1999

Text based altitude: Modes in a cockpit display of traffic information

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TEXT BASED ALTITUDE

MODES IN A COCKPIT DISPLAY OF TRAFFIC INFORMATION

A Thesis

Presented to

the Faculty of the Department of Psychology

San Jose State University

In Partial Fulfillment

of the of the Requirements for the Degree

Masters of Arts

by

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May 1999

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ABSTRACT

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This study evaluated relative versus absolute text-based altitude representation in a cockpit display of traffic information (CDTI). The concept of the Future Air Navigation System is expected to make CDTIs important components for the flight deck. Twelve pilots each ran in 108 part task simulator trials where the task was to identify conflict aircraft on the CDTI. The study evaluated; (1) three altitude modes (relative, absolute, pilot selectable), (2) three profiles of the participants aircraft (ownship level, climbing and descending), (3) two levels of time to closest approach (low and high), and (4) two levels of traffic density (low and high). Encounter geometries, airspeed and vertical speed were randomized. Display mode had no main effect. In some conditions, the presence of complex interacting variables indicate relative and selectable display modes have accuracy advantages over absolute mode but do not indicate which display mode to use for all flight conditions.

ACKNOWLEDGMENTS

I would like to express my thanks and gratitude to the following people for their contribution to this study. Vern Battiste and Dr. Walter Johnson of NASA Ames Research Center for development, feedback and review, Dominic Wong of Rayethon Corporation for software development and implementation, Sheila Bochow of San Jose State University Foundation for guidance in statistics and data management, Dr. Kevin Jordan and Dr. Robert Cooper of San Jose State University for text review, and Captain Donald Rozel of United Airlines for providing facilities for the study.

This work was supported by the NASA Advanced Aeronautical Transportation Technologies program.

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Abstract

This study evaluated relative versus absolute text-based altitude representation in a cockpit display of traffic information (CDTI). The concept of Future Air Navigation System is expected to make CDTIs important components for the flight deck. Twelve pilots ran in 108 part task simulator trials where the task was to identify conflict aircraft on the CDTI. The study evaluated (1) three altitude modes (relative, absolute, pilot selectable) (2) three vertical profiles of the participants aircraft (ownship level, climbing and descending), (3) two levels of time to closest approach (low and high), and (4) two levels of traffic density (low and high). Encounter geometries, airspeed and vertical speed were randomized. Display mode had no main effect. In some conditions, the presence of complex interacting variables indicate relative and selectable display modes have accuracy advantages over absolute mode but do not indicate which display mode to use for all flight conditions.

Text Based Altitude Modes in a Cockpit Traffic Information Display

In civil aviation, while there are collision avoidance systems such as the Traffic-Alert and Collision Avoidance System (TCAS) that display proximal collision threats, there are presently no displays in use that show pilots general traffic information. Such displays are known as cockpit displays of traffic information (CDTI).

CDTIs are envisioned as important components of a new U. S. concept of air traffic management known as Future Air Navigation Systems, or free flight. In a free flight environment, traffic separation during the enroute portion of the flight may shift towards becoming more of a flight crew responsibility than with the present system of air traffic control (RTCA, 1995). Enabling pilots to directly monitor traffic is expected to safely aid traffic separation and enhance overall flight efficiency by loosening constraints in the current route structure.

2D display constraints

A free flight environment using CDTIs will require depiction of the horizontal and vertical positions of any aircraft that may affect the host (ownship) aircraft's path. Current electronic flight instrumentation (EFIS) utilizes color, symbols, and text on a plan view display to present navigation and traffic information.

Using 2D displays to determine an aircraft's horizontal position is the display convention in Air Traffic Control (ATC) and current TCAS displays. Using these 2D perspective displays to assess an aircraft's vertical position can be spatially difficult and less accurate when compared to determining an aircraft's lateral position (Johnston, Horlitz, & Edmiston 1993). Using a 2D display to determine another aircraft as a possible vertical threat may be an important challenge.

Display conventions

For the purposes of this study, the following terms and conventions are described. Relative altitude is the altitude relative to one's own position, in this case, referenced to ownship. Absolute altitude is the altitude referenced to altitude above mean sea level. An altitude mode is pilot selectable, and an altitude value is the information the pilot will interpret after selecting a particular altitude mode. In relative altitude mode, displaying another aircraft's altitude that is 2100 feet above ownship would appear as +21. The value is truncated to indicate altitude in hundreds of feet. A plus (+), or minus (-) sign is used to indicate whether an aircraft is above or below ownship's current altitude. Absolute altitude value, also truncated, of another aircraft at 37,000 ft would be 370. To indicate a displayed aircraft's direction of vertical movement, an up or down arrow is placed next to the altitude value. The addition of the aircraft's call sign and flight number to these values constitutes a data box. The data box concept is similar to current ATC displays. However, call sign and flight number are not used in TCAS displays. TCAS has a nominal vertical range of 2700 ft above and below ownship. This range can be extended to 9999 ft for depicting traffic either above or below ownship, but not in both directions simultaneously.

A possible first generation CDTI may incorporate a hybrid of TCAS and ATC display symbols to provide a higher level of traffic awareness than either a TCAS or ATC type display. Table 1 shows information displayed by a TCAS display, an ATC display, and a prototype CDTI.

Rationale

In a free flight environment, where flight crews will assume a higher level of responsibility for traffic separation, detecting and assessing the vertical states and possible threats to separation of other aircraft may become more difficult than in the current system of ATC voice control and TCAS single aircraft traffic advisories. This will likely be due to an increase in the number of depicted aircraft, the different vertical rate of change of the depicted aircraft, and the complexities of aircraft vertically converging from different directions towards ownship. For the same type of traffic encounter, use of a relative or a absolute mode may result in significant differences in threat detection and threat assessment. The purpose of this study is to determine the optimal text based altitude format for pilots using a CDTI, by finding when a relative, absolute, or a pilot selectable mode of either relative or absolute, is most appropriate during

Table 1

Basic information provided by TCAS, ATC, and prototype CDTI

Traffic information	TCAS	ATC display	CDTI
Altitude mode			
Relative	Yes	No	Yes
Absolute	Yes	Yes	Yes
Selectable	(most selectable)	No	Yes
Arrow for vertical directionality	Yes	Yes	Yes
Vertical speed	No	No	No
+ or - to indicate traffic above or below	Yes[a]	N/A	Yes[a]
Ground speed	No	Yes	No
Magnetic heading	No	No	No
Track by orientation of aircraft icon	No	No	Yes
Track or north up orientation	Track	Any[b]	Track
Aircraft call sign and flight number	No	Yes	Yes
Vertical range	-2700 to +2700 ft or +/- 9999 ft	0 to 60,000+ ft	Undecided
Depicted horizontal range	40 NM	Adjustable[c]	120 NM[d]

Note. [a] Relative mode. [b] North up typically. [c] 200 NM typically. [d] Proposed by the RTCA.

different traffic encounters. This information may lead to a human performance baseline for vertical threat detection and assessment using text in a CDTI equipped flight deck environment.

Towards CDTI use

An indication of the trends in aviation that are driving implementation of CDTIs is the occasional use of TCAS as a pseudo CDTI. Several airlines' flight crews now manage and monitor in-trail separation for certain oceanic routes using the TCAS 40 nautical mile (NM) range. TCAS is also unofficially used by some crews in the terminal area to monitor arrival sequencing. This traffic information allows early planning for appropriate changes in speed and aircraft configuration.

TCAS textually displays traffic altitude information in either the relative or absolute modes. Flight crews may by choice use TCAS in the relative mode or absolute mode, or may not have a choice of a mode because only one altitude mode is set by their company. In support of a free flight traffic management, TCAS is expected to be used as an integral tool with CDTIs and ATC as a fail-safe solution for tactical collision avoidance. Because of pilots' familiarity with TCAS symbology, and the critical nature of the alerting provided by TCAS, a similar format will be used in this study for the depiction of an aircraft's position, direction, and associated data.

When altitude is depicted as a relative value, accurate threat detection and assessment of a single aircraft's altitude using TCAS is not difficult (Chappell, 1990). One possible performance factor, during the task of assessing vertical threat, may be the cognitive demands of interpreting text altitude information on a 2D display in either the relative or absolute altitude mode, with one or more possible threat aircraft displayed. However, there are no published studies that use TCAS to evaluate target detection and threat assessment between numerically depicted relative and absolute values with either single or multiple aircraft.

CDTI Investigations

Early CDTI studies prior to the advent of TCAS, or the free flight concept, were characterized by exploring alternative formats instead of text, or alternative formats combined with text, to represent another aircraft's lateral and vertical position on a 2D display. Alternative formats were generally compared with other types of alternative formats, rather than to a text baseline or an all text condition.

Lester and Palmer's (1983) CDTI study used text and looked at pilots' judgments of current or future vertical separations. The study used absolute mode, absolute mode with an absolute value predictor for future altitude position, and an absolute value that was combined with a relative value predictor that predicted altitude position. While the results generally found better performance with relative values, it is not possible to determine if the better performance was due to the relative value or the predictor included in that condition.

Hart and Loomis' (1980) CDTI used relative values of altitude that were coded symbolically by object shape and orientation. The symbols used were selected using questionnaire results measured from a range of general aviation and commercial pilots. During training the pilots indicated a preference for the shape that depicted relative altitude. Data from this study showed that error rates to detect a vertical threat were higher when compared with a target shape that had an added numerical value for absolute altitude. Detection and selection performance was unchanged when an arrow was added to the symbols to indicate a climb or a descent.

Beringer (1991), using non-pilots, investigated relative and absolute altitude non-text symbols sized to represent another aircraft's altitude. Comparison of these values with relative and absolute text values, collapsed with symbols that used predictors of future altitude position, resulted in the absolute digital condition having the fastest threat selection. It is not known whether absolute text values, or absolute text values with altitude predictors collapsed into the overall absolute condition, provided for the better performance of the absolute mode.

Among flight crews there is a lack of consensus on the issue of usefulness in altitude values when using a TCAS or CDTI display. Johnson, Battiste, Delzell, Holland, and Belcher (1997), after a series of aircraft simulator demonstration trials of CDTIs, found differing opinions among, and within crews, about the effectiveness of relative or absolute values while using the CDTI. Some crews believed it easier to use relative values in all traffic situations. Others felt absolute values have advantages, and some believed that there are circumstances where it would be useful to have both values available. Still others thought there would be no difference between either value. Similar opinions were expressed about the merits of a particular mode when using TCAS. Some of these crews were unaware that absolute values are available using TCAS, or that their company may have locked out this value.

Early evaluations of CDTIs (Lester & Palmer, 1983; Hart & Loomis, 1980; Beringer, 1991), have little that is generalizable to providing a text based relative and absolute mode baseline for evaluations of threat detection and threat assessment. These experiments did not directly compare performance using absolute and relative altitude text values. In addition, none of these studies used more than one other aircraft that changed altitude. More importantly, none of these studies investigated cases when ownship changed altitude.

The addition of such conditions may affect threat detection and threat assessment processing, and thus, performance. High processing requirements in these tasks could result in delayed target detection and possible hazardous threat assessment errors. These processing requirements could also negatively impact concurrent tasks. Processing requirements, however, may contrast significantly in differing vertical encounters. These processing requirements may cause workload to vary, may differ in difficulty, and may affect accuracy within a specific encounter depending on whether a relative or absolute altitude value is depicted. This view is similar to the varying comments made by flight crews about CDTI altitude values. In determining where high processing requirements occur in altitude separation tasks, a human constraint may be revealed which may affect performance in a free flight environment. If limitations are apparent, decision aiding tools for vertical and lateral separation tasks may be required that do not adversely impact the primary tasks required of the navigation display.

The scan task

High processing loads might be reflected by an increase in scan time. Previous to Electronic Flight Instrument System (EFIS) display use, Harris and Cristhilf (1980) observed that during non-maneuvering flight, pilots' scan had a mean dwell of .9 s on the navigation display. Tole, Stephens, Harris, and Ephrath (1982) found that under verbal loading tasks, when crews communicated with ATC or among themselves, visual scan dwells increased on the instruments associated with the present dynamic or navigational task. With the map features, introduced in 1983 and now commonly used on EFIS navigation displays, and the addition of CDTI traffic information, further increases in scan dwell may be observed when performing two tasks. Increases in scan time may adversely impact other crew tasks.

Dynamic considerations

To assess the impact of the complexities of the environment on the usefulness of text-based displays, some consideration should be given towards the dynamic nature of altitude changes. Aircraft climb and descend in various ways at varying rates. These rates are determined by optimum performance profiles generated by the flight management computer (FMC), by pilot calculation, or, for traffic separation, by ATC. It is within this environment that the display characteristics indicating the changing vertical states of one or more target aircraft, as well as ownship's, may impose the greatest processing load for a pilot to determine which aircraft may become a threat. A threat, in this instance, is defined by the current high-altitude separation standards. Aircraft above 29,000 ft. that are less than 5 NM laterally distant and less than 2000 feet vertically from another are in separation violation.

An information process model for evaluating altitude threat

To determine and to assess threat traffic displayed on a CDTI, pilots may use some components of a proposed vertical threat decision processing model (see Figure 1). To reach the problem solution, this proposed model operates on

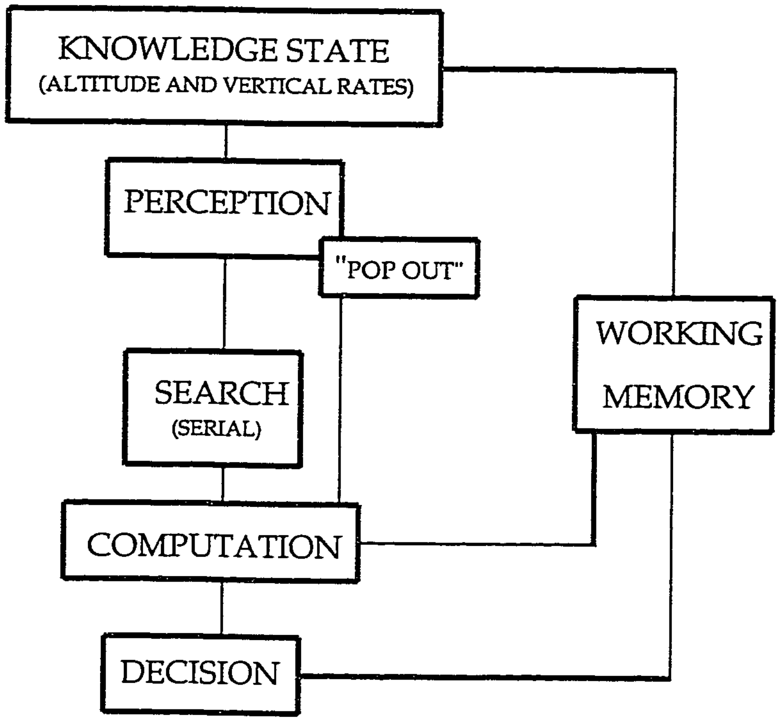

Figure 1. Information processing model for evaluating altitude threat.

the assumption of the pilot making use of 5 stages to achieve what they believe to be a positive threat identification. The five steps are:

(1) Knowledge state of their altitude and vertical speed.

(2) Perception of salient homogenous and pop-out features (e.g., an aircraft that is level and within ownship's vertical separation, or, an aircraft that is changing altitude in an environment with variable noise or traffic density, respectively).

(3) Search process: a serial search based on an object's bearing, horizontal and vertical position to ownship, and whether aircraft are changing altitude in a converging manner. This results in identification of aircraft that are target(s). Once an aircraft is determined to be a target, it is then classified as a potential threat.

(4) Comparison consistency of target aircraft by (a) all target aircraft concurrently, not serially, compared to ownship's state using differences in their rate of change in relation to their altitude, or (b) individual target aircraft rate of vertical change and in altitude serially compared to ownship's state. Method of comparison for (a) or (b) can be mental arithmetic (i.e., altitude/rate of change) or an estimation based on altitude difference and relative rates of vertical change between the targets indicated by the changing of their digits. Using these methods, the target which will first reach separation violation is identified as the threat aircraft.

(5) Solution; threat determination based on confidence of methods used during comparison stage.

When the displayed properties of relative and absolute altitude values, as they occur in a specific vertical encounter are applied to this model, general predictions about target detection and threat assessment performance can be made.

Properties of an altitude value's threat

It is anticipated that a pilot's ability to detect and process vertical threat will vary with altitude display mode in an identical vertical encounter. Irrespective of the process model used to determine vertical threat, the signal properties of the displayed altitude values will provide cues of varying salience. Recognizing and accurately identifying these cues may be key to efficiently implementing the steps of the vertical threat process model. The signal properties of relative and absolute values are described by the following examples: when ownship is level and when ownship is changing altitude.

Ownship level. When ownship is level, and altitude is depicted in either the relative or absolute mode, vertical changes in any displayed aircraft are signaled equally by the movement of the numbers in the relevant data box. With ownship level and the absolute mode is used, the only considerations are that assessment of threat requires memory of ownship altitude, and the evaluation of when the changing altitude numbers will reach the vertical separation criterion.

This evaluation will probably be in the form of mental arithmetic. Using relative mode when ownship is level does not require memory of ownship altitude and only requires evaluation of the threat aircraft's approach towards the vertical separation criteria. The participant would most likely accomplish this evaluation using the memory of a known vertical separation criterion, and would not require mental arithmetic to evaluate proximity, or to signal changing proximity. However, during level flight using either mode, any aircraft altitude values that change unambiguously signal that another aircraft is changing its altitude.

Ownship changing. If using the relative mode when ownship is changing altitude, altitude values on all other aircraft will change, unless these aircraft are changing altitude at exactly the same rate as ownship. Thus, using the relative mode, if one of these aircraft begins to change its altitude, this will tend to be masked by all the other changing values. Using absolute mode in this case, only aircraft that are also changing altitude will be signaled by their changing values. As in the first example, ownship changing altitude using absolute mode probably requires mental arithmetic to evaluate proximity, but not to signal proximity. Relative altitude display mode, in this instance, would not require mental arithmetic to evaluate proximity or to signal changing proximity. It is not hypothesized where or when in the altitude process model the recognition and identification of the signal property cues will occur.

Other performance factors

Detection and assessment of threat may be affected by other factors. Drury and Clement (1978) found that search time was heavily dependent on the number of background characters but not their density of grouping. CDTIs are currently envisioned to display aircraft at ranges at up to 80 NM. This range, twice that of current versions of TCAS, has the potential of depicting large numbers of aircraft. Due to ATC's lateral separation requirements and restrictions in the number of altitudes bands displayed, these aircraft will be dispersed across the display, keeping the grouping density of the aircraft low. Thus, each additional aircraft depicted on the CDTI may negatively affect vertical threat detection and assessment performance.

Other cases that may affect threat detection and assessment performance are pilots that experience multiple vertical encounters, multiple directions of vertical closure (e.g., occurring above, below, or from above and below), large differences in altitude between relevant aircraft, and varying rates of vertical change among all aircraft. For example, it would be possible for an aircraft initially distant from ownship but closing at a high rate, to be masked by an already identified slowly, closing aircraft.

Expected performance

The experiment evaluated three altitude display modes (relative, absolute, or pilot selectable) with ownship level, climbing, or descending, in two (low or high) levels of traffic density, and with two levels (60-70 s and 110-120 s) of time to a loss of separation. First, it is expected that the use of relative values will lead to better performance when ownship is level and the threat aircraft are changing altitude in low and high traffic levels. Although the signaling properties of the absolute and relative modes will be similar (i.e., the altitude values in both conditions change) it is expected that the relative condition will lead to higher performance due to not having to use mental arithmetic.

Second, absolute values may offer detection performance advantages over the relative altitude mode when ownship is changing altitude and target aircraft are also changing altitude. In this case, while use of relative mode would not require mental arithmetic, the relative mode's changing values could mask detection, compared with using the absolute mode. As the number of displayed aircraft increases, this masking effect may increase.

Third, using the selectable mode may provide the best overall performance if the participants recognize when to utilize each mode for the given ownship profiles mentioned above. There is, however, a possibility that performance may suffer in unknown ways using the selectable modes if the participant uses sub-optimal strategies (e.g., a participant uses the selectable mode because they anticipate superior performance due to its flexibility, but do not perceive where or when to apply the appropriate mode).

Finally, the high time to closest approach level may result in larger error rates because of the generally increased initial vertical distance from ownship. This may increase the difficulty of the task because it requires a larger altitude extrapolation to perform the detection and threat selection compared with the low temporal level.

Method

Participants

Twelve pilots with airline transport ratings who are active flight crew members with a major U.S. airline were run in a within participants design. All participants were either captains or first officers, with the exception of one participant who was a flight engineer but had extensive pilot experience. The mean flight hours were 7925 (range = 4000 – 21,000 hours) with 2433 hours in EFIS equipped aircraft (range = 800 – 5000 hours). All participants had EFIS and TCAS experience. Thirty-three percent of the participants had fighter or interceptor experience using an on-board display of aircraft traffic obtained during military service. Participants were paid an hourly rate, administered by The Sterling Corporation, acting under a human research contract with the National Aeronautics and Space Administration (NASA).

Experimental conditions adhered to APA (American Psychological Association, 1992), San Jose State University, and NASA human research ethical principles. Informed consent forms for San Jose State University and NASA were completed by all the participants prior to the experiment.

Apparatus

The experiment was administered using a computer based work station. The equipment included a 17 inch diagonal color monitor with a resolution of 1024 x 768. The display was driven by a P-6, 200 MHz processor with audio feedback capability. Aircraft data and movement was updated at 20 Hz. The screen refresh rate was 75Hz. The CDTI screen size measured 7 x 8 in, the same size as the navigation display used in the Boeing 747-400. Format and display conventions were nearly identical to the 747-400 navigation display, except for the deletion of most navigation functions. To accommodate participant's handedness, left and right hand mouse selection tools were provided.

Design

A 3 (mode) x 3 (ownship state) x 2 (temporal) x 2 (traffic density) within subjects factorial design was used. There were three levels of mode; relative altitude, absolute altitude, and pilot selectable for either relative or absolute modes. The three levels of ownship state are level, climbing, or descending. The temporal factor was time of closest approach of a threat aircraft to ownship. The two levels of the temporal factor were a range of 60-70 s and 110-120 s. The two levels of traffic density were low and high. In the low condition, 5 or 6 context aircraft populated the screen. High traffic level was 10 to 12 context aircraft displayed on the screen. For each trial, 1 or 2 context aircraft changed altitude, but their horizontal distance and heading did not make them a threat and were not included as a design factor. Three replications of the factors allowed a total of 108 trials for each participant for analysis.

Twenty-two types of vertical encounter configurations were presented; six for ownship level, 8 for ownship climbing, and 8 for ownship descending. Encounter configurations are illustrated in Figure 2 and the altitude display modes in Figure 3. For each encounter configuration, the program generated 100 scenarios, and randomly selected 36 trials from each configuration. Relative and absolute display modes were counterbalanced for subjects. Each display mode was presented in three respective blocks. Each block contained equal numbers of trails of time to closest approach, traffic density and ownship profiles, with those variables presented randomly. To allow for general threat assessment and threat detection strategy formation, the selectable altitude mode was presented after the relative and absolute conditions.

Procedure

The experiment was conducted in a room with low noise and stable light conditions and was free from interruption. To monitor the experiment and the equipment the experimenter was in the room with the participant, though separated by a partition. For any malfunction or interruption, replacement trials

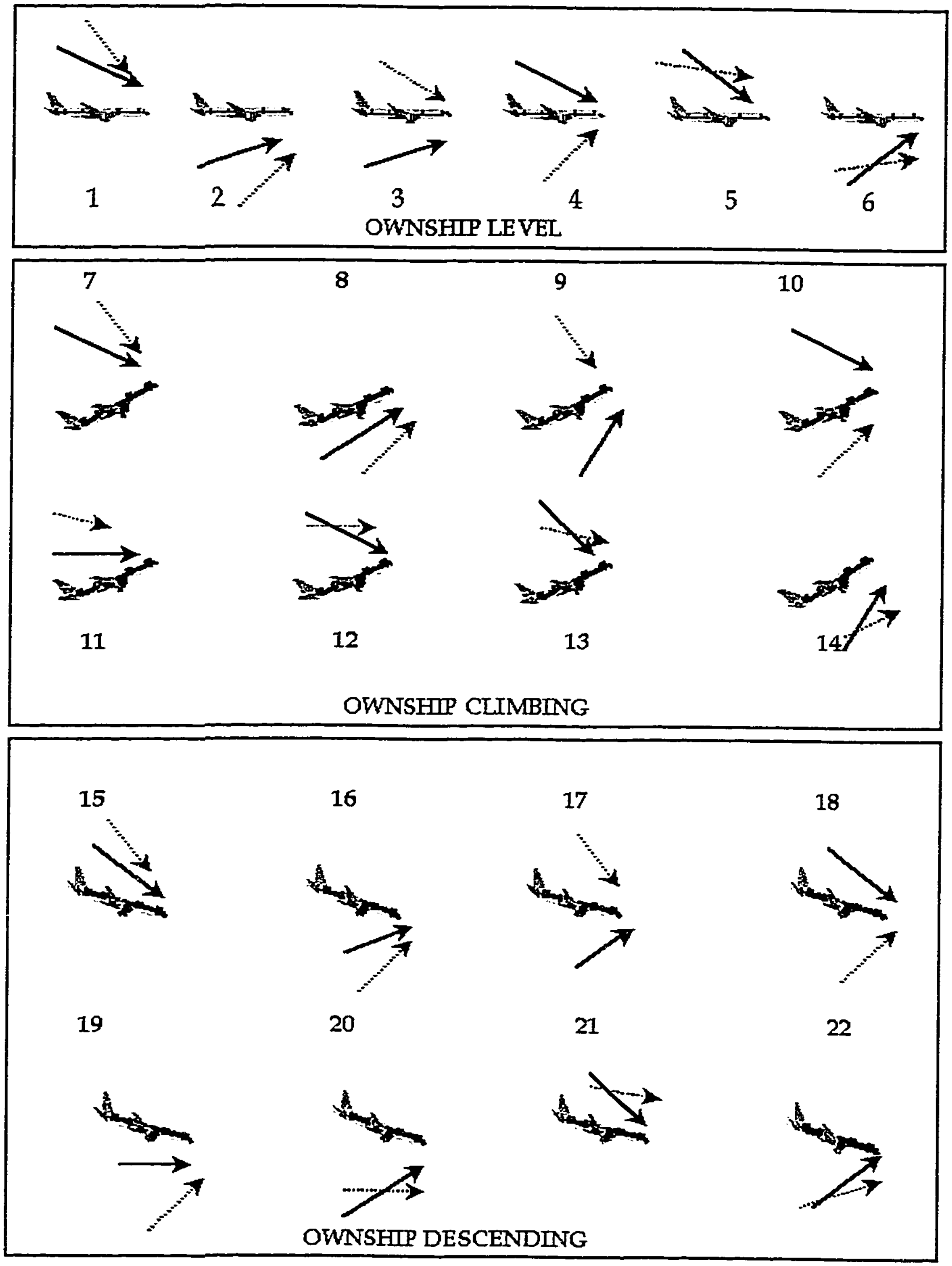

Figure 2. Types of vertical encounter configurations.

= OWNSHIP = THREAT = SECONDARY THREAT

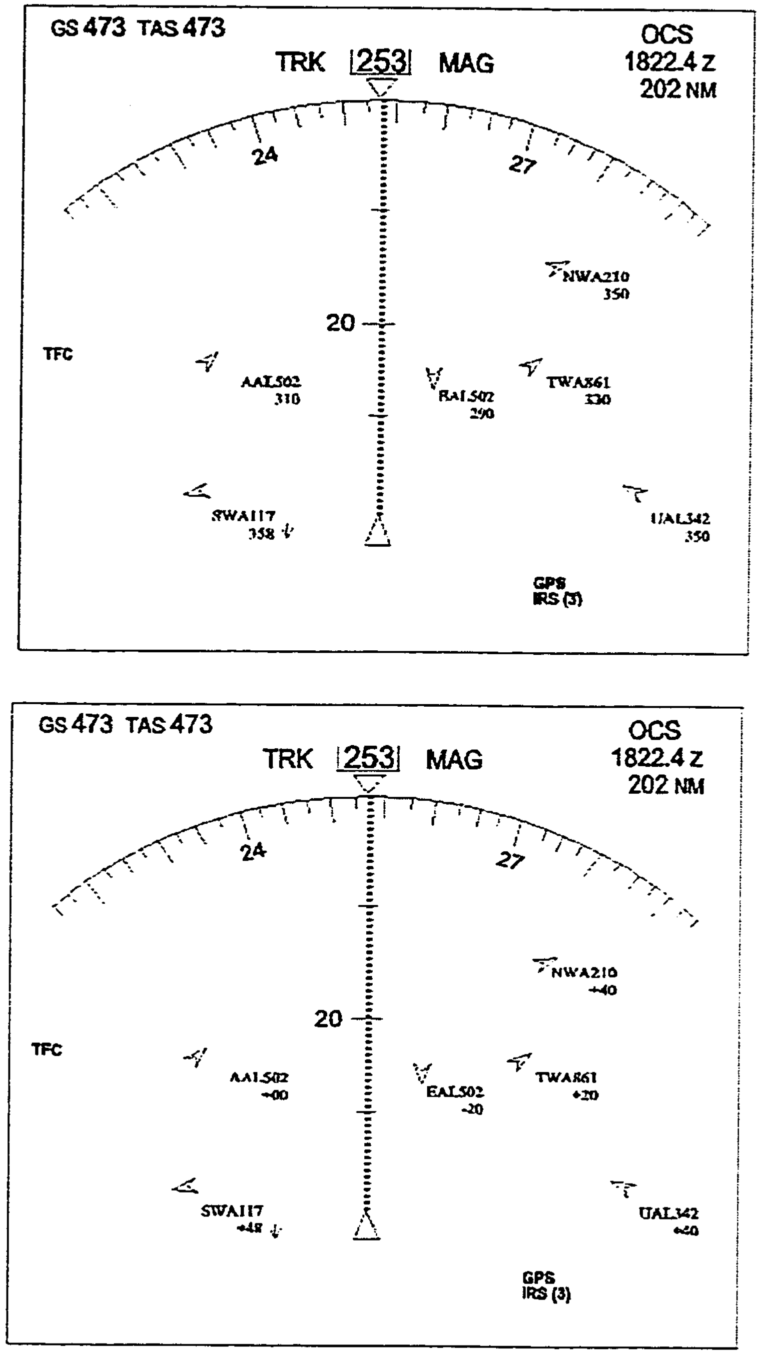

Figure 3. Experimental CDTI display set at 40 nm range. The top displays absolute values and the bottom displays relative values.

of the same type could be added at the end of each experiment run, though no replacement trials were required.

Instructions for the participant were in printed and verbal form. A static picture of the display, the screen symbology, and their specific meanings were provided in relative and absolute modes. The task was described to the participant with emphasis on the participant making a timely and accurate determination of the aircraft that would first violate separation standards of 5 NM and 2000 ft vertically. Participants were instructed that a separation threat existed only when one or more aircraft (including ownship) were changing altitude. Nine practice trials were given (three in each altitude mode) to allow familiarity. To mitigate practice effects, an additional 12 trials, equally distributed over the three modes, were presented before the 108 experimental trial sessions and were not included in the analysis. The experiment, including introduction, training, breaks, and debriefing, took an average of 2.5 hours.

At the beginning of each mode, a preview curtain appeared on the screen prior to the start of the trial. The curtain informed the participant of the altitude mode to follow and whether ownship was level, climbing or descending. The curtain provided no information about the traffic density or temporal level. Ownship's altitude, vertical speed, and ground speed, was displayed on the participants screen using "round dial" type aircraft flight instruments that displayed altitude in feet (ft), vertical speed in feet per minute (VS), and airspeed in knots true airspeed (GS) in a no wind condition. The display's range was set at 40 NM for all trials and was not adjustable. This setting was a compromise in order to allow all threat aircraft to be displayed and to avoid close range traffic clutter if the display was allowed to cycle out towards more extended ranges.

The trial started when the participant clicked the mouse on the ownship symbol. The duration of the trial was a maximum of 45 s, and ended when the participant selected the aircraft they determined would first violate separation standards, or when 45 s had elapsed. After each trial, the mouse icon was automatically returned to the ownship position. During selectable mode trials, the participant was to first select the desired mode for the flight conditions from the preview screen and then initiate the trial from ownship position. Participants could then switch between the two modes during the trial. Registering accuracy and RT occurred when the mouse icon was placed on an aircraft data box and then selected.

The rate of vertical change of ownship, threat, and secondary threat aircraft were randomized from a range of values that represent typical aircraft performance for the altitudes of 25,000 ft to 43,000 ft. To ensure adequate numbers of encounters that had vertical threats directed towards ownship, the altitude range for ownship was 29,000 to 37,000 ft. To ensure threat closure on ownship's lateral and vertical position, both the GS and VS of threat and secondary threat aircraft were always higher than ownship's. At both the low and high temporal ranges, the threat aircraft was to be ultimately less than 2000 ft vertically and between 0.5 and 4 NM horizontal from ownship's position. For the same temporal and density conditions, the secondary threat was also to arrive between 0.5 and 4 NM from the primary threat aircraft. The secondary threat aircraft, for both temporal ranges, was more than 3000 ft and no more than 4000 ft vertically from ownship. To eliminate the complexities involved with (1) ensuring that the threat and secondary threat aircraft did not conflict or collide prior to reaching their programmed temporal level while (2) maintaining a threatening posture in regards to ownship position, these aircraft were programmed to arrive at the same approximate lateral position. The complexities in programming also caused the exclusion of the condition in which any threat or secondary threat aircraft first climbed or descended through ownship's altitude before it became a real or perceived separation violation for lateral distances less than 5 NM.

For either temporal level, threat and secondary threat aircraft arriving at the same approximate position resulted in their placement at the trial beginning at a relatively uniform horizontal distance from ownship. Uniform lateral distances at the beginning of a trial could have led to cues which may have assisted in early detection of threat aircraft. This was mitigated, for both temporal ranges, by the above method of varying terminal distance and by varying the airspeed of the threat, secondary threat, and ownship from trial to trial. Thus, relative to ownship's start position, the horizontal distance between either the threat or secondary threat aircraft could vary up to 19 NM for the120 s temporal condition. Table 2 depicts the ranges of aircraft speeds, rates of climbs, and separations at either temporal condition.

During a single trial, ownship, threat, and secondary threat or context aircraft did not vary their GS or VS. Additionally, all aircraft were on a constant magnetic heading. The horizontal closure angle for threat and secondary threat aircraft towards ownship were randomized and overlapping horizontal trajectories for threat and secondary threat aircraft were prevented by restricting their heading to no less than 15 degrees between them. Ownship's level flight path adhered to the cardinal rules of altitude for high altitude airspace (e.g., if on a west heading, 31,000 ft, 35,000 ft. etc.). Ownship's heading, however, was randomized, trial to trial, from either of the cardinal directions.

Results

Twelve participants each completed 108 trials with no replacement trials required.

The dependent variables analyzed in this study were aircraft threat selection accuracy and aircraft threat selection reaction time (RT). Table 3 presents descriptive statistics for accuracy and RT. Overall accuracy was 66%. When the participant failed to respond during a response interval, the values for that cell were replaced by a mean of the subject, condition, and overall accuracy

Table 2

GS, VS, and separation for relevant aircraft

	Level	Climb	Descent	Separation
Ownship				
GS	450-455	410-415	460-465	-
VS fpm	-	810-1650	1160-2900	-
Threat				
GS	465-470	420-430	480-500	- 2000ft & .5 to 4 NM
VS fpm	-	1100-2350	1560-3700	-
Secondary Threat				
GS	465-470	420-430	480-500	3000 to 4000ft .5 to 4 NM
VS fpm	-	1110-2350	1560-3700	-

Table 3

Mean accuracy (percent), standard error, mean reaction time and standard error.

	Accuracy		RT	
	%	SE	M	SE
Overall	66	.014	26.57	.25
Display mode				
Relative	64	.024	25.90	.42
Absolute	65	.026	27.00	.44
Selectable	71	.025	26.75	.44
Ownship				
Level	74	.022	25.90	.42
Climb	65	.023	27.04	.43
Descent	60	.027	26.75	.44
Time to Closest Approach				
60 - 70 s	79	.018	24.57	.35
110-120 s	54	.019	28.56	.29
Traffic Density				
Low	69	.018	26.29	.37
High	64	.022	26.84	.33

means (Winer, Brown & Michels, 1991). When no selection was made this same cell replacement method was utilized for RT. Such time outs occurred on 9% of the trials, contributing to an overall error rate of 34%.

For the 432 selectable trials across the 12 participants, 94% of the threat selections were made using the relative display mode. In 59% of these selections, the participants started the trial in the relative mode and made no alternations between modes before selecting the threat aircraft. Frequently, the participants started in the relative mode, switched modes, but then made their response after switching back to the relative mode. For the remaining cases, the participants either started the selectable trial in the absolute mode and switched to relative mode or they started and made their selection in the absolute mode.

Accuracy Performance

Separate 3 (altitude display mode) x 3 (ownship profile) x 2 (time to closest approach) x 2 (traffic density) within subjects analysis of variance (ANOVA) were conducted on the accuracy and RT data. There was no main effect for altitude display mode for the overall ANOVA performed on accuracy data. However, accuracy was affected by whether ownship was level, climbing or descending, $F(2, 22)=11.30$, $p<.01$. Comparisons among the three measures of ownship revealed a significant effect for ownship level versus ownship climbing, $F(1, 11)=9.47$, $p = .01$, and for ownship level versus ownship descending, $F(1, 11)=17.97$, $p< .01$ (see Figure 4). Bars depicted in figure captions indicate ± 1

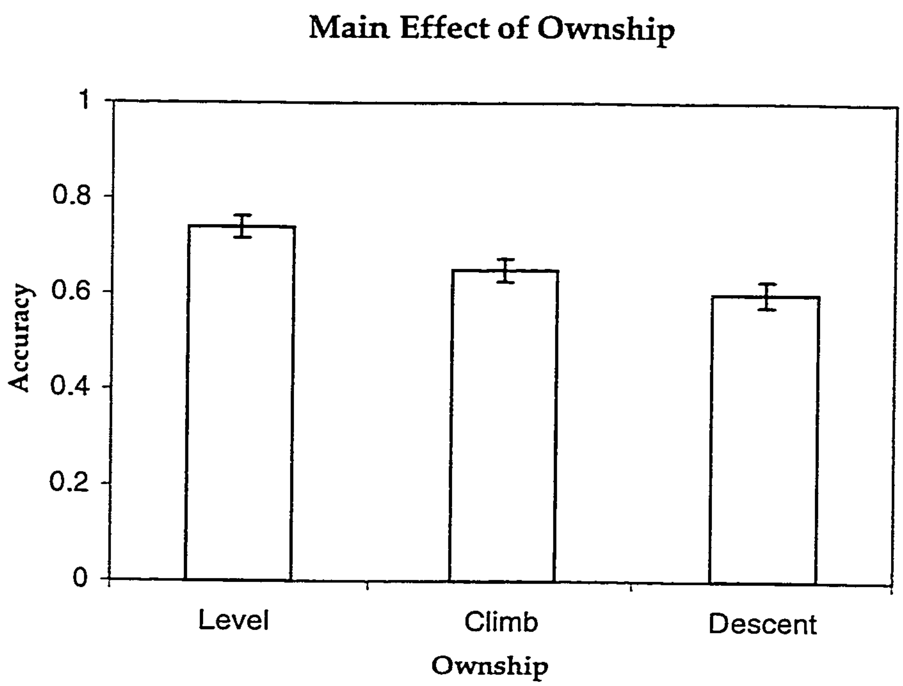

Figure 4. Accuracy differences for ownship profile.

standard error of the mean. In these two comparisons accuracy performance decreased when ownship was not level. There was no significant difference when comparing ownship climbing to ownship descending, $F(1, 11)=3.50$, $p >$ .05. Time to closest approach also had a significant main effect, $F(2, 22)=47.33$, $p<.01$, with accuracy decreasing in the 110- 120 s time to closest approach condition (see Figure 5). The results also indicated that there was no effect of density, $F(1, 11)=3.13$, $p>.05$.

Significant interactions for accuracy were found with display mode by time to closest approach, $F(2, 22)=8.61$, $p<.01$, for time to closest approach by density $F(2, 22)=6.32$, $p<.05$, and for mode by time to closest approach by density, $F(2, 22)=4.41$, $p<.05$. The simple effects analyses of time to closest approach at each of the three levels of display mode showed performance was significantly better for all three altitude display modes in the time to closest approach 60-70 s condition (relative mode, $F(1, 11)=22.39$, $p<01$, absolute mode, $F(1, 11)= 120.46$, $p<.01$, selectable mode, $F(1, 11)=16.70$, $p<.01$). Simple effects for display mode at time to closest approach 60-70 s did not reach significance, $F(2, 22)=1.59$, $p>.05$, indicating no difference in accuracy performance between display modes at time to closest approach 60-70 s. Display mode at time to closest approach 110-120 s did, however, reveal a significant effect for mode, $F(2, 22)=8.44$, $p<.01$, indicating that performance was better in the 110-120 s condition when using the selectable mode (see Figure 6).

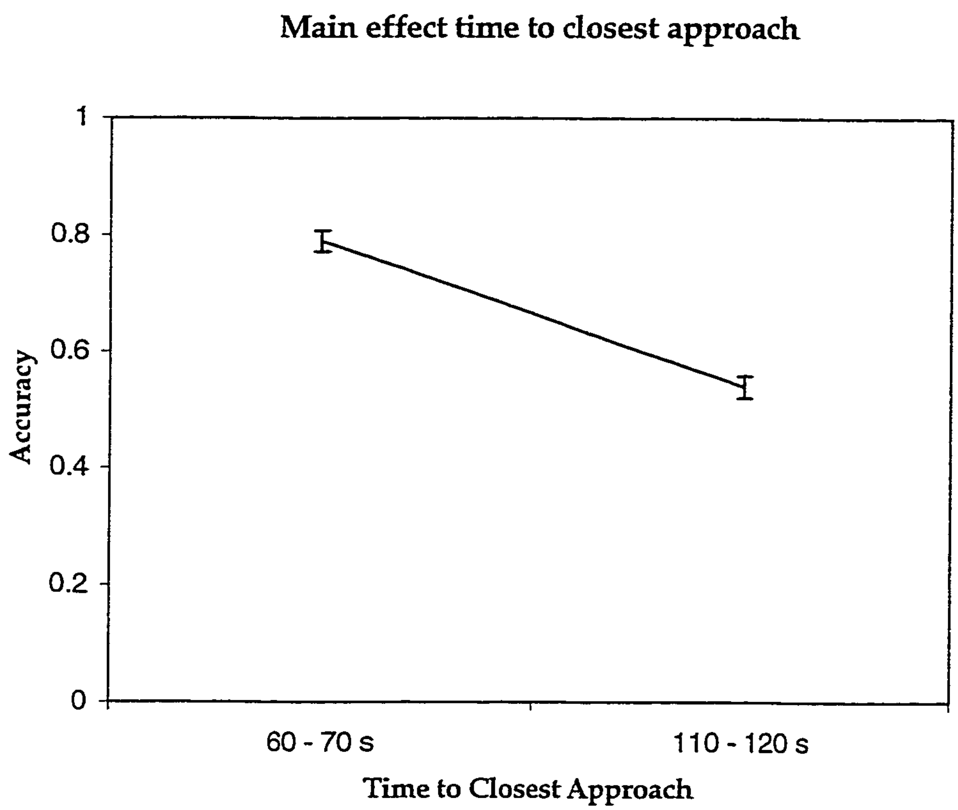

Figure 5. Accuracy differences for time to closest approach

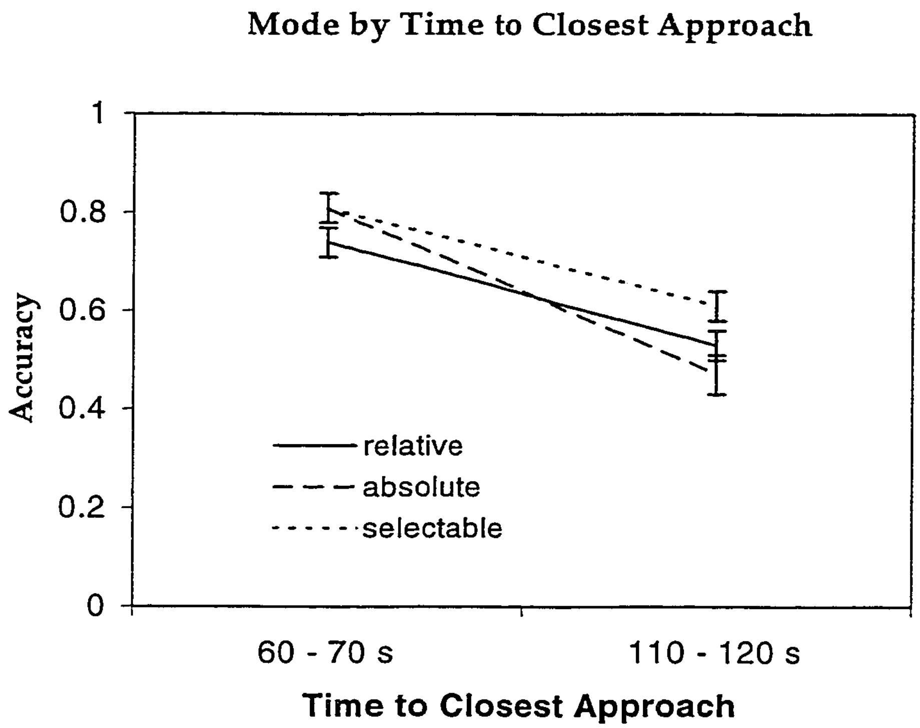

Figure 6. Accuracy differences for mode at time to closest approach.

Given that over 90% of the threat selections in the selectable condition of the experiment were made with the relative display mode, an ANOVA of relative and absolute display modes was run with the selectable trials dropped. The interaction of display mode by time to closest approach remained significant, $F(1, 11)=12.38$, $p<01$). Simple comparisons of this effect showed participants in the relative display mode to have significantly better accuracy than the absolute display mode in the 110-120 s time to closest approach condition, $F(1, 11)=5.22$, $p<.05$. At time to closest approach 60-70 s, there was a crossover with absolute display mode indicating a trend towards better performance than the relative display mode for this condition, though the effect was marginal, $F(1, 11)=3.53$, $p=.087$ (see Figure 7).

Simple effects conducted on the time to closest approach by density interaction indicate no significant difference in accuracy performance for traffic density at time to closest approach 60-70 s, $F(1, 11)=<1.0$ (Figure 8). For the 110-120 s time to closest approach level, there was a significant effect for density, $F(1, 11)=7.29$, $p<.05$. Simple effects for the time to closest approach at the two levels of density show a decline in performance for both low and high traffic densities at the longer time to closest approach, $F(1, 11)=23.26$, $p<.01$, and $F(1, 11)=39.26$, $p<.01$, respectively. Where overall accuracy performance is worse than in the 60-70 s time to closest approach condition, the combination of high density traffic and large extrapolation distances resulted in further decreases in performance.

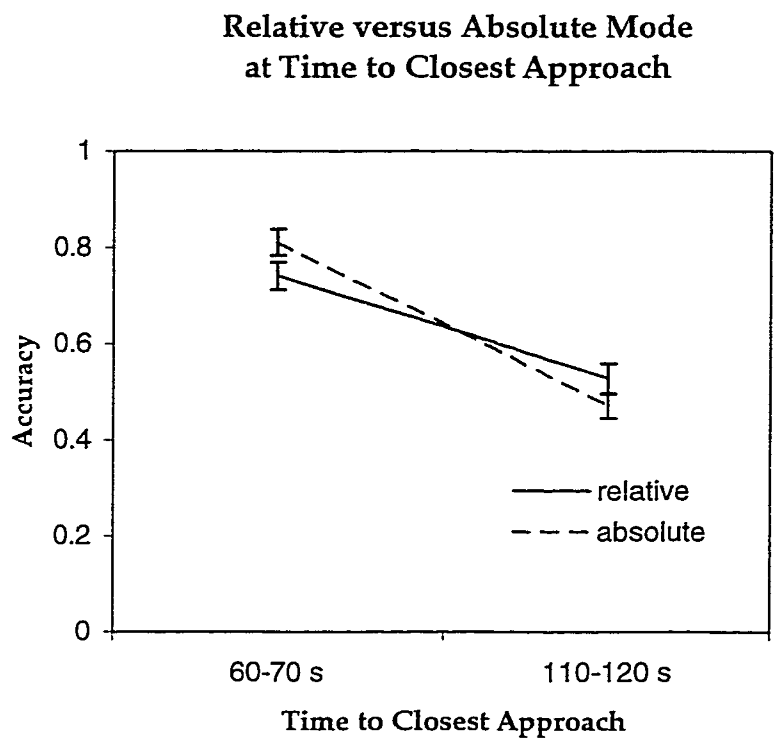

Figure 7. Accuracy differences between relative and absolute display-modes at time to closest approach.

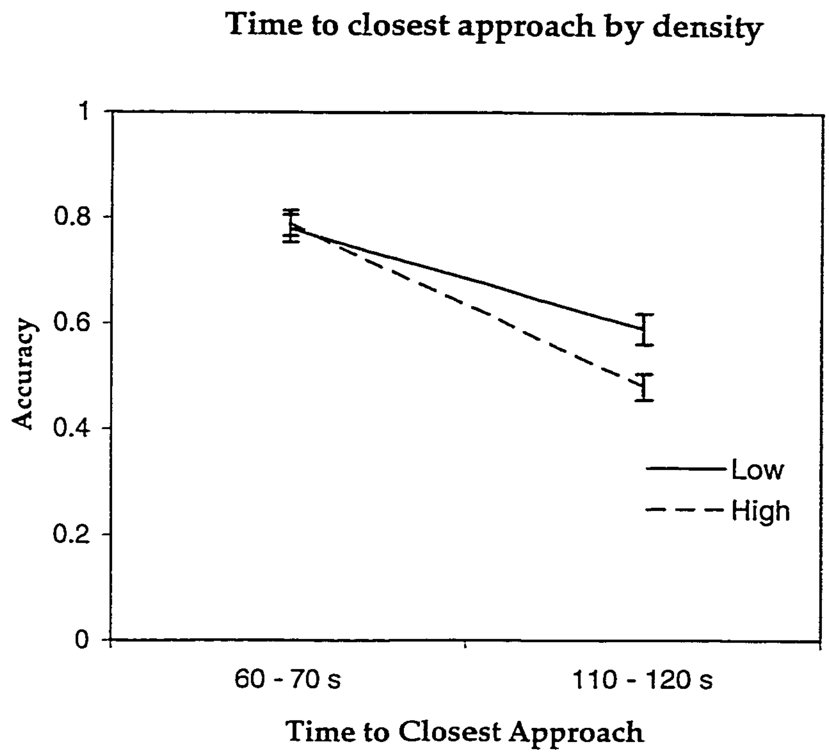

Figure 8. Accuracy differences by time to closest approach and density.

The display mode by time to closest approach by density interaction was examined for each of the three display modes. For the relative display mode there was a significant main effect for time to closest approach, $F(1, 11)=22.39$, $p<.01$, non-significant main effect for density, $F(1, 11)<1.0$, and a significant interaction for time to closest approach by density, $F(1, 11)=9.66$, $p=.01$ (See Figure 9). The same comparisons were run on the absolute and selectable modes. Similar results were obtained for both these display modes, with time to closest approach for both the absolute and selectable modes exhibiting a significant main effect, $F(1, 11)=120.46$, $p<.01$ and $F(1, 11)=16.62$, $p<.01$ with both obtaining non-significant results for density $F(1, 11)= 3.74$, $p>.05$ and $F(1, 11)>1.0$ (See Figures 10 and 11). For the absolute mode, an interaction was found for time to closest approach by density, $F(1, 11)=8.00$, $p<.05$. No interaction was found for the selectable mode, $F(1, 11)<1.0$, though the selectable display mode was utilized essentially as a relative display mode. These results indicate no effect for density on any display mode at time to closest approach 60-70 s. The interactions are explained by the decrease in performance seen in the high density traffic, 110-120 s time to closest approach condition. There was, however, no significant difference between relative and absolute altitude displays at the high traffic density, 110-120 s time to closest approach condition, $F(1, 11)=3.40$, $p>.05$.

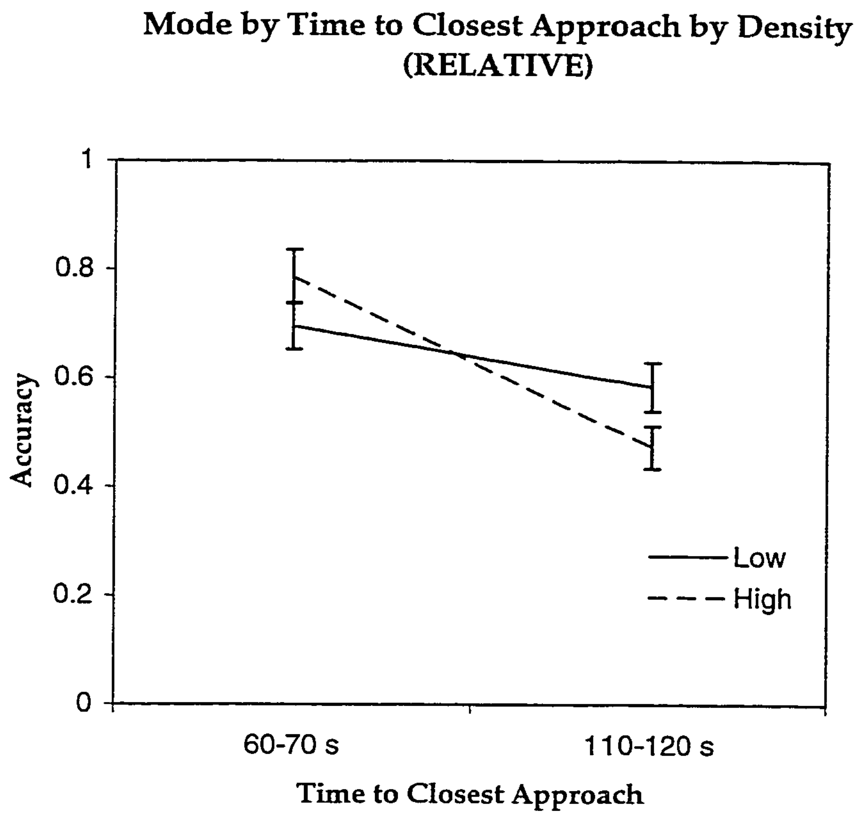

Figure 9. Accuracy differences for relative mode for time to closest approach and density.

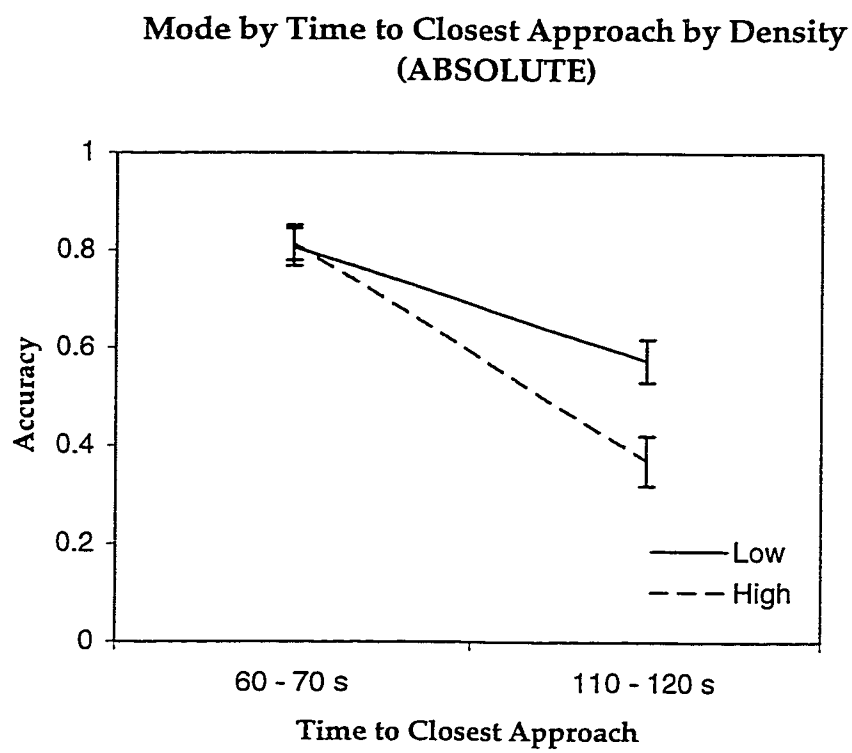

Figure 10. Accuracy differences for absolute mode for time to closest approach and density.

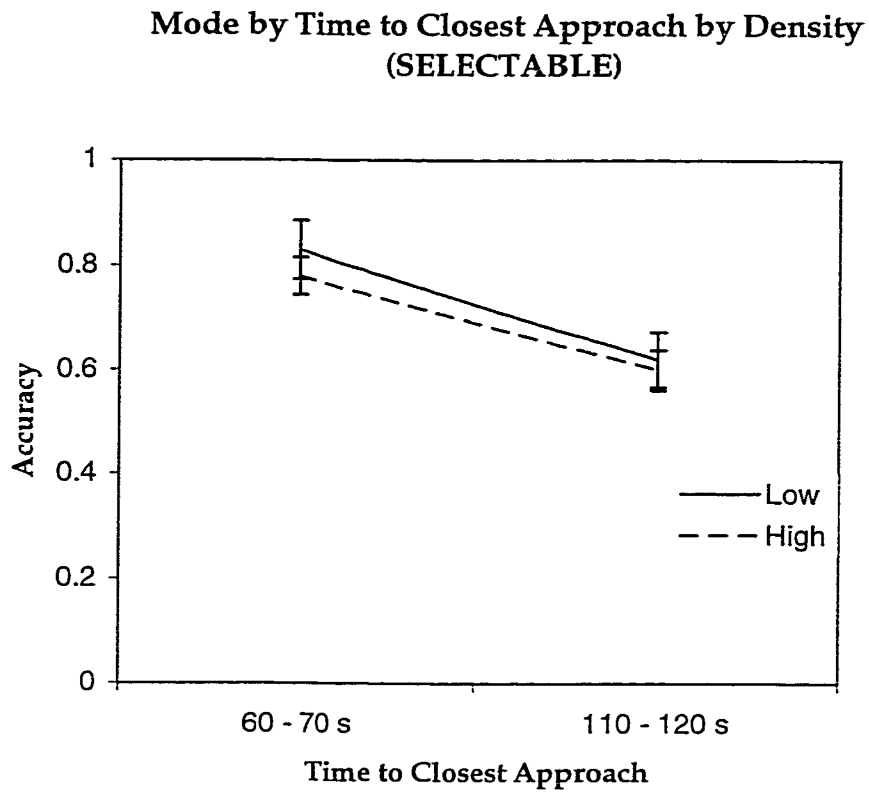

Figure 11. Accuracy differences for selectable mode for time to closest approach and density.

Indications that participants guessed to select a threat aircraft did not occur. Omitting trials where no response was made (45 seconds), comparing the accuracy rates for low and high traffic densities when participants selected the context show that in low density traffic the context aircraft was selected 6.0% of the time while in high density traffic the context traffic was selected 11.0% of the time, a rate that corresponds to the doubling of the numbers of depicted between the two traffic density conditions.

In general, accuracy performance between the three altitude display modes can be explained as not significantly different in performance, except in conditions of longer time to extrapolate a selection decision. The addition of higher traffic density resulted in accuracy performance decrement at the longer threat detection and selection conditions. Additionally, when ownship was climbing or descending, performance for threat detection and selection suffered to a higher extent still.

Reaction Time

The overall ANOVA performed on the reaction time data resulted in a significant main effects of ownship, $F(2, 22)=6.02$, $p<.01$, and a main effect for time to closest approach, $F(1, 11)=74.20$, $p<.01$ (see Figures 12 and 13). Neither mode or density were significant, $F(2, 22)>1.0$ and $F(1, 11)=3.52$, $p<.05$. In the time to closest approach conditions, participants were slower to select a threat in the 110-120 s condition than in the 60-70 s condition. The main effects of time to

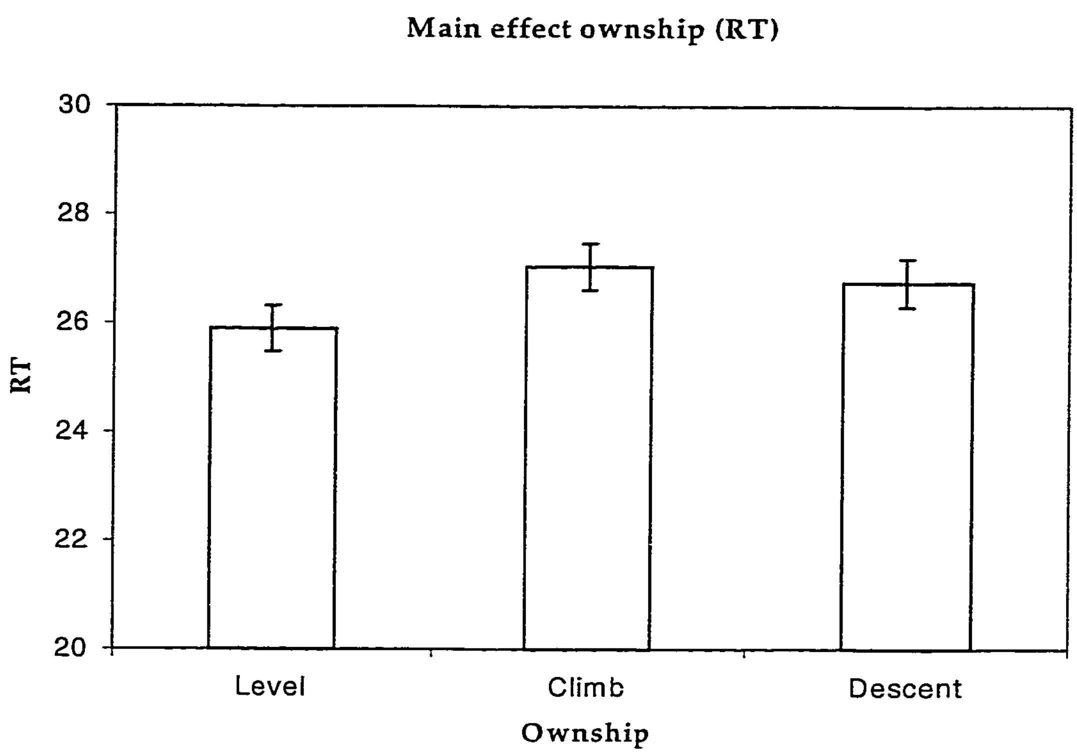

Figure 12. Reaction time differences between ownship profile.

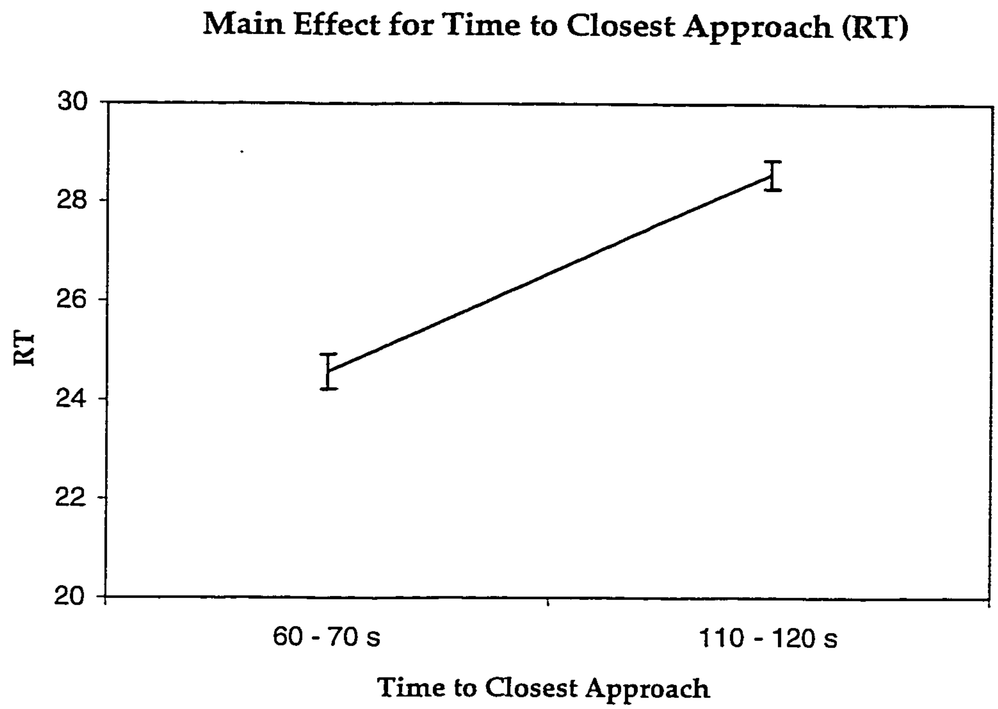

Figure 13. Reaction time differences for time to closest approach.

closest approach and ownship profiles on RT are comparable to the main effect for ownship on accuracy. Participants took longer to make their selections in the climbing and descending. As in the accuracy results, there was no significant difference in RT between ownship climb and ownship descent, $F(1, 11)<1.0$.

Interactions occurred for ownship profile by time to closest approach, $F(2, 22)=3.62$, $p<05$ (Figure 14) and for time to closest approach by traffic density, $F(1, 11)=9.59$, $p=.01$ (Figure 15). Analysis of the simple effects for time to closest approach for all three levels of ownship reveal a significant difference in RT for each test; ownship level, $F(1, 11)=49.10$, $p<.01$, ownship climbing, $F(1, 11)=67.57$, $p<.01$, and ownship descending, $F(1, 11)=13.13$, $p<.05$. RT for ownship was then compared with the two levels of time to closest approach. A significant main effect was found on RT for ownship at time to closest approach 60-70 s, $F(2, 22)=6.86$, $p<.01$, but not for ownship at time to closest approach 110-120 s, $F(2, 22)=1.72$, $p>.05$. At time to closest approach 60-70 s, ownship level versus ownship climb, and ownship level versus ownship descent, there was a significant difference in RT, $F(1, 11)=8.41$, $p<.05$, and $F(1, 11)=10.11$, $p<.01$, respectively. This is comparable to differences in ownship level versus climb and level versus descent observed for the overall accuracy performance data.

The time to closest approach by density interaction analysis of RT simple effects was significant for density at time to closest approach 60-70 s, $F(1, 11)=13.17$, $p<.01$, but did not reach significance for density at time to closest

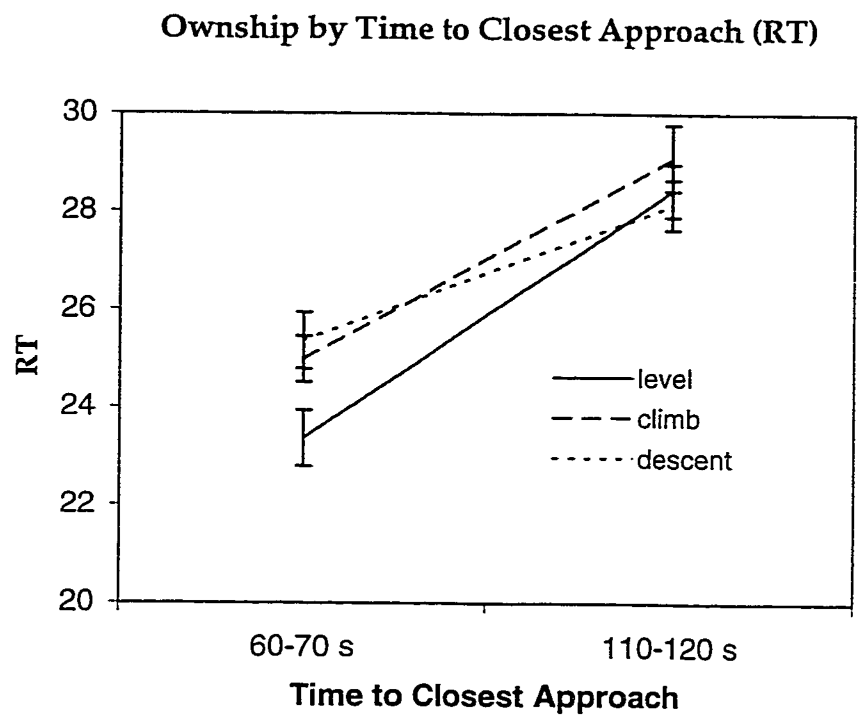

Figure 14. Reaction time differences for ownship at time to closest approach.

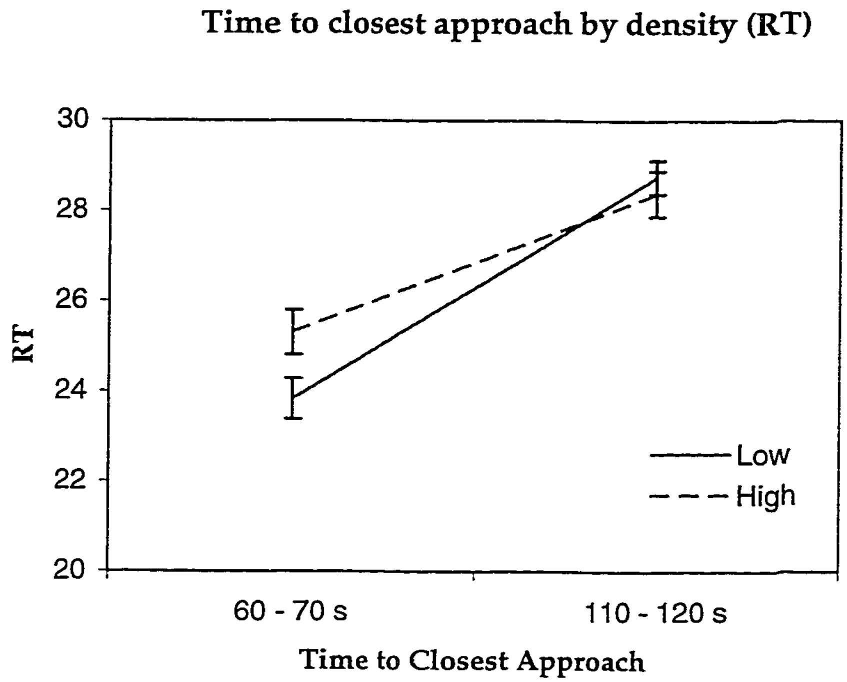

Figure 15. Reaction time differences for time to closest approach by density.

approach 110-120 s, $F(1, 11)<1.0$. Simple effects for time to closest approach at low and high density traffic levels were both significant, $F(1, 11) = 87.71$, $p<.01$, $F(1, 11)=28.72$, $p<.01$, respectively. This indicates a trend of increasing RT as the time to closest approach is extended. The interaction suggests that density only negatively affects performance when the task has already been made more difficult by requiring the participants to extrapolate a longer distance in the 110-120 s time to closest approach condition. The pattern of RT data closely approximates the pattern of results for threat selection accuracy and thus indicates no occurrence of a speed accuracy tradeoff.

Qualitative Measures

The participants completed a post-experiment questionnaire, an interview with the experimenter and a debriefing (see Appendix A). The questionnaire consisted of 5-point Likert type scale questions about how the participant felt about the fidelity of the experiment, and their level of effectiveness in responding to aircraft that represented separation threats in the various conditions. A separate portion of the questionnaire queried the participants about their method for detecting and selecting threat aircraft. The responses are summarized in Table 4. Generally, the participants felt the experiment had high fidelity, with the dynamics of the aircraft "frequently" occurring in a real world manner and judged the task of detecting and selecting threat aircraft to be both "difficult" and "engaging". Overall, in regards to performance and confidence in a successful

Table 4

Qualitative judgements of task characteristics, task difficulty, and confidence

Task, behavior, or question	Participants judgement	M	SD
Task difficulty	Engaging	2.7	.78
Confidence to detect aircraft that may have become a factor	High	4.0	.90
Confidence to select aircraft that first would become separation factor.	Fair	2.8	.53
When unsure of threat, waited for reduction in vertical separation between ownship and suspect aircraft.	Sometimes	2.6	1.36
Guessed in complicated situations.	Rarely	3.7	1.1
Scenarios represented real world aircraft dynamics.	Frequently	2.5	.82
Felt operationally safe detecting aircraft.	Frequently	2.2	.93
Felt operationally safe selecting aircraft.	Sometimes	2.6	.88
Need for automated predictor for separation.	Important	1.6	.90

Note. Nine items from questionnaire each scored using a five-point scale outcome of the tasks, participants indicated "high" confidence to detect a threat aircraft, but only "fair" confidence to select a threat aircraft. Considering the level of overall accuracy obtained from the experimental data, the participants may have felt somewhat overconfident about their abilities. Somewhat lower levels of confidence or conservative feelings were expressed about whether they would feel safe using these detection ("frequently") and selection ("sometimes") techniques in a operational environment. The need for an automated predictor for threat detection was rated as being "essential" and "important". The participants, it seems, felt generally good about their abilities to detect a possible separation threat aircraft, but they were inclined towards a more conservative approach regarding their feelings for the efficacy of their selections when considering a real flight environment. This may indicate that the participants were generally unsure of their overall performance.

Participants were also able to comment on areas or flight regimes where they would expect their detection and selection for threat aircraft would decline. Operations in terminal area airspace, navigating around weather, and during abnormal operations (e.g. a system limitation) were the prevalent responses. Half the participants responded to the question about their method for detecting and selecting a threat aircraft. All who responded used essentially the same procedure. After noting their own altitude and vertical speed they scanned for aircraft that were changing altitude, or that were level, that were trending towards ownship on the x, y, and z axes. A comparison of the trend in rate of altitude change between the possible threat aircraft and ownship was then used. One respondent, with experience as a civil and military test and certification pilot, wrote he consistently used, and noted, a subtraction and rate of change division formula to calculate vertical threat.

The interview also revealed no formal operating procedure in effect at the participants' company regarding the relative or absolute display mode settings to be used for their TCAS equipment. These crews said they usually leave the setting where they find it set by the previous crew, or set it to whatever the preference of the captain, or other crewmember might be.

Discussion

This study had a principle goal of determining an optimal text based altitude display format for pilots to detect and select aircraft that may become a separation threat. It was expected to reveal when the use of relative, absolute, or selectable altitude display modes are most appropriate in an environment with multiple levels of traffic densities, temporal variables, and aircraft vertical profiles. The dependent measures used to assess performance were selection accuracy and selection RT.

Evaluation of Study Goal and Hypotheses

Overall results indicated no definitive advantage for one specific altitude display mode. However, significant main effects for conditions other than altitude display mode and several interactions among many of the variables, which included display mode, may be interpreted to indicate where the use of a particular altitude display mode could be optimally utilized. To explore where an altitude display mode may be more effectively utilized, a number of different conditions were presented. The results will be discussed in terms of the hypotheses.

Hypothesis One. It was expected that the use of relative altitude display mode would provide for better performance over the absolute altitude display mode when ownship was level in either low or high traffic density levels. This effect would have been attributed to not needing to use mental arithmetic in the relative altitude display mode, coupled with relatively similar signaling properties of threat traffic when changing altitude.

This hypothesis was not supported. There were no significant accuracy or RT differences among the three altitude modes when ownship was level. The highest threat selection accuracy for all trials occurred when ownship was level, ranging from 64, 65, and 71% accurate for the relative, absolute, and selective display modes, respectively. No accuracy differences in this condition may indicate a reduction in processing load for the participants. With ownship in level flight the participant probably did not have the additional processing task of accounting for ownship's changing vertical state as when ownship was either climbing or descending in order to make a correct selection.

Hypothesis Two. The second hypothesis was that the absolute display mode would provide for better performance when ownship and other aircraft were changing altitude simultaneously. This hypothesis was not supported. While there were overall accuracy decrements when ownship changed altitude, the results indicated that the negative effects impacted all of the modes in the same manner.

Hypothesis Three. The third hypothesis was that the use of the selectable altitude display mode would provide for the best overall accuracy performance to select aircraft that were to become a threat to separation. This was based on the assumption that participants would recognize when to utilize the optimal altitude display mode for a particular ownship vertical flight profile and traffic density condition. This hypothesis is hard to evaluate since participants did not engage in selection choices for selectable trials but left the display in the relative mode the majority of the time.

While the overall difference in accuracy performance was not statistically significant between relative and absolute altitude display modes, marginally better overall accuracy was found for the selectable altitude display mode. However, the pattern of interactions showed that there were instances where using the selectable display mode led to better performance than the absolute display mode. These cases occurred in the high density and time to closest approach 110-120 s condition. That the participants chose to use the relative display mode for 93.5% of all threat selections for the selectable trials indicates a preference for this mode. This selection preference was also supported by the accuracy data. This particular finding supports the hypothesis. Overall, the marginal gain in accuracy performance for selectable altitude versus the relative display mode data can probably be attributed to a practice, or learning effect since the selectable display mode condition was always run last.

Hypothesis Four. The fourth hypothesis was that an increase in time to closest approach would result in higher errors rates for threat detection and selections. This was attributed to the larger extrapolation required due to both altitude magnitude and the increases in lateral distance of threat aircraft, and due to more intervening aircraft masking the threat aircraft.

The results supported this hypothesis. A longer time to closest approach for threat aircraft resulted in a reduction in accuracy and an increase in RT when selecting threat aircraft. This effect was evidenced in overall accuracy performance, where accuracy rates decreased in the 110-120 s time to closest approach condition. The time to closest approach condition also interacted with the display mode. Both relative and absolute altitude display modes showed a decline in accuracy performance at 110-120 s time to closest approach condition. There were also significant accuracy differences between the relative and selectable display modes (again, predominately used in relative mode) both showed significantly better performance than the absolute display mode. RT was similarly affected by the time to closest approach 110-120 s condition; a significant increase in RT was observed as a main effect of time to closest approach 110-120 s.

Conclusion and Future Research

The present experiment indicates where differences exist between text based altitude mode presentations. These differences occur in an environment where variables interact in a relatively complex manner. The principal findings indicate that when a pilot's aircraft is either climbing or descending, accuracy of selecting an aircraft that will become a separation threat declines. When a pilot needs to extrapolate threat decisions over a longer temporal period further decreases in selection accuracy occur. When a pilot faces higher traffic densities in longer temporal decision periods selection errors will increase to a greater extent.

Environmental variables where a particular altitude presentation mode leads to better or worse selection accuracy do not necessarily occur as an exclusive component during the course of a flight. During a single flight pilots may make climbs and descents in a step-like manner and will encounter fluctuating levels of traffic densities occurring at different horizontal and vertical distances. Therefore, it is important to place any possible recommendation about what may constitute an optimal or a preferred text-based display mode for altitude into an environmental context where all dynamic, temporal and traffic variables are allowed to exert their maximum influence. It could be argued that those variables would be similar to the conditions of ownship changing altitude, in high traffic densities, and at the 110-120 s time to closest approach used in this experiment. In such cases it was shown that the relative display mode of altitude provided the best accuracy.

It may be tempting to suggest that because of these findings a recommendation for relative display mode may be considered because the 110-120 s time to closest approach condition may, in a practical sense, represent a minimum temporal period for pilots to be buffered from other traffic in a en-route environment. However, regardless of the extent of prediction automation, it would be unrealistic to expect that pilots be able to asses and navigate around aircraft that may become a threat at temporal periods of less than two minutes in a way that results in maneuvers that are strategic and not tactical. Temporal periods in which to assess and select a separation threat aircraft that are less than 110-120 s (e.g. 60-70 s) may pose a conflict with existing threat detection and alerting procedures. At approximately 40 s time to closest approach TCAS becomes an alerting factor. In this study TCAS was not included as a factor, though this does not negate the need to better understand which altitude display mode should be employed for threat detection and selection between TCAS alerting and the 110-120 s time to closest approach.

The results of this experiment also do not indicate that a relative display mode is necessarily preferable to an absolute display mode at temporal ranges much in excess of 110-120 s time to closest approach. In order to satisfy the strategic design goals envisioned for CDTIs, there may be a need to determine a temporal region where a clear delineation is defined between where detection of possible threats is preferable or necessary, and where accurate threat selection or alerting might be required. This temporal region beyond 120 s is untested and may be an equally important environmental variable that should be evaluated in order to support which text based altitude display format is optimal for circumstances which are more strategic in nature.

This study does not indicate that pilots should undertake manual processing of threat detection and resolution. The accuracy results, confidence ratings, and pilot opinions presented here clearly indicate that some form of automated threat predictor is warranted and desirable. In this study, the pilots had no other task but to detect, assess, and select, in relation to their own aircraft, between a possible threat aircraft and a real threat aircraft. Without automated threat prediction and resolution, the marginal accuracy rates found here, even mitigated with training for when to use the appropriate mode for a given condition, could be expected to decline with normal task loadings that were not present in this study.

Critical to the development of CDTIs is acquiring a much deeper understanding of the most effective ways to present pilots text and symbol formats that depict automated processes, modes, and mode transitions. This study used pilot cognitive processes for threat detection and selection and determined that the task was difficult and that error rates were arguably high. The fact that the relative altitude display mode surfaced as a better display mode in the 110-120 s time to closest approach condition and in the 110-120 s time to closest approach by high density conditions, is insufficient to justify that these results are complete in regards to a full measure of applicability in a CDTI using a relative display mode for a system implementation. Additionally, for the temporal and traffic density conditions described, an inference should not be made that a text based relative altitude display mode is the preferable mode to be used with an automated predictor without further research.

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Appendix A

CDTI ALTITUDE MODE DEBRIEF QUESTIONNAIRE

Date:________ Crew Position__________ In type AC__________
Total time___________ Total "glass" time (estimate)_______________
Experience as: (yes/no)
Military: interception or RIO using on-board display screens________
AWACS controller_________________ATC controller___________

Please circle the number that best reflects your answer to the following questions.

1) Overall, did the training effectively prepare you for the experimental trials?

1	2	3	4	5
No	Could be better	Fair	Pretty good	Yes

2) Was there enough practice using the computer/CDTI ?

1	2	3	4	5
Not enough	Lacking	About right	Too much	Excessive

For the following questions consider:

Detecting an aircraft that may become a threat means you were able to detect one or more aircraft that because of its proximity, altitude, or rate of vertical speed, you thought could become a separation factor.

Selecting an aircraft that would first violate separation means you have determined a single aircraft from one or more aircraft on the display, that will violate separation.

3) Overall, rate your confidence in accurately ***detecting*** aircraft that may have become a factor?

1	2	3	4	5
Very low	low	fair	high	very high

4) Overall, rate your confidence in accurately ***selecting*** the aircraft that first would have violated separation?

1	2	3	4	5
Very low	low	fair	high	very high

5) For each level of traffic rate the altitude mode which provided you the highest confidence to ***detect*** the aircraft that may have become a separation factor for your aircraft. (1 = very low, 2 = low, 3 = fair, 4 = high, 5 = very high).

YOUR AIRCRAFT LEVEL	Low traffic	relative	absolute	selectable
	High traffic	relative	absolute	selectable

YOUR AIRCRAFT CLIMBING	Low traffic	relative	absolute	selectable
	High traffic	relative	absolute	selectable

YOUR AIRCRAFT DESCENDING	Low traffic	relative	absolute	selectable
	High traffic	relative	absolute	selectable

6) For each level of traffic rate the altitude mode which provided you with the highest confidence to ***select*** the aircraft that would have become a separation factor for your aircraft (1 = very low, 2 = low, 3 = fair, 4 = high, 5 = very high).

YOUR AIRCRAFT LEVEL	Low traffic	relative	absolute	selectable
	High traffic	relative	absolute	selectable

YOUR AIRCRAFT CLIMBING	Low traffic	relative	absolute	selectable
	High traffic	relative	absolute	selectable

YOUR AIRCRAFT DESCENDING	Low traffic	relative	absolute	selectable
	High traffic	relative	absolute	selectable

7) Overall, for all encounters, did you feel the task was;

1	2	3	4	5
very difficult	difficult	engaging	easy	very easy

8) In general, describe in order of use, any method or strategies you used to ***detect*** aircraft that may become a separation factor.

____

9) In general, describe in order of use, any method or strategies you used to ***select*** an aircraft that would become a separation factor.

____

10) If you were unsure of which aircraft to identify, did you ever wait until the separation decreased between your aircraft and other aircraft before doing so?

1	2	3	4	5
Always	Frequently	Sometimes	Rarely	Never

11) If the situation was too complicated to detect and select threat aircraft, did you guess?

1	2	3	4	5
Always	Frequently	Sometimes	Rarely	Never

12) Did you find the aircraft encounter profiles (direction of closure, vertical speeds) a real world representation?

1	2	3	4	5
Always	Frequently	Sometimes	Rarely	Never

13) Overall, given your usual enroute tasks, did you feel operationally safe about ***detecting*** aircraft that may have become a vertical separation factor?

1	2	3	4	5
Always	Frequently	Sometimes	Rarely	Never

14) In what sorts of encounters, or enroute tasks, would you feel less operationally safe in ***detecting*** aircraft that may have become a vertical separation factor?

____
____
____
____

15) Overall, given your usual enroute tasks, did you feel operationally safe about ***detecting*** aircraft that may have become a vertical separation factor?

1	2	3	4	5
Always	Frequently	Sometimes	Rarely	Never

16) In what sorts of encounters or enroute tasks would you feel less operationally safe in ***selecting*** a threat aircraft?

____
____
____
____

17) From this experience, how important would it be for you to have a predictor that would determine and identify aircraft that are likely to become a vertical threat?

1	2	3	4	5
Essential	Important	Somewhat important	not important	not needed at all

18) As an assessment of pilot performance in determining and selecting threat aircraft were there any critical factors that we missed?

____
____
____

Thank you for your participation. Please do not discuss the details of this experiment with colleagues that may be interested in participating. If you are interested in the results of this experiment please ask the experimenter to send you the findings. (Please note; published findings can take up to a year).

San José State
UNIVERSITY

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Appendix B

HSIRB APPROVAL

TO: Sean A. Belcher
NASA Ames Research Center
C/O Walter Johnson, #N 262-3
Moffett Field, CA 94035-1000

FROM: Serena W. Stanford *Serena W. Stanford*
AAVP, Graduate Studies & Research

DATE: April 25, 1997

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

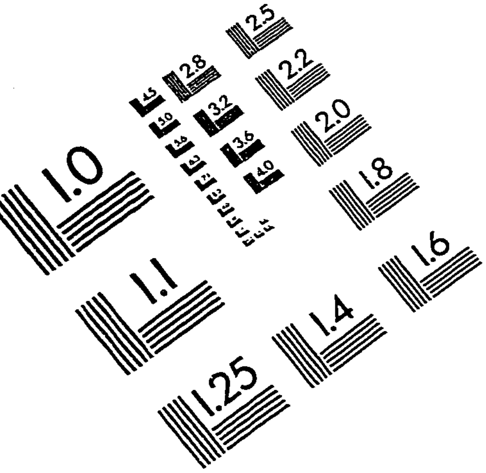
"Mode of Altitude Presentation in Cockpit Display of Traffic Information"

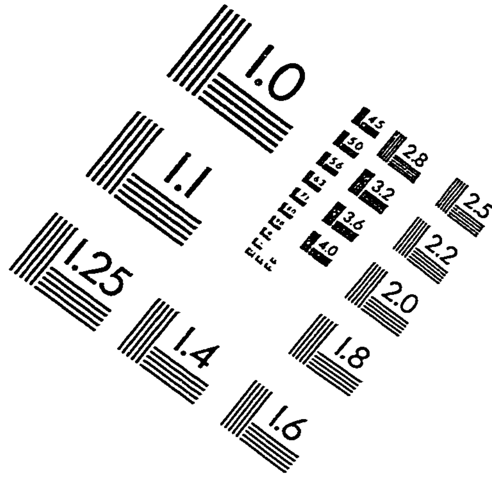
This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The Board's approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Serena Stanford, Ph.D., immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

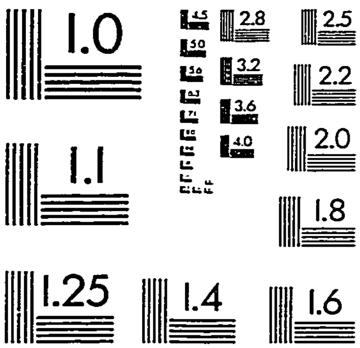
Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480.

IMAGE EVALUATION TEST TARGET (QA-3)

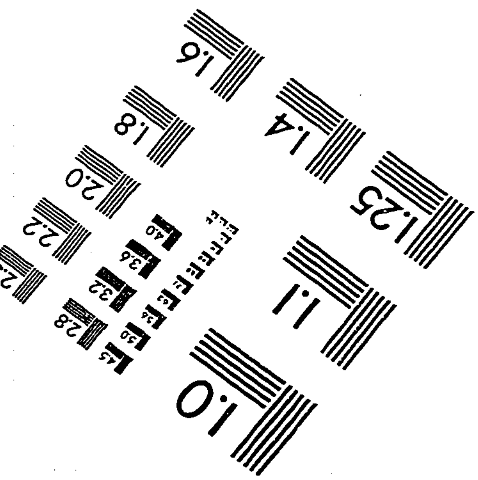


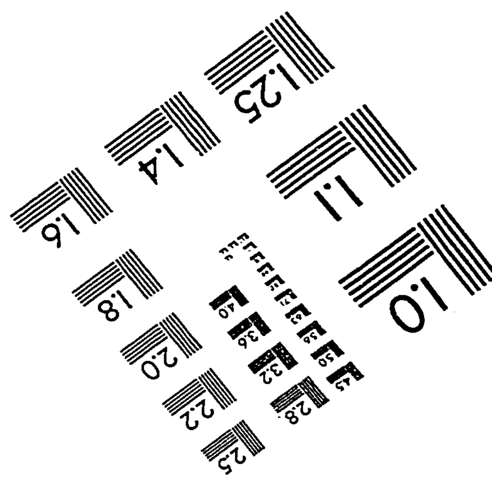




150mm

6″





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