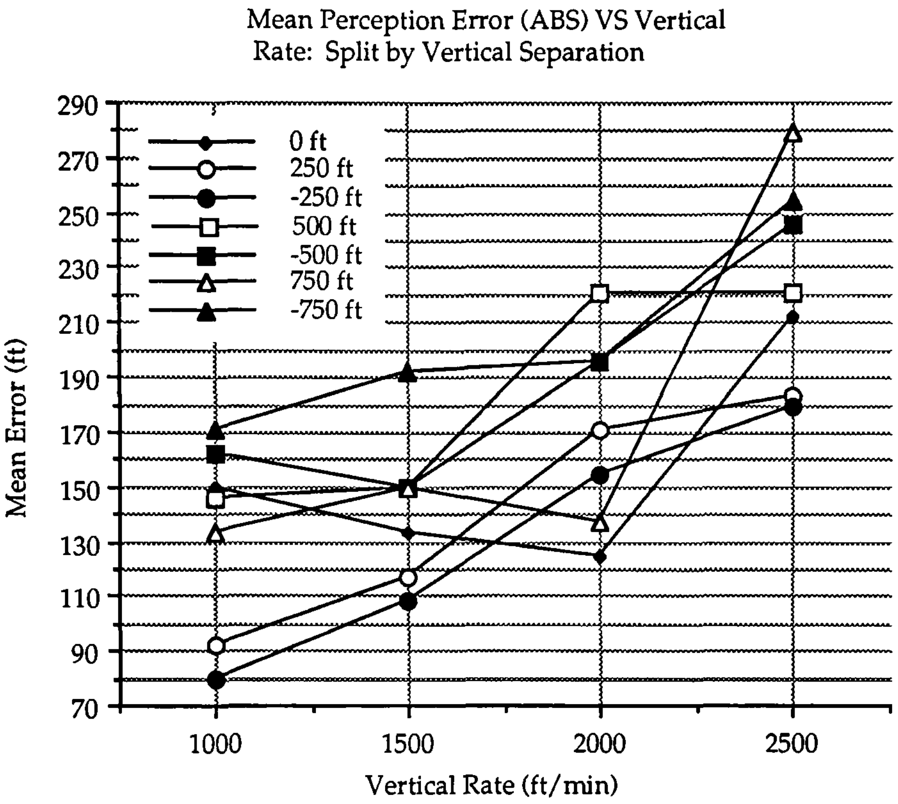

Figure 13. Mean error split by vertical rate and miss distance.

seem to follow the same trend as the collision VMD, whereas the +750 ft VMD follows the overall trend. Overall, the lower VMD's follow the expected trend of more error with increasing VMD. The collision, which was expected to produce the least mean error, follows the trend at 2000 ft/min., but shows somewhat more error than the +/- 250 ft VMD's at 1500 and 2500 ft/min.. The mean error found at 0 VMD and 1000 ft/min. is erroneous due to a faulty variable value in one of those particular scenarios. The odd behavior of the +/-750 ft VMD's could possibly result from the experiment structure. The +/-750 ft VMD's are outside separation choices in the experiment and as a result, may show less error simply because there are no other miss distances to choose from once the intruder's separation appears to be large enough. A far superior decision button setup was realized just before the experiment took place (courtesy of Dr. Wise), but it presented a difficult software massage that could not be completed within the time allotted. The new setup is discused in the recommendations section.

Frequencies Analysis

Frequency distributions were constructed for absolute error and decision time to delve further into pilots' decision trends and support previous findings. Both dependent variables are split by vertical rate and then by vertical miss distance.

Figure 14 shows the number of correct responses (zero error) to fall noticeably with increasing vertical rate. Each magnitude of absolute error (250, 500, 750 ft) shows the trend of increasing absolute error with increasing vertical rate. While correct responses drop off rapidly with increasing vertical

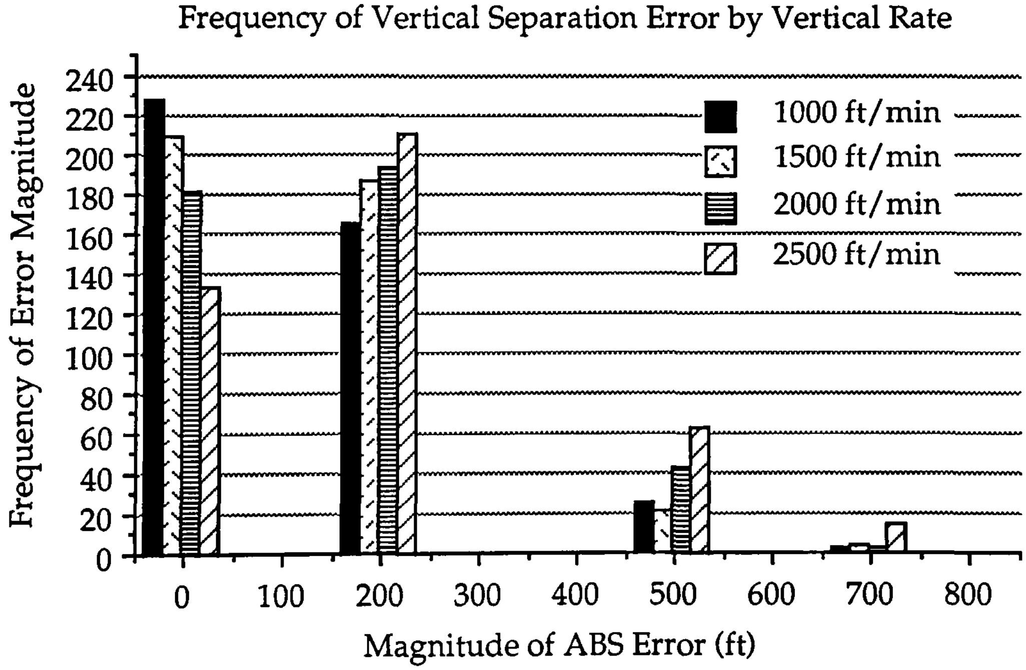

Figure 14. Frequency of pilots' absolute error in terms of magnitude.

rate, the increase in absolute error for the 250 ft and 500 ft magnitudes is a constant 20 ft of error. The 750 ft absolute error magnitude did not occur often enough to show any noticeable trends.

The actual error magnitudes are depicted in Figure 15 to show the effect of pilots forgetting whether the intruder would pass above or below. The same trends are present in this graph as the previous one, except for the presents of large magnitudes of error. These large magnitudes are the result of pilots guessing, for example, 750 ft above ownship when the intruder actually passed below ownship at -750 ft. The absolute value correction employed

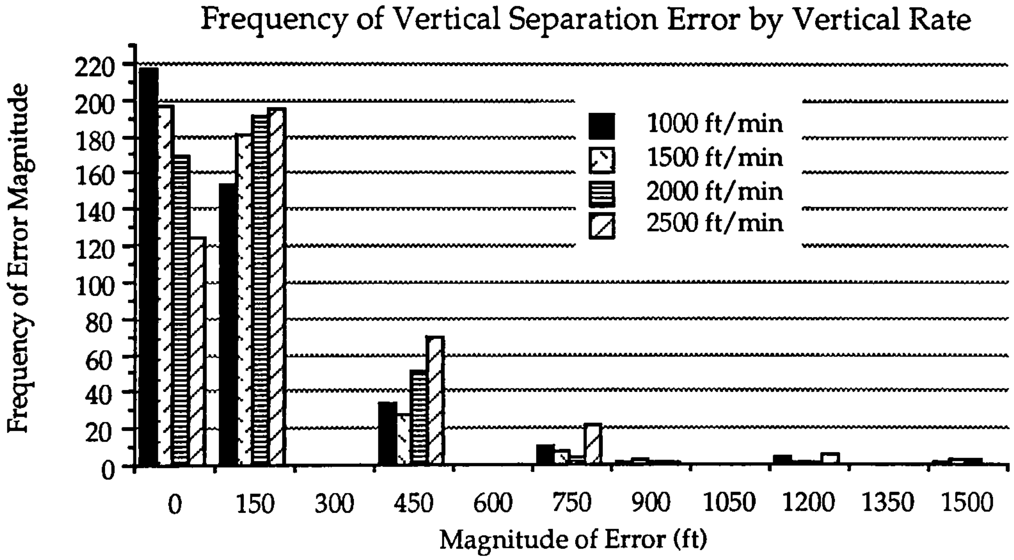

Figure 15. Frequency of pilots' uncorrected error in terms of magnitude.

forces the actual error data to reflect pilots' ability, to determine magnitudes of vertical separation, as if they had not encounter the difficulty. The correction redistributed the wrong guesses among the magnitudes where they would have occurred had the pilot not forgot the the separation direction..

The absolute error was split by vertical separation and is presented in Figure 16. The correct responses (zero error) show a decrease in correct response with increasing vertical miss distance. The large number of correct responses for +/-750 ft VMD supports the supposition that their being the end

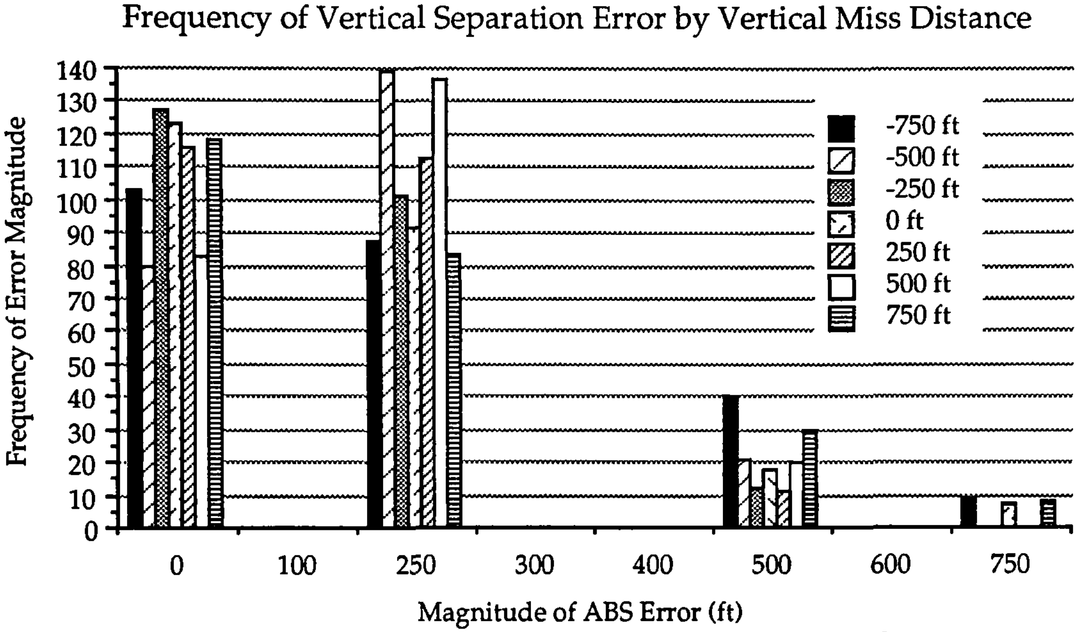

Figure 16. Frequency of pilots' ABS error split by vertical miss distance.

of the miss distance scale made it easier for pilot to determine. This possibility is supported by the greatly reduced error for +/-750 ft VMD at the 250 ft error magnitude. The 250 ft magnitude also lends weight to the trend of more error with increasing vertical miss distance. When the error in miss distance became as large as 500 ft, showing pilots were not easily determining the miss distance, the expected trend of increasing error with increasing miss distance returns for the +/-750 ft VMD's.

The frequency of differing decision times, split by vertical rate, is depicted in Figure 17. The graph shows the majority of decisions being made in the region of 45 to 50 seconds, which is supported by the graph in Figure 6. A trend of increasing time with increasing vertical rate was expected, but the method of making a decision at the three mile range ring nullifies the possibility of any such trend. No noticeable shift in the most frequent decision time exists as vertical rate increases.

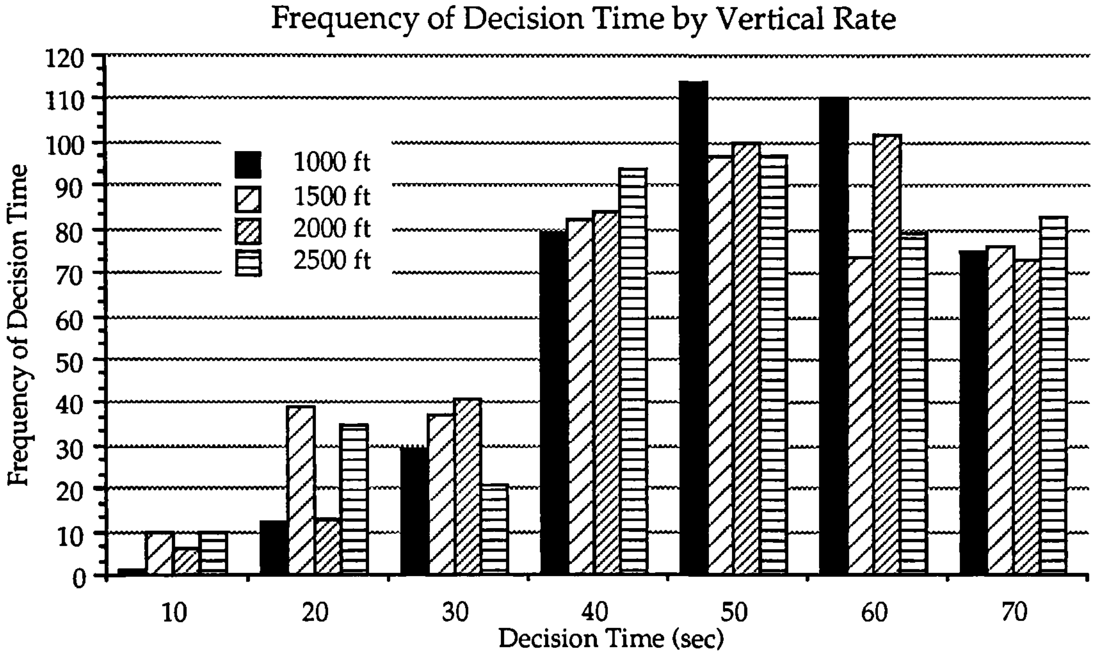

Figure 17. Frequency of decision time split by vertical rate

The frequency of decision time, split by miss distance, is shown in Figure 18. Again, no trends are noticeable, but the peak frequency is located in the 45 to 50 sec range as expected.

One of the most intriguing frequency graphs is displayed in Figure 19. The graph depicts how often pilots made errors (a distance from the *expected miss distance*) by placing the intruder as passing farther away from or closer to ownship than it really would have. For example, the intruder actually flies past 500 ft underneath ownship, but the pilot thought the intruder was going to fly underneath by 250ft. In this case, the pilot has made an error that placed the intruder closer to ownship than it really was. A strong trend of increasingly frequent error that places the intruder closer ownship, as vertical separation

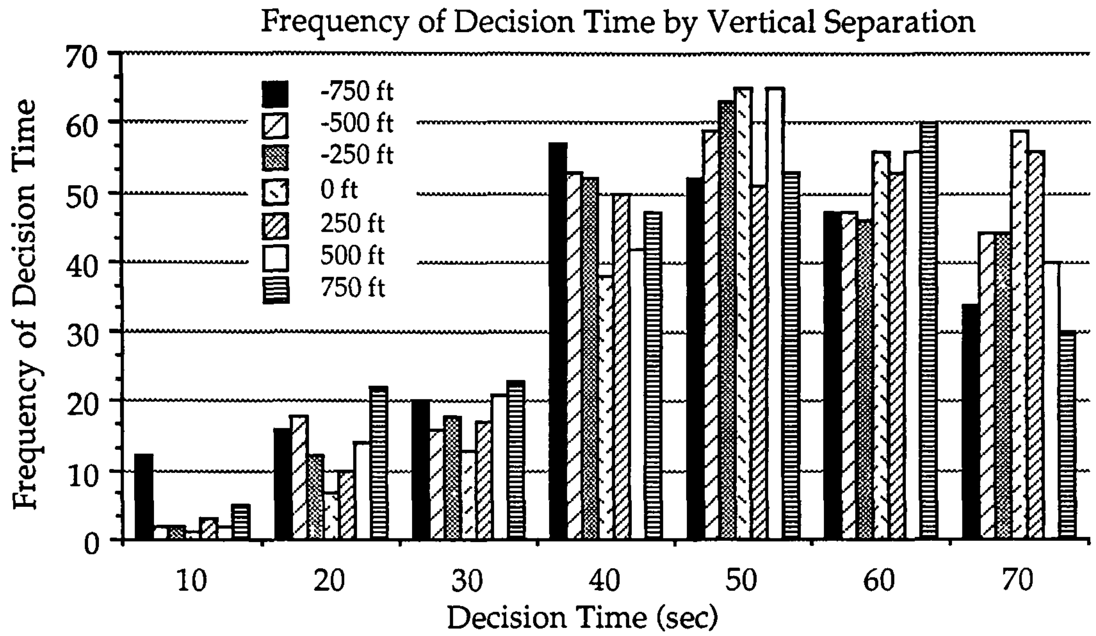

Figure 18. Frequency of decision time split by vertical miss distance.

increases, is present. This trend is inverted for separation errors that place the intruder farther from ownship. If the graph is viewed from the point of overall frequency, pilots made errors placing the intruder closer to ownship more frequently. If errors are going to be made, it is better that pilots think the intruder passed closer than it really would have. This will, in effect, give pilots a vertical buffer distance and allow a little more time to react when necessary. If the trend of the graph is considered, as vertical miss distance decreased (intruders passing closer to ownship) pilots tended to think the intruder was closer to ownship, than it was, less often and farther away from ownship, than it was, more often. Pilots monitoring the display would maintain their buffer distance if they made errors in a direction closer to ownship, with increasing frequency, as vertical miss distance decreased. The trend depicted by the graph has pilots' placing intruders' farther away, at the smaller miss distances, then they really are, which eliminates any buffer distance. This result must be tempered with the fact that overall, pilots did think the intruder was closer to ownship than it really was more often. The scenarios are simple straight flight, steady climb, and constant speed flight paths. It is possible that scenarios involving more complex flight paths could reduce the quantity of errors that place the intruder closer to ownship , thereby removing the only vertical buffer distance in the pilots' decision method.

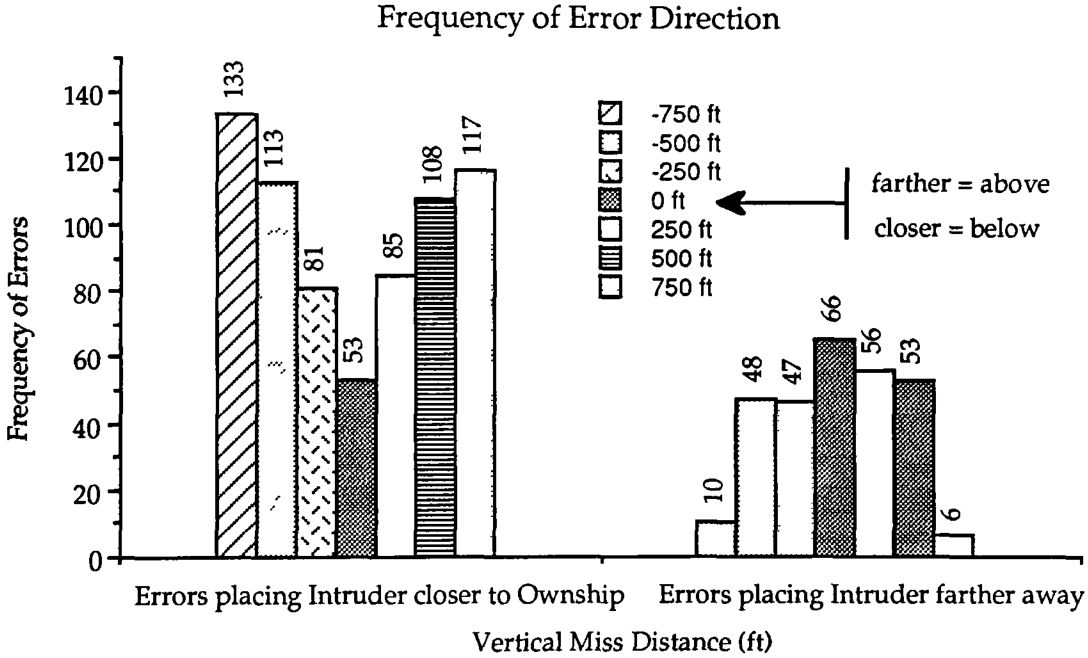

Figure 19. Frequency of errors that place intruders closer or farther from ownship.

Analysis of Pilot Decision Method

This study focused on pilots' ability to quickly judge future vertical separation. This focus favored pilots trading off accuracy for larger intruder distances from ownship at decision time. A different focus could be to stress to pilots the need for accuracy where they would have to trade of safety to be more accurate by letting intruders fly in closer. Pilots were instructed to make their choice as soon as they determined a separation distance. They were not to wait to build confidence in their determination. This point is made in the training instructions. The focus on larger intruder distances at decision time may have slightly altered the methods pilot used to make their determinations.

Pilots used different methods to arrive at their decisions, but all the methods can be reduced to using some fixed distance(s) from ownship. The most readily used distance was the three mile range ring.

The methods discused below are examples of how pilots would use fixed distances to make their decisions. One method was to let the intruder fly to what was considered the four nautical mile mark where the change in altitude for three nautical miles could be determined. This change was added/subtracted from the relative altitude found at the three nautical mile ring to determine the future separation. A more complex method involved flying to the three nautical mile ring (a four nautical mile distance), determining the change in altitude just flown, dividing the change by four to obtain the change for one nautical mile, and multiply by the remaining three nautical miles to arrive at a separation distance that could be added/subtracted to the relative altitude obtained at the range ring. A simple and less fatiguing method involved, surprisingly, the resourceful use of the mouse pointer to judge the halfway distance. The altitude change at half way was determined and the result, along with the relative altitude of the intruder at half way, was used to determine the future separation. This method was unique in that different approach angles did not affect it as much. Pilots that flew fixed distances had to gauge the fixed distance differently for different approach angles, whereas pilots judging halfway with the mouse simply eyeballed a halfway spot. The most common methods employed were ones that let the intruder fly for three nautical miles to find the altitude change needed to make a separation decision at the range ring.

All the above methods depend upon the intruder not deviating from its course. Changes in the intruder flight path will plague the effectiveness of any display that requires the operator to make predictions. Subjects knew the intruder would not deviate from its path and that it would pass directly over ownship. This knowledge undoubtedly assisted the pilots in making more accurate decisions. When an intruder deviates from its original course, pilots will calculate another time consuming future vertical separation . A computer predicted vertical separation will have to be recalculate as well, but will be done with much greater speed.

There were a couple of pilots who more concerned with "beating the test." These pilots would let the intruder flying in and count the number of updates until the software halted them just in front of the intruder. They would then take the single update change in altitude of the subsequent intruders and multiply by the number of updates it would have taken the intruder to reach ownship. This method defeats the purpose of the study simply because it would not be a viable method in a real cockpit environment.

CONCLUSIONS

Vertical rate and miss distance were found to significantly effect the error rate of pilots judging future vertical separation, ($p = .0001$, $F = 25.3$) and ($p = .0001$, $F = 6.1$) respectively. Mean error rates increased with increasing vertical rate as Figures 5, 13, and 14 tend to support. A weakly supported trend of increasing error rate with increasing vertical separation was seen in the later three figures.

The results found must be tempered with the fact that subjects were erroneously presented with a nonrandom sequence of variable levels. This introduced a possible training effect that does not appear to oppose the expected outcome and could possibly add to the error if accounted for. The possibility of boredom/fatigue could not be ruled out, so its effect on decision time must be considered. The mean decision time dropped a total of five seconds, which translates into approximately one less datatag update. The argument remains whether pilots that monitored one less update could have caused the 125 ft increase in the mean absolute error. The answer to this question can not be addressed with the data from this experiment due to the faulty variable presentation. However, it is felt that the increase in mean absolute error was not caused by boredom/fatigue, but by the combination of increasing vertical rate and separation.

The pilots' decision methods were based on the three mile range ring. The use of the range ring in determining future vertical separation caused certain patterns to emerge in the intruders altitude at decision time. Viewed from the vertical plane, intruding aircraft flying crossover scenarios approached closer to ownship's altitude than noncrossover scenarios.

Increasing vertical rate increased aircraft vertical separation at decision time for noncrossover scenarios and crossover scenarios that crossed after passing the range ring. Increasing vertical rate decreased vertical separation at decision time for crossover scenarios that crossed before the range ring.

Analyses of the direction (in the vertical plane) that pilots tended to error showed the pilots' general decision method to be possibly unsafe. The overall error direction frequency shows a tendency to error towards ownship, which can be considered safe. It was found that as vertical miss distance decreased pilots tended to error with decreasing frequency towards ownship and with increasing frequency away from ownship. This trend means pilots placed the intruder farther away with increasing frequency as the vertical miss distance decreased. This can be considered an unsafe trend that could become more serious should the overall frequency of pilots' errors toward ownship decrease.

Hart and Loomis (1980) found that pilots' performance in predicting whether an intruder would pass above or below ownship was *not* significantly improved by the addition of a climb/descend arrow in the datatag or by encoding relative altitude information into the intruder's symbol. The present study lacked both of the fore mentioned features and pilots experienced difficulties in remembering whether intruders were above or below them. While the coded information did not improve pilot performance in the Hart and Loomis (1980) study, it is possible that the coding provided the pilot with an essential directional cue that was absent in the present study.

RECOMMENDATIONS

The methods used by pilots in this study to determine future vertical separation of an intruding aircraft simply take to much time. Pilots in a real flight environment do not have time to focus their attention on the display as the test subjects did. This calls into question the methods used by pilots to project separation in a real cockpit environment. If the pilot methods used in this study are used in the real cockpit environment, it is likely that errors would be larger than experienced in this study, due to the reduction in available monitoring time. Perhaps pilots in a real cockpit environment would approach the display use with a totally different strategy, such as making decisions about intruders when they are farther out (10 nm, 20 nm) so that fewer decisions have to be made about proximity aircraft. Regardless, in a TCA pilots are bound to use smaller display ranges to reduce clutter and will be faced with judging the threat level of proximate aircraft. For these reasons it is recommended that current display manufacturers study and consider implementing a pilot selectable datatag option that displays the predictive, relative altitude of an intruding aircraft at its closest point of approach. This recommendation is supported by the Lester and Palmer (1983) study

Cockpit traffic displays are a reality now. On current, commercially available displays, that depict intruding aircraft altitude relative to ownship, the range ring will play a major role in pilots' decision methods. A display option employed in past studies replaces the intruder's relative altitude information with a computer predicted relative altitude at closest point of approach (Lester, Palmer, 1983; Palmer, 1983, Palmer, Ellis, 1983). The predictive, numerical information was found to significantly reduce error rates of pilots predicting whether intruding aircraft would be within 1000 ft vertically of ownship at the closets point of approach (Lester, Palmer, 1983). Making the predictive information an option selectable by the pilot would eliminate the excessively lengthy time taken to predict future vertical separations in a TCA environment.

A past study found that update interval had no effect on pilots' ability to make predictions about whether an intruder would pass in front or behind ownship (Jago, Baty, O'Conner, Palmer, 1981). The study did not address the effect update had on pilots use of datatag information. Display dwell time has been mentioned as a point of concern buy numerous studies. It is felt from observing the pilots in this study that changes in the update rate will have a significant effect on pilots' ability to make vertical separation predictions. How fast the datatag information is presented to the pilot will likely effect the math work used in making their decisions.

In future studies of dynamic traffic displays, it would be wise to have the software store *all* the variables after each scenario. This includes variables that are not determined by the subject, such as the variables that make each scenario individual. This will avoid the time consuming manual appending of information to very large data files.

Future studies that focus on vertical separation should consider using a sliding scale that pilot would use to select their separation choice from. The scale should extend beyond the actual range of separation distances used in the experiment to avoid the problems encountered with having obvious end points (such the +/- 750 ft choices in this study).

Given that most plan-view displays currently in operation have no predictive vertical information, it recommended that further studies examine pilots decision methods more closely to determine what the least time consuming and effective method of predicting vertical separation might be.

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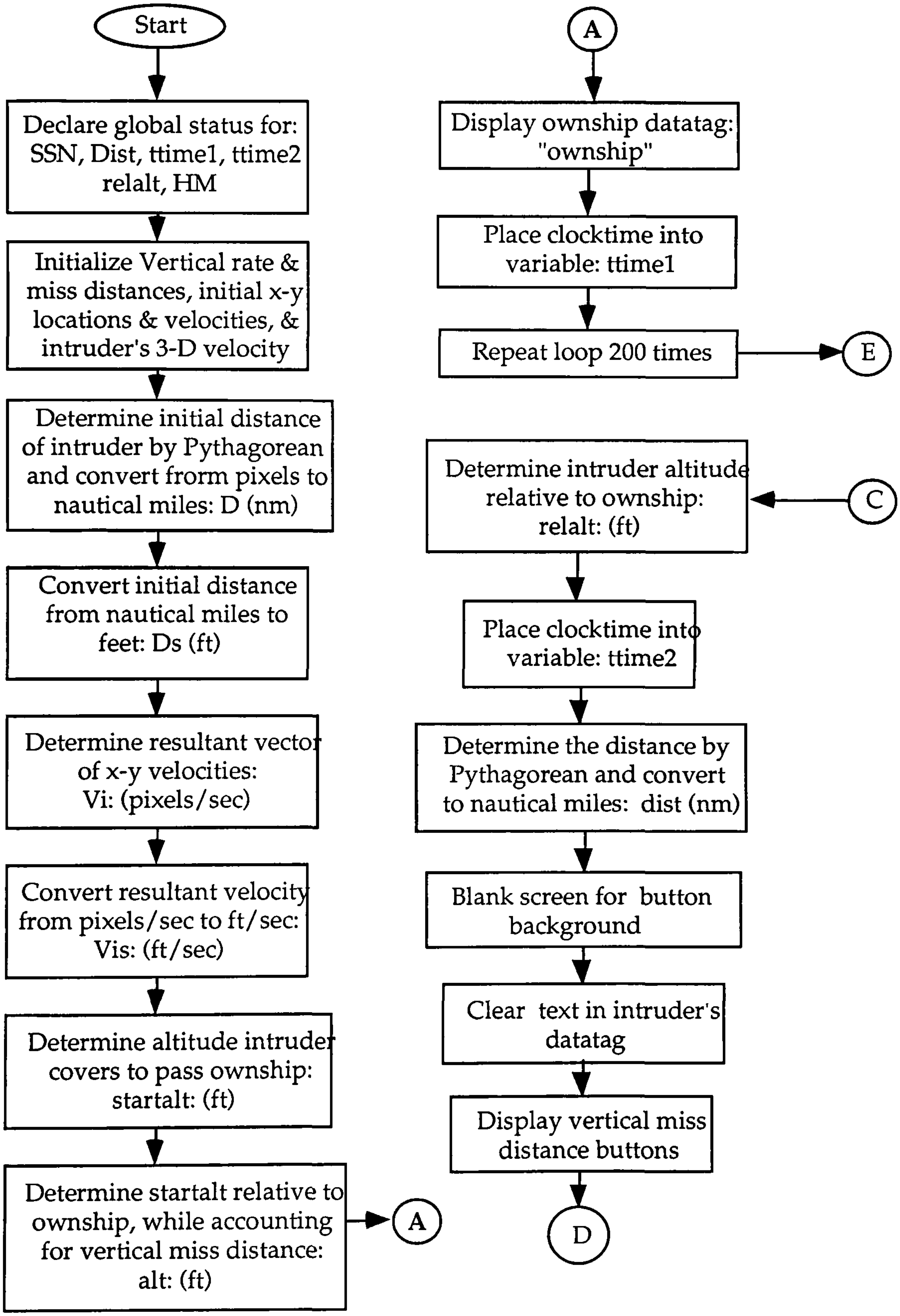
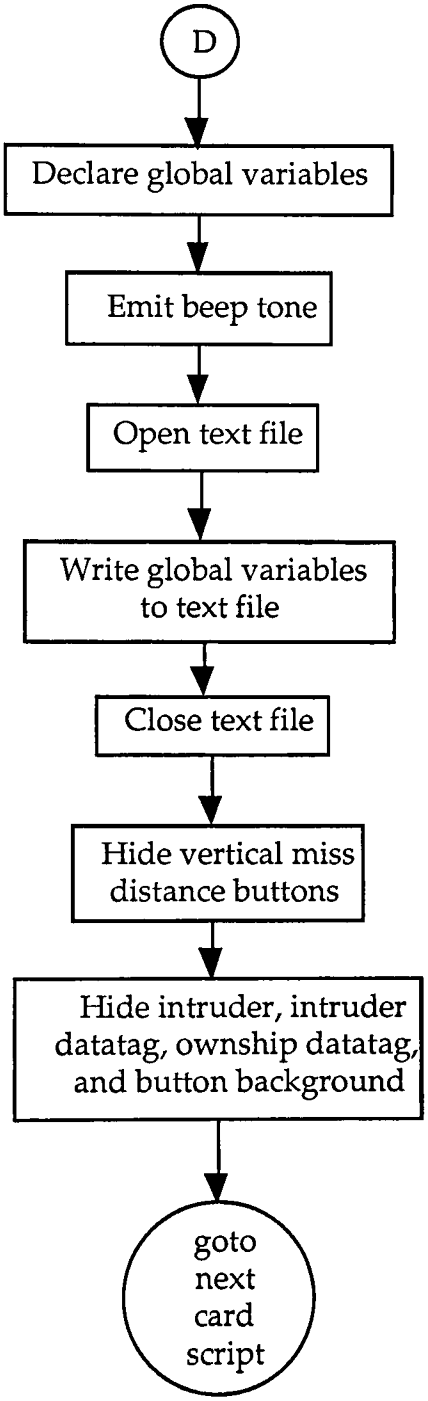
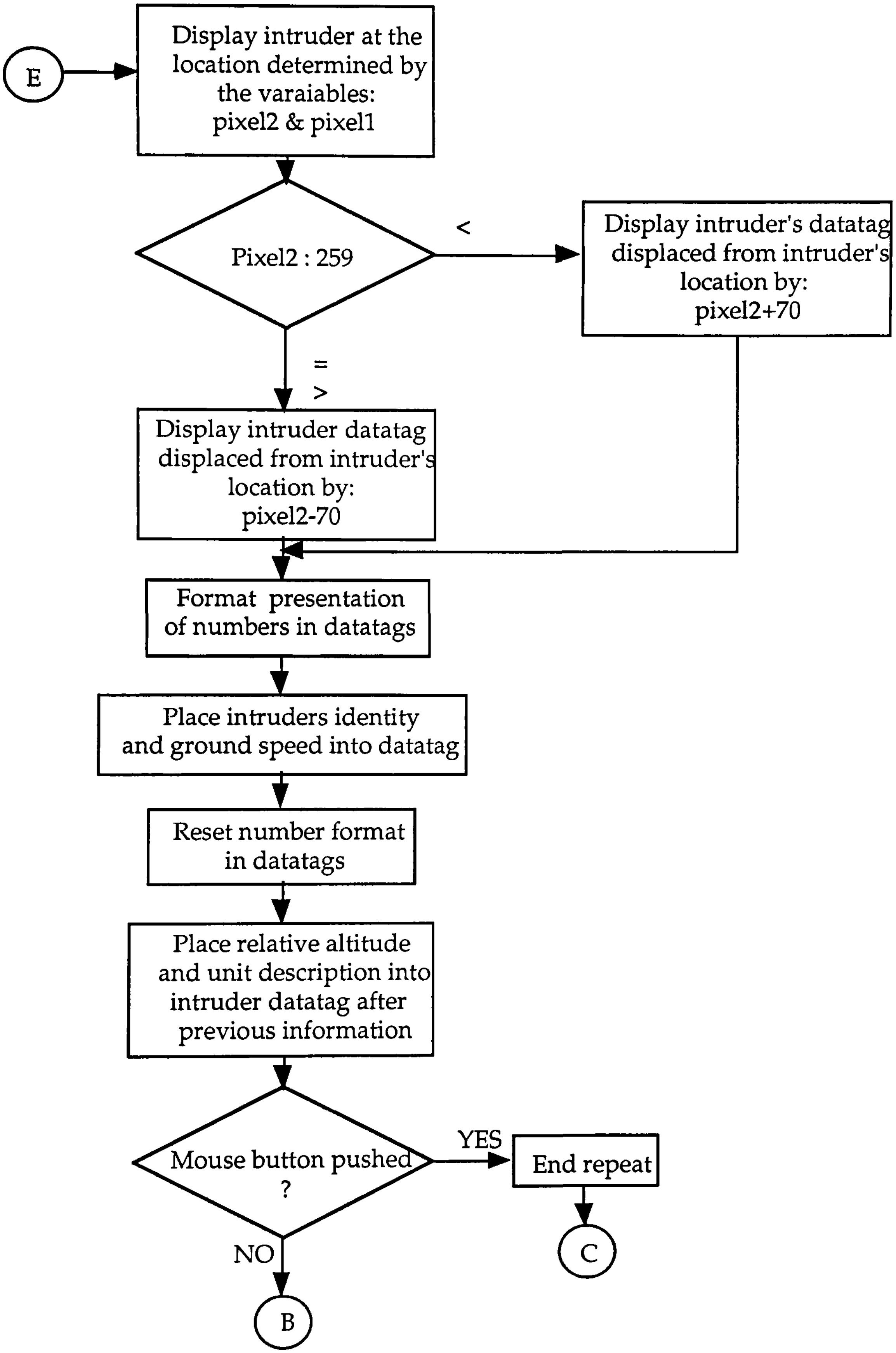
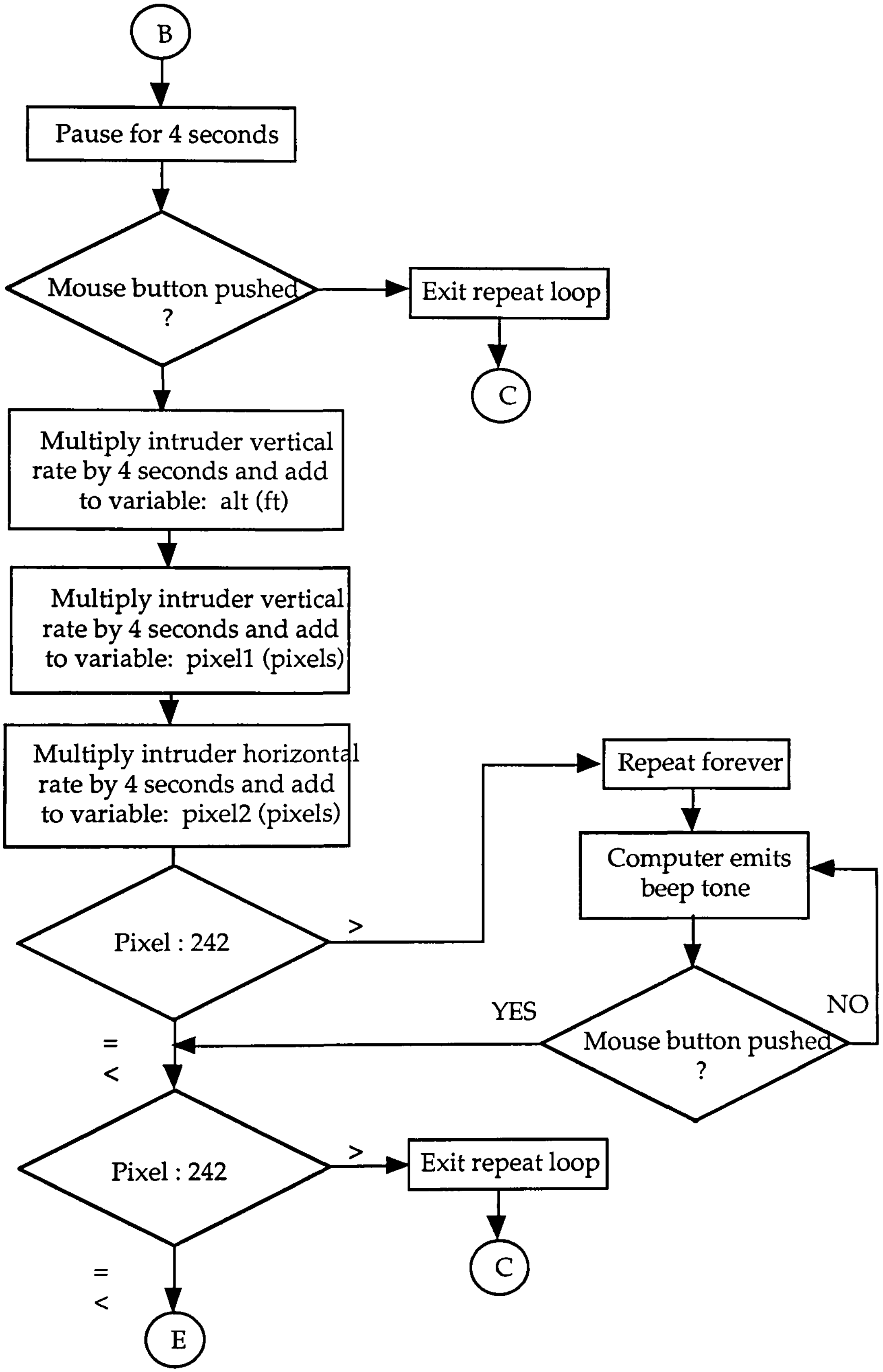
Appendix A

Software Flowcharts & Scripting


Start
Declare global status for: SSN, Dist, ttime1, ttime2 relalt, HM
Initialize Vertical rate & miss distances, initial x-y locations & velocities, & intruder's 3-D velocity
Determine initial distance of intruder by Pythagorean and convert frorm pixels to nautical miles: D (nm)
Convert initial distance from nautical miles to feet: Ds (ft)
Determine resultant vecto of x-y velocities: Vi: (pixels/sec)
Convert resultant velocit from pixels/sec to ft/sec: Vis: (ft/sec)
Determine altitude intrude covers to pass ownship: startalt: (ft)
Determine startalt relative to ownship, while accounting for vertical miss distance: alt: (ft)
A
A
Display ownship datatag: "ownship"
Place clocktime into variable: ttime1
Repeat loop 200 times
E
Determine intruder altitud relative to ownship: relalt: (ft)
C
Place clocktime int variable: ttime2
Determine the distance by Pythagorean and convert to nautical miles: dist (nm)
Blank screen for button background
Clear text in intruder's datatag
Display vertical miss distance buttons
D


D
Declare global variables
Emit beep tone
Open text file
Write global variables to text file
Close text file
Hide vertical miss distance buttons
Hide intruder, intruder datatag, ownship datatag, and button background
goto next card script


E
Display intruder at the location determined by the varaiables: pixel2 & pixel1
Pixel2 : 259
<
Display intruder's datatag displaced from intruder's location by: pixel2+70
=
>
Display intruder datatag displaced from intruder's location by: pixel2-70
Format presentation of numbers in datatags
Place intruders identity and ground speed into datatag
Reset number format in datatags
Place relative altitude and unit description into intruder datatag after previous information
Mouse button pushed ?
YES
End repeat
C
NO
B


B
Pause for 4 seconds
Mouse button pushed ?
Exit repeat loop
C
Multiply intruder vertical rate by 4 seconds and add to variable: alt (ft)
Multiply intruder vertical rate by 4 seconds and add to variable: pixel1 (pixels)
Multiply intruder horizontal rate by 4 seconds and add to variable: pixel2 (pixels)
Pixel : 242
>
Repeat forever
Computer emits beep tone
Mouse button pushed ?
YES
NO
=
<
Pixel : 242
>
Exit repeat loop
C
=
<
E

Project script:

```
on startUp
  hide menubar
  go last card of window 1
end startUp
```

Example of a Window script:

```
on openWindow
  global SSN, ttime1, ttime2, relalt, HM, dist
    repeat
      ask "Please type in the last six digits of your SSN."
      put it into SSN
      ask "Is " & SSN & " correct? (y/n)"
      if it is "y" then exit repeat
    end repeat
end openWindow
```

Example of a card script (7 nm display range):

```
on mouseUp
  global SSN, dist, ttime1, ttime2, relalt, HM
  put 268 into Vb3D
  put 16.7 into vr
  put 122 into pixel1
  put 438 into pixel2
  put 2.1 into H
  put -2.5 into V
  put 0 into HM
  put 276-pixel1 into y
  put y^2 into y1
  put 259-pixel2 into x
  put x^2 into x1
  put (sqrt(y1+x1))/33.1446 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
  put (5000-startalt)+HM into alt
  show cd field "ownship"
  put the long time into ttime1
  repeat for 200 times
    put alt-5000 into relalt
    show grc Intruder at pixel2,pixel1
    if pixel2 < 259 then
      show cd field "datatag" at pixel2+70,pixel1
    else show card field "datatag" at pixel2-70,pixel1
    set numberformat to "000.#"
    put "UA597    " & Vb3D & "kts" & numtochar(13) & "     " into card field "datatag"
    set numberformat to "0000.#"
    put relalt & " ft" after last character of card field "datatag"
```

```
    if the mouseClick then exit repeat
    wait for 4 second
    if the mouseClick then exit repeat
    add 4*vr to alt
    add 4*H to pixel1
    add 4*V to pixel2
    if pixel1 > 242 then
      repeat forever
        beep
        if the mouseClick then exit repeat
      end repeat
    end if
    if pixel1 > 242 then exit repeat
  end repeat
  put the long time into ttime2
  put 276-pixel1 into y
  put y^2 into y1
  put 259-pixel2 into x
  put x^2 into x1
  put (sqrt(y1+x1))/33.1446 into dist
  show cd field "screenblock"
  put "      " into cd field "datatag"
  show cd btn 1
  show cd btn 2
  show cd btn 3
  show cd btn 4
  show cd btn 5
  show cd btn 6
  show cd btn 7
end mouseUp
```

Example of a button script (250 ft miss distance button):

```
on mouseDown
  global SSN, dist, ttime1, ttime2, relalt, HM
  beep
  open file "SHD 650:Bryan:PilotData:" & SSN
  write SSN & "," & "250" & "," & HM &"," & dist & "," & relalt & "," & ttime1 & "," &
    ttime2 & numToChar(13) after file "SHD 650:Bryan:PilotData:" & SSN
  close file "SHD 650:Bryan:PilotData:" & SSN
  hide cd btn 1
  hide cd btn 2
  hide cd btn 3
  hide cd btn 4
  hide cd btn 5
  hide cd btn 6
  hide cd btn 7
  hide grc Intruder
  hide cd field "datatag"
  hide cd field "ownship"
  hide cd field "screenblock"
  go next cd
end mouseDown
```

Appendix B

Consent Form & Verbal/Written Pilot Instruction

INFORMED CONSENT FORM

I, ______________________________, agree to participate in the research entitled "Effect of Vertical Rate on perception of Aircraft Separation on a Cockpit Display of Traffic Information," which is being conducted by Bryan H. Rooney. Mr. Rooney can be reached at the ERAU Daytona Campus, Glass Office #6 (904)226-6725. 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, 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 pressing a button. Upon pressing the button I will be presented with seven possible passing geometries. I will then be required to make a decision as to which passing geometry more closely matches my perception of how the intruding aircraft would pass my aircraft.

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 School of Graduate Studies and Research. Questions or problems regarding these activities should be addressed to Dr. Richard Gibson, Acting Dean, School of Graduate Studies and Research, Embry-Riddle Aeronautical University, Daytona Beach, Florida 32114-3900 (904)239-6715.

Cockpit Display of Traffic Information Study

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

Determining how the approaching aircraft will pass is only one part of how pilots will use this display. Pilots need time to make decisions about how to respond to approaching aircraft after they have judged how the aircraft will pass. Keep in mind you are flying an aircraft and are relying solely on the display to judge the approaching aircraft passing distance due to **zero visibility**. 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 buttons and then determine/figure-out the separation. The study is **not studying nor is it interested** in whether pilots follow FAR's. If you let the approaching aircraft fly in to within .5 nautical miles of your aircraft the software will halt the scenario and beep until you click the mouse button.

By clicking the mouse button you will activate a screen displaying the approaching aircraft's possible passing distances (+/- 250 ft, +/- 500 ft,+/- 750 ft, or collision). From the displayed choices you must click one of the seven buttons causing the computer to store your decision and begin the next scenario.

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

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

Appendix C

(ANOVA and T-test Results)

ANOVA for Absolute Error Rate (or corrected)

Anova table for a 3-factor Analysis of Variance on Y$_1$: Magnitude of Absolute Error (ft)

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Vertical Rate (A)	3	2139732.143	713244.048	25.254	.0001
Vertical Miss Distanc...	6	1035342.262	172557.044	6.11	.0001
AB	18	604538.69	33585.483	1.189	.2612
Approach Angle (C)	2	21056.548	10528.274	.373	.6889
AC	6	310491.071	51748.512	1.832	.0893
BC	12	311755.952	25979.663	.92	.5259
ABC	36	1623363.095	45093.419	1.597	.0142
Error	1596	45075000	28242.481		

Page 1 of the AB Incidence table on Y$_1$: Magnitude of Absolute Error (ft)

	Vertical Miss ...	vm-750	vm-500	vm-250	vm0	vm250	vm500
Vertical Rate	vr1000	60 170.833	60 162.5	60 79.167	60 150	60 91.667	60 145.833
	vr1500	60 191.667	60 150	60 108.333	60 133.333	60 116.667	60 150
	vr2000	60 195.833	60 195.833	60 154.167	60 125	60 170.833	60 220.833
	vr2500	60 254.167	60 245.833	60 179.167	60 212.5	60 183.333	60 220.833
Totals:		240 203.125	240 188.542	240 130.208	240 155.208	240 140.625	240 184.375

Page 2 of the AB Incidence table on Y$_1$: Magnitude of Absolute Error (ft)

	Vertical Miss ...	vm750	Totals:
Vertical Rate	vr1000	60 133.333	420 133.333
	vr1500	60 150	420 142.857
	vr2000	60 137.5	420 171.429
	vr2500	60 279.167	420 225
Totals:		240 175	1680 168.155

The AC Incidence table on Y_1 : Magnitude of Absolute Error (ft)

Approach Ang...		AA0	AA25	AA50	Totals:
Vertical Rate	vr1000	140 114.286	140 123.214	140 162.5	420 133.333
	vr1500	140 133.929	140 153.571	140 141.071	420 142.857
	vr2000	140 160.714	140 183.929	140 169.643	420 171.429
	vr2500	140 244.643	140 216.071	140 214.286	420 225
Totals:		560 163.393	560 169.196	560 171.875	1680 168.155

The BC Incidence table on Y_1 : Magnitude of Absolute Error (ft)

Approach Ang...		AA0	AA25	AA50	Totals:
Vertical Miss Distance	vm-750	80 206.25	80 190.625	80 212.5	240 203.125
	vm-500	80 159.375	80 193.75	80 212.5	240 188.542
	vm-250	80 109.375	80 143.75	80 137.5	240 130.208
	vm0	80 168.75	80 165.625	80 131.25	240 155.208

Page 2 of the BC Incidence table on Y_1 : Magnitude of Absolute Error (ft)

Approach Ang...		AA0	AA25	AA50	Totals:
Vertical Miss Di...	vm250	80 134.375	80 150	80 137.5	240 140.625
	vm500	80 190.625	80 162.5	80 200	240 184.375
	vm750	80 175	80 178.125	80 171.875	240 175
Totals:		560 163.393	560 169.196	560 171.875	1680 168.155

Page 1 of the ABC Incidence table on Y_1 : Magnitude of Absolute Error (ft)

Vertical Miss ...		vm-750			vm-500		
Approach Ang...		AA0	AA25	AA50	AA0	AA25	AA50
Vertical Rate	vr1000	20 175	20 87.5	20 250	20 112.5	20 150	20 225
	vr1500	20 175	20 225	20 175	20 137.5	20 175	20 137.5
	vr2000	20 162.5	20 262.5	20 162.5	20 150	20 237.5	20 200
	vr2500	20 312.5	20 187.5	20 262.5	20 237.5	20 212.5	20 287.5
Totals:		80 206.25	80 190.625	80 212.5	80 159.375	80 193.75	80 212.5

Page 2 of the ABC Incidence table on Y_1 : Magnitude of Absolute Error (ft)

Vertical Miss ...		vm-250			vm0		
Approach Ang...		AA0	AA25	AA50	AA0	AA25	AA50
Vertical Rate	vr1000	20 50	20 125	20 62.5	20 112.5	20 175	20 162.5
	vr1500	20 87.5	20 100	20 137.5	20 137.5	20 137.5	20 125
	vr2000	20 137.5	20 125	20 200	20 150	20 137.5	20 87.5
	vr2500	20 162.5	20 225	20 150	20 275	20 212.5	20 150
Totals:		80 109.375	80 143.75	80 137.5	80 168.75	80 165.625	80 131.25

Page 3 of the ABC Incidence table on Y_1 : Magnitude of Absolute Error (ft)

Vertical Miss ...		vm250			vm500		
Approach Ang...		AA0	AA25	AA50	AA0	AA25	AA50
Vertical Rate	vr1000	20 75	20 100	20 100	20 150	20 100	20 187.5
	vr1500	20 112.5	20 125	20 112.5	20 162.5	20 125	20 162.5
	vr2000	20 200	20 112.5	20 200	20 212.5	20 200	20 250
	vr2500	20 150	20 262.5	20 137.5	20 237.5	20 225	20 200
Totals:		80 134.375	80 150	80 137.5	80 190.625	80 162.5	80 200

Page 4 of the ABC Incidence table on Y $_1$: Magnitude of Absolute Error (ft)

Vertical Miss ...		vm750			Totals:
Approach Ang...		AA0	AA25	AA50	
Vertical Rate	vr1000	20 125	20 125	20 150	420 133.333
	vr1500	20 125	20 187.5	20 137.5	420 142.857
	vr2000	20 112.5	20 212.5	20 87.5	420 171.429
	vr2500	20 337.5	20 187.5	20 312.5	420 225
Totals:		80 175	80 178.125	80 171.875	1680 168.155

ANOVA for Decision Time

Anova table for a 3-factor Analysis of Variance on Y $_1$: Decision Time (sec)

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Vertical Rate (A)	3	3645.74	1215.247	5.652	.0008
Vertical Miss Distanc...	6	8301.84	1383.64	6.435	.0001
AB	18	1562.764	86.82	.404	.9875
Approach Angle (C)	2	7623.776	3811.888	17.728	.0001
AC	6	476.633	79.439	.369	.8986
BC	12	1098.524	91.544	.426	.954
ABC	36	3126.6	86.85	.404	.9994
Error	1596	343170.75	215.019		

Page 1 of the AB Incidence table on Y $_1$: Decision Time (sec)

Vertical Miss ...		vm-750	vm-500	vm-250	vm0	vm250	vm500
Vertical Rate	vr1000	60 42.967	60 45.833	60 46.95	60 51.25	60 48.533	60 46.533
	vr1500	60 41.167	60 43.883	60 43.467	60 46.9	60 44.167	60 42.533
	vr2000	60 41.467	60 45	60 45.817	60 47.117	60 46.2	60 45.25
	vr2500	60 39.017	60 43.333	60 44.333	60 47.6	60 45.683	60 44.717
Totals:		240 41.154	240 44.513	240 45.142	240 48.217	240 46.146	240 44.758

Page 2 of the AB Incidence table on Y_1 : Decision Time (sec)

Vertical Miss ...		vm750	Totals:
Vertical Rate	vr1000	60 44.583	420 46.664
	vr1500	60 37.6	420 42.817
	vr2000	60 45.05	420 45.129
	vr2500	60 40.633	420 43.617
Totals:		240 41.967	1680 44.557

The AC Incidence table on Y_1 : Decision Time (sec)

Approach Ang...		AA0	AA25	AA50	Totals:
Vertical Rate	vr1000	140 43.921	140 47.8	140 48.271	420 46.664
	vr1500	140 38.943	140 45.257	140 44.25	420 42.817
	vr2000	140 42.293	140 46.807	140 46.286	420 45.129
	vr2500	140 41.021	140 44.157	140 45.671	420 43.617
Totals:		560 41.545	560 46.005	560 46.12	1680 44.557

The BC Incidence table on Y_1 : Decision Time (sec)

Approach Ang...		AA0	AA25	AA50	Totals:
Vertical Miss Distance	vm-750	80 38.5	80 41.625	80 43.338	240 41.154
	vm-500	80 41.588	80 46.438	80 45.513	240 44.513
	vm-250	80 42.412	80 47.088	80 45.925	240 45.142
	vm0	80 45.175	80 50.138	80 49.338	240 48.217

Page 2 of the BC Incidence table on Y $_1$: Decision Time (sec)

	Approach Ang...	AA0	AA25	AA50	Totals:
Vertical Miss Di...	vm250	80 42.6	80 45.85	80 49.987	240 46.146
	vm500	80 41.825	80 46.487	80 45.963	240 44.758
	vm750	80 38.713	80 44.412	80 42.775	240 41.967
Totals:		560 41.545	560 46.005	560 46.12	1680 44.557

Page 1 of the ABC Incidence table on Y $_1$: Decision Time (sec)

	Vertical Miss ...	vm-750			vm-500		
	Approach Ang...	AA0	AA25	AA50	AA0	AA25	AA50
Vertical Rate	vr1000	20 39.6	20 43.8	20 45.5	20 45.8	20 47.7	20 44
	vr1500	20 38.6	20 44.35	20 40.55	20 39.3	20 46.25	20 46.1
	vr2000	20 39.2	20 40.75	20 44.45	20 42.25	20 48.1	20 44.65
	vr2500	20 36.6	20 37.6	20 42.85	20 39	20 43.7	20 47.3
Totals:		80 38.5	80 41.625	80 43.338	80 41.588	80 46.438	80 45.513

Page 2 of the ABC Incidence table on Y $_1$: Decision Time (sec)

	Vertical Miss ...	vm-250			vm0		
	Approach Ang...	AA0	AA25	AA50	AA0	AA25	AA50
Vertical Rate	vr1000	20 44.4	20 46	20 50.45	20 48.95	20 54.55	20 50.25
	vr1500	20 39.35	20 48.65	20 42.4	20 40.9	20 49.2	20 50.6
	vr2000	20 43.55	20 48.85	20 45.05	20 44.35	20 48.4	20 48.6
	vr2500	20 42.35	20 44.85	20 45.8	20 46.5	20 48.4	20 47.9
Totals:		80 42.412	80 47.088	80 45.925	80 45.175	80 50.138	80 49.338

Page 3 of the ABC Incidence table on Y_1 : Decision Time (sec)

Vertical Miss ...		vm250			vm500		
Approach Ang...		AA0	AA25	AA50	AA0	AA25	AA50
Vertical Rate	vr1000	20	20	20	20	20	20
		46.8	48.1	50.7	42.4	47.85	49.35
	vr1500	20	20	20	20	20	20
		39.95	43.55	49	39.45	44.45	43.7
	vr2000	20	20	20	20	20	20
		41.15	47	50.45	43.9	48.1	43.75
	vr2500	20	20	20	20	20	20
		42.5	44.75	49.8	41.55	45.55	47.05
Totals:		80	80	80	80	80	80
		42.6	45.85	49.987	41.825	46.487	45.963

Page 4 of the ABC Incidence table on Y_1 : Decision Time (sec)

Vertical Miss ...		vm750			Totals:
Approach Ang...		AA0	AA25	AA50	
Vertical Rate	vr1000	20	20	20	420
		39.5	46.6	47.65	46.664
	vr1500	20	20	20	420
		35.05	40.35	37.4	42.817
	vr2000	20	20	20	420
		41.65	46.45	47.05	45.129
	vr2500	20	20	20	420
		38.65	44.25	39	43.617
Totals:		80	80	80	1680
		38.713	44.412	42.775	44.557

Error Rate T-test Comparisons for Vertical Rate

Paired t-Test X_1 : 1000 ft/min Y_3 : 2500 ft/min

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
419	-91.67	-7.83	.0001

Paired t-Test X_1 : 1000 ft/min Y_1 : 1500 ft/min

DF:	Mean X Y:	Paired t value:	Prob. (2-tail):
419	-9.52	-.91	.3641

Paired t-Test X_1 : 1000 ft/min Y_2 : 2000 ft/min

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
419	-38.1	-3.56	.0004

Paired t-Test X_1 : 1500 ft/min Y_1 : 2000 ft/min

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
419	-28.57	-2.58	.0101

Paired t-Test X_1 : 1500 ft/min Y_2 : 2500 ft/min

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
419	-82.14	-7.72	.0001

Paired t-Test X_1 : 2000 ft/min Y_1 : 2500 ft/min

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
419	-53.57	-4.24	.0001

Error Rate T-test Comparisons Vertical Separation

Paired t-Test X_1 : -750 ft Y_1 : -500 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	14.58	1.07	.2839

Paired t-Test X_1 : -750 ft Y_2 : -250 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	72.92	4.42	.0001

Paired t-Test X_1 : -750 ft Y_3 : 0 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	47.92	2.68	.0079

Paired t-Test X_1 : -750 ft Y_4 : 250 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	62.5	3.87	.0001

Paired t-Test X_1 : -750 ft Y_5 : 500 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	18.75	1.35	.1778

Paired t-Test X_1 : -750 ft Y_6 : 750 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	28.12	2.22	.0277

Paired t-Test X_1 : -500 ft Y_1 : -250 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	58.33	4.74	.0001

Paired t-Test X_1 : -500 ft Y_2 : 0 ft

DF:	Mean X Y:	Paired t value:	Prob. (2-tail):
239	33.33	2.4	.0174

Paired t-Test X_1 : -500 ft Y_3 : 250 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	47.92	3.89	.0001

Paired t-Test X_1 : -500 ft Y_4 : 500 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	4.17	.37	.7135

Paired t-Test X_1 : -500 ft Y_5 : 750 ft

DF:	Mean X Y:	Paired t value:	Prob. (2-tail):
239	13.54	.96	.3376

Paired t-Test X_1 : -500 ft Y_5 : 750 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	13.54	.96	.3376

Paired t-Test X_1 : -250 ft Y_1 : 0 ft

DF:	Mean X Y:	Paired t value:	Prob. (2-tail):
239	-25	-1.76	.08

Paired t-Test X_1 : -250 ft Y_2 : 250 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	-10.42	- 1	.3183

Paired t-Test X_1 : -250 ft Y_3 : 500 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	-54.17	-4.5	.0001

Paired t-Test X_1 : -250 ft Y_4 : 750 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	-44.79	-2.85	.0048

Paired t-Test X_1 : 0 ft Y_1 : 250 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	14.58	1.06	.2895

Paired t-Test X_1 : 0 ft Y_2 : 500 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	-29.17	-1.98	.0486

Paired t-Test X_1 : 0 ft Y_3 : 750 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	-19.79	-1.15	.2493

Paired t-Test X_1 : 0 ft Y_3 : 750 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	-19.79	-1.15	.2493

Paired t-Test X_1 : 250 ft Y_1 : 500 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	-43.75	-3.78	.0002

Paired t-Test X_1 : 250 ft Y_2 : 750 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	-34.38	-2.16	.0318

Paired t-Test X_1 : 500 ft Y_1 : 750 ft

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
239	9.38	.66	.5116

Appendix D

(Results of "RVcalc" Calculations)

	angle (+/-)	Vert. Miss	Vert. Rate (+/-)	VR (knots)	(V)b/a 3D (knots)	(V)b/a 2D	(V)b/a j (> J?)	(V)b/a i & (V)b i	(V)a j	(V)b j	(V)b 2D	(V)b 3D (UNITS!)	VR (ft/s)
1	50.0	0.0	1000.0	13.1	350	349.8	-224.8	-267.9	240.0	15.2	268.4	268.7	16.7
2	-25.0	0.0	-1000.0	-13.1	350	349.8	-317.0	147.8	240.0	-77.0	166.7	167.2	-16.7
3	0.0	0.0	1000.0	13.1	350	349.8	-349.8	0.0	240.0	-109.8	109.8	110.5	16.7
4	-50.0	250.0	-1000.0	-13.1	350	349.8	-224.8	267.9	240.0	15.2	268.4	268.7	-16.7
5	25.0	250.0	1000.0	13.1	350	349.8	-317.0	-147.8	240.0	-77.0	166.7	167.2	16.7
6	0.0	250.0	-1000.0	-13.1	350	349.8	-349.8	0.0	240.0	-109.8	109.8	110.5	-16.7
7	50.0	-250.0	1000.0	13.1	350	349.8	-224.8	-267.9	240.0	15.2	268.4	268.7	16.7
8	-25.0	-250.0	-1000.0	-13.1	350	349.8	-317.0	147.8	240.0	-77.0	166.7	167.2	-16.7
9	0.0	-250.0	1000.0	13.1	350	349.8	-349.8	0.0	240.0	-109.8	109.8	110.5	16.7
10	-50.0	500.0	-1000.0	-13.1	350	349.8	-224.8	267.9	240.0	15.2	268.4	268.7	-16.7
11	25.0	500.0	1000.0	13.1	350	349.8	-317.0	-147.8	240.0	-77.0	166.7	167.2	16.7
12	0.0	500.0	-1000.0	-13.1	350	349.8	-349.8	0.0	240.0	-109.8	109.8	110.5	-16.7
13	50.0	-500.0	1000.0	13.1	350	349.8	-224.8	-267.9	240.0	15.2	268.4	268.7	16.7
14	-25.0	-500.0	-1000.0	-13.1	350	349.8	-317.0	147.8	240.0	-77.0	166.7	167.2	-16.7
15	0.0	-500.0	1000.0	13.1	350	349.8	-349.8	0.0	240.0	-109.8	109.8	110.5	16.7
16	-50.0	750.0	-1000.0	-13.1	350	349.8	-224.8	267.9	240.0	15.2	268.4	268.7	-16.7
17	25.0	750.0	1000.0	13.1	350	349.8	-317.0	-147.8	240.0	-77.0	166.7	167.2	16.7
18	0.0	750.0	-1000.0	-13.1	350	349.8	-349.8	0.0	240.0	-109.8	109.8	110.5	-16.7
19	50.0	-750.0	1000.0	13.1	350	349.8	-224.8	-267.9	240.0	15.2	268.4	268.7	16.7
20	-25.0	-750.0	-1000.0	-13.1	350	349.8	-317.0	147.8	240.0	-77.0	166.7	167.2	-16.7
21	0.0	-750.0	1000.0	13.1	350	349.8	-349.8	0.0	240.0	-109.8	109.8	110.5	16.7
22	-50.0	0.0	-1500.0	-19.6	350	349.4	-224.6	267.7	240.0	15.4	268.1	268.9	-25.0
23	25.0	0.0	1500.0	19.6	350	349.4	-316.7	-147.7	240.0	-76.7	166.4	167.6	25.0
24	0.0	0.0	-1500.0	-19.6	350	349.4	-349.4	0.0	240.0	-109.4	109.4	111.2	-25.0
25	50.0	250.0	1500.0	19.6	350	349.4	-224.6	-267.7	240.0	15.4	268.1	268.9	25.0
26	-25.0	250.0	-1500.0	-19.6	350	349.4	-316.7	147.7	240.0	-76.7	166.4	167.6	-25.0
27	0.0	250.0	1500.0	19.6	350	349.4	-349.4	0.0	240.0	-109.4	109.4	111.2	25.0
28	-50.0	-250.0	-1500.0	-19.6	350	349.4	-224.6	267.7	240.0	15.4	268.1	268.9	-25.0
29	25.0	-250.0	1500.0	19.6	350	349.4	-316.7	-147.7	240.0	-76.7	166.4	167.6	25.0
30	0.0	-250.0	-1500.0	-19.6	350	349.4	-349.4	0.0	240.0	-109.4	109.4	111.2	-25.0
31	50.0	500.0	1500.0	19.6	350	349.4	-224.6	-267.7	240.0	15.4	268.1	268.9	25.0
32	-25.0	500.0	-1500.0	-19.6	350	349.4	-316.7	147.7	240.0	-76.7	166.4	167.6	-25.0
33	0.0	500.0	1500.0	19.6	350	349.4	-349.4	0.0	240.0	-109.4	109.4	111.2	25.0
34	-50.0	-500.0	-1500.0	-19.6	350	349.4	-224.6	267.7	240.0	15.4	268.1	268.9	-25.0
35	25.0	-500.0	1500.0	19.6	350	349.4	-316.7	-147.7	240.0	-76.7	166.4	167.6	25.0
36	0.0	-500.0	-1500.0	-19.6	350	349.4	-349.4	0.0	240.0	-109.4	109.4	111.2	-25.0
37	50.0	750.0	1500.0	19.6	350	349.4	-224.6	-267.7	240.0	15.4	268.1	268.9	25.0
38	-25.0	750.0	-1500.0	-19.6	350	349.4	-316.7	147.7	240.0	-76.7	166.4	167.6	-25.0
39	0.0	750.0	1500.0	19.6	350	349.4	-349.4	0.0	240.0	-109.4	109.4	111.2	25.0
40	-50.0	-750.0	-1500.0	-19.6	350	349.4	-224.6	267.7	240.0	15.4	268.1	268.9	-25.0
41	25.0	-750.0	1500.0	19.6	350	349.4	-316.7	-147.7	240.0	-76.7	166.4	167.6	25.0
42	0.0	-750.0	-1500	-19.6	350	349.4	-349.4	0.0	240.0	-109.4	109.4	111.2	-25.0

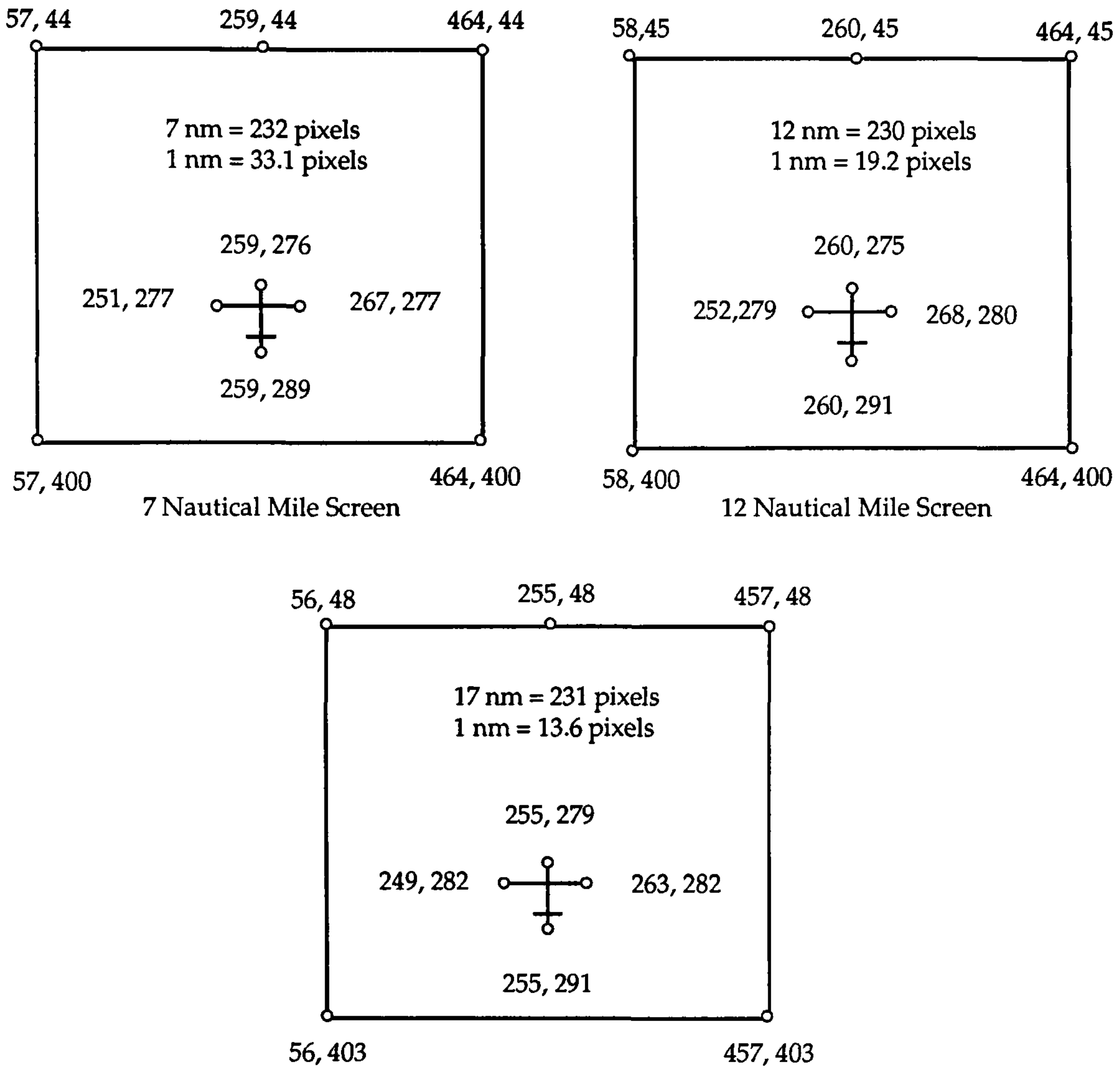
	angle (+/-)	Vert Miss	Vert Rate (+/-)	VR (knots)	(V)b/a 3D	(V)b/a 2D	(V)b/a j (> J?)	(V)b/a i & (V)b i	(V)a j	(V)b j	(V)b 2D	(V)b 3D (UNITS!)	VR (ft/s)
43	50.0	0.0	2000	26.2	350	349.0	-224.3	-267.4	240.0	15.7	267.8	269.1	33.3
44	-25.0	0.0	-2000	-26.2	350	349.0	-316.3	147.5	240.0	-76.3	166.1	168.1	-33.3
45	0.0	0.0	2000	26.2	350	349.0	-349.0	0.0	240.0	-109.0	109.0	112.1	33.3
46	-50.0	250.0	-2000	-26.2	350	349.0	-224.3	267.4	240.0	15.7	267.8	269.1	-33.3
47	25.0	250.0	2000	26.2	350	349.0	-316.3	-147.5	240.0	-76.3	166.1	168.1	33.3
48	0.0	250.0	-2000	-26.2	350	349.0	-349.0	0.0	240.0	-109.0	109.0	112.1	-33.3
49	50.0	-250.0	2000	26.2	350	349.0	-224.3	-267.4	240.0	15.7	267.8	269.1	33.3
50	-25.0	-250.0	-2000	-26.2	350	349.0	-316.3	147.5	240.0	-76.3	166.1	168.1	-33.3
51	0.0	-250.0	2000	26.2	350	349.0	-349.0	0.0	240.0	-109.0	109.0	112.1	33.3
52	-50.0	500.0	-2000	-26.2	350	349.0	-224.3	267.4	240.0	15.7	267.8	269.1	-33.3
53	25.0	500.0	2000	26.2	350	349.0	-316.3	-147.5	240.0	-76.3	166.1	168.1	33.3
54	0.0	500.0	-2000	-26.2	350	349.0	-349.0	0.0	240.0	-109.0	109.0	112.1	-33.3
55	50.0	-500.0	2000	26.2	350	349.0	-224.3	-267.4	240.0	15.7	267.8	269.1	33.3
56	-25.0	-500.0	-2000	-26.2	350	349.0	-316.3	147.5	240.0	-76.3	166.1	168.1	-33.3
57	0.0	-500.0	2000	26.2	350	349.0	-349.0	0.0	240.0	-109.0	109.0	112.1	33.3
58	-50.0	750.0	-2000	-26.2	350	349.0	-224.3	267.4	240.0	15.7	267.8	269.1	-33.3
59	25.0	750.0	2000	26.2	350	349.0	-316.3	-147.5	240.0	-76.3	166.1	168.1	33.3
60	0.0	750.0	-2000	-26.2	350	349.0	-349.0	0.0	240.0	-109.0	109.0	112.1	-33.3
61	50.0	-750.0	2000	26.2	350	349.0	-224.3	-267.4	240.0	15.7	267.8	269.1	33.3
62	-25.0	-750.0	-2000	-26.2	350	349.0	-316.3	147.5	240.0	-76.3	166.1	168.1	-33.3
63	0.0	-750.0	2000	26.2	350	349.0	-349.0	0.0	240.0	-109.0	109.0	112.1	33.3
64	-50.0	0.0	-2500	-32.7	350	348.5	-224.0	266.9	240.0	16.0	267.4	269.4	-41.7
65	25.0	0.0	2500	32.7	350	348.5	-315.8	-147.3	240.0	-75.8	165.6	168.8	41.7
66	0.0	0.0	-2500	-32.7	350	348.5	-348.5	0.0	240.0	-108.5	108.5	113.3	-41.7
67	50.0	250.0	2500	32.7	350	348.5	-224.0	-266.9	240.0	16.0	267.4	269.4	41.7
68	-25.0	250.0	-2500	-32.7	350	348.5	-315.8	147.3	240.0	-75.8	165.6	168.8	-41.7
69	0.0	250.0	2500	32.7	350	348.5	-348.5	0.0	240.0	-108.5	108.5	113.3	41.7
70	-50.0	-250.0	-2500	-32.7	350	348.5	-224.0	266.9	240.0	16.0	267.4	269.4	-41.7
71	25.0	-250.0	2500	32.7	350	348.5	-315.8	-147.3	240.0	75.8	165.6	168.8	41.7
72	0.0	-250.0	-2500	-32.7	350	348.5	-348.5	0.0	240.0	-108.5	108.5	113.3	-41.7
73	50.0	500.0	2500	32.7	350	348.5	-224.0	-266.9	240.0	16.0	267.4	269.4	41.7
74	-25.0	500.0	-2500	-32.7	350	348.5	-315.8	147.3	240.0	-75.8	165.6	168.8	-41.7
75	0.0	500.0	2500	32.7	350	348.5	-348.5	0.0	240.0	-108.5	108.5	113.3	41.7
76	-50.0	-500.0	-2500	-32.7	350	348.5	-224.0	266.9	240.0	16.0	267.4	269.4	-41.7
77	25.0	-500.0	2500	32.7	350	348.5	-315.8	-147.3	240.0	-75.8	165.6	168.8	41.7
78	0.0	-500.0	2500	-32.7	350	348.5	-348.5	0.0	240.0	-108.5	108.5	113.3	-41.7
79	50.0	750.0	2500	32.7	350	348.5	-224.0	-266.9	240.0	16.0	267.4	269.4	41.7
80	-25.0	750.0	-2500	-32.7	350	348.5	-315.8	147.3	240.0	-75.8	165.6	168.8	-41.7
81	0.0	750.0	2500	32.7	350	348.5	-348.5	0.0	240.0	-108.5	108.5	113.3	41.7
82	-50.0	-750.0	-2500	-32.7	350	348.5	-224.0	266.9	240.0	16.0	267.4	269.4	-41.7
83	25.0	-750.0	2500	32.7	350	348.5	-315.8	147.3	240.0	-75.8	165.6	168.8	41.7
84	0.0	-750.0	-2500	-32.7	350	348.5	-348.5	0.0	240.0	-108.5	108.5	113.3	-41.7

17 nm Scale (V)b/a i	17 nm Scale (V)b/a j	12 nm Scale (V)b/a i	12 nm Scale (V)b/a j	7 nm Scale (V)b/a i	7 nm Scale (V)b/a j	angle	Vert. Miss	VR (ft/s)	(V)b 2D (UNITS!)	Test
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	0	16.7	268	1
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	0	-16.7	167	2
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	0	16.7	110	3
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	250	-16.7	268	4
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	250	16.7	167	5
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	250	-16.7	110	6
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	-250	16.7	268	7
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	-250	-16.7	167	8
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	-250	16.7	110	9
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	500	-16.7	268	10
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	500	16.7	167	11
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	500	-16.7	110	12
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	-500	16.7	268	13
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	-500	-16.7	167	14
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	-500	16.7	110	15
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	750	-16.7	268	16
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	750	16.7	167	17
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	750	-16.7	110	18
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	-750	16.7	268	19
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	-750	-16.7	167	20
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	-750	16.7	110	21
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	0	-25.0	268	22
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	0	25.0	166	23
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	0	-25.0	109	24
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	250	25.0	268	25
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	250	-25.0	166	26
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	250	25.0	109	27
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	-250	-25.0	268	28
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	-250	25.0	166	29
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	-250	-25.0	109	30
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	500	25.0	268	31
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	500	-25.0	166	32
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	500	25.0	109	33
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	-500	-25.0	268	34
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	-500	25.0	166	35
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	-500	-25.0	109	36
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	750	25.0	268	37
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	750	-25.0	166	38
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	750	25.0	109	39
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	-750	-25.0	268	40
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	-750	25.0	166	41
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	-750	-25.0	109	42

17 nm Scale (V)b/a i	17 nm Scale (V)b/a j	12 nm Scale (V)b/a i	12 nm Scale (V)b/a j	7 nm Scale (V)b/a i	7 nm Scale (V)b/a j	angle	Vert. Miss	VR (ft/s)	(V)b 2D (UNITS!)	Test
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	0	33.3	268	43
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	0	-33.3	166	44
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	0	33.3	109	45
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	250	-33.3	268	46
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	250	33.3	166	47
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	250	-33.3	109	48
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	-250	33.3	268	49
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	-250	-33.3	166	50
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	-250	33.3	109	51
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	500	-33.3	268	52
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	500	33.3	166	53
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	500	-33.3	109	54
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	-500	33.3	268	55
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	-500	-33.3	166	56
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	-500	33.3	109	57
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	750	-33.3	268	58
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	750	33.3	166	59
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	750	-33.3	109	60
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	-750	33.3	268	61
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	-750	-33.3	166	62
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	-750	33.3	109	63
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	0	-41.7	267	64
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	0	41.7	166	65
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	0	-41.7	108	66
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	250	41.7	267	67
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	250	-41.7	166	68
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	250	41.7	108	69
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	-250	-41.7	267	70
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	-250	41.7	166	71
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	-250	-41.7	108	72
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	500	41.7	267	73
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	500	-41.7	166	74
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	500	41.7	108	75
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	-500	-41.7	267	76
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	-500	41.7	166	77
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	-500	-41.7	108	78
-1.0	-0.8	-1.4	-1.2	-2.5	-2.1	50	750	41.7	267	79
0.6	-1.2	0.8	-1.7	1.4	-2.9	-25	750	-41.7	166	80
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	750	41.7	108	81
1.0	-0.8	1.4	-1.2	2.5	-2.1	-50	-750	-41.7	267	82
-0.6	-1.2	-0.8	-1.7	-1.4	-2.9	25	-750	41.7	166	83
0.0	-1.3	0.0	-1.9	0.0	-3.2	0	-750	-41.7	108	84

Appendix E

(Display Information)



7 Nautical Mile Screen

12 Nautical Mile Screen

17 Nautical Mile Screen

Screen and aircraft pixel locations on the SuperCard window.

Angle	7 nm	12 nm	17 nm
0 Degrees	254, 60	256, 63	258, 63
25 Degrees	356, 60	358, 63	360, 60
50 Degrees	438, 122	440, 125	442, 125
-25 Degrees	152, 60	154, 63	156, 60
-50 Degrees	66, 122	68, 125	70, 125

Pixel location for desired angle of approach.