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Conflict detection and maneuver assessment with combined traffic information

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CONFLICT DETECTION AND MANEUVER ASSESSMENT WITH COMBINED
TRAFFIC INFORMATION

A Thesis

Presented to
the Faculty of the Department of Psychology
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

by

Sheila K. Holland

December, 1998

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ABSTRACT

CONFLICT DETECTION AND MANEUVER ASSESSMENT WITH COMBINED TRAFFIC INFORMATION

by Sheila K. Holland

The effective use of traffic information on a cockpit display largely depends upon the speed and accuracy with which pilots can extract information about the current and future traffic situation. Prediction information and traffic symbols have been shown to enhance pilot performance on tasks designed to evaluate their understanding of a traffic situation. These forms of traffic information have traditionally been presented either relative to the ground or relative to ownship, and each presentation has proven to be better for the completion of certain tasks. This study attempted to determine if a proposed display of combined ground- and ownship-referenced traffic information would support the tasks of conflict detection and avoidance maneuver assessment without the need for pilots to switch between displays.

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Conflict Detection and Maneuver Assessment with Combined

Traffic Information

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Footnotes

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Abstract

The effective use of traffic information on a cockpit display largely depends upon the speed and accuracy with which pilots can extract information about the current and future traffic situation. Previous studies have shown that the presentation of prediction information in addition to traffic symbols enhances pilot performance in conflict detection, maneuvering to avoid a spacing violation, and merging. Certain tasks have been shown to be better facilitated with ground-referenced information and others with ownship-referenced. It may seem appropriate to give pilots a tool allowing them to select which information is presented, but problems with this approach (i.e., workload, possible confusion) make it necessary to investigate other solutions. This study attempted to determine if a proposed display of combined ground- and ownship-referenced traffic information would support the tasks of conflict detection and maneuver assessment without the need for pilots to switch between displays. Four traffic information conditions were presented to the pilots, two containing single-mode information and the other two mixed-modes. The results from the conflict detection and avoidance maneuver assessment analyses indicated that purely ownship-referenced traffic information resulted in better performance on the first task and may also support the second. The results from the combined task overall error analysis, which measured how well pilots were able to complete both tasks using the same display, indicated that there were no differences in performance between the four display presentations.

Conflict Detection and Maneuver Assessment with Combined Traffic Information

Free-flight has been defined as “a safe and efficient flight operating capability under instrument flight rules in which the operators have the freedom to select their path and speed in real time” (RTCA, 1995, p. 23). This RTCA document also states “The architecture and technology on which the emerging ATM (Air Traffic Management) system is based makes increasingly heavy use of new displays...that provide flight crews with accurate, real time situational awareness” (p. 8). The required functionality of these new flight deck displays has not been specified completely since the roles and responsibilities of the aircraft crew in free-flight remain unspecified. However, an ambitious yet seemingly reasonable role for the crew during en route flight would be the maintenance of safe separation from other aircraft. This would require resources that allow for early detection and resolution of potential conflicts. Thus, the free-flight concept and the prospect of having pilots self-separate requires research on the information pilots need and the display format most compatible with that needed information.

Currently, aircraft spacing en route is handled by Air Route Traffic Control Centers (ARTCC). En route controllers are responsible for large blocks, or sectors, of airspace in which a variety of air operations may be simultaneously in progress. The boundary lines of the sectors were built around specific traffic flows that help to balance controller workload. Despite this, controllers have to place significant restrictions on traffic in order to maintain safety due to the system's inability to handle an ever-increasing traffic volume.

With the exception of the pilot's own view out the window, the only backup to the air traffic control (ATC) system onboard the aircraft is the Traffic-Alert and Collision Avoidance System (TCAS). TCAS provides independent backup to ATC by displaying range, bearing, and when possible, the altitudes of proximal traffic. Designed to prevent mid-air collisions, TCAS also provides the pilot with traffic warnings, conflict alerts, and conflict resolutions for near term threats.

TCAS is currently the only cockpit display of traffic information (CDTI) available on most non-military flight decks. The display, which is situated on the instrument panel, is track-up and has a continuously moving background allowing the position of the crew's own aircraft to be depicted by a fixed aircraft symbol (ownship). When present, ground-referenced objects painted on the display move down the display at a rate proportional to the aircraft's ground speed. When the aircraft turns, the ownship remains fixed and all objects on the display rotate around it. Displayed traffic moves with respect to both ground-referenced objects and the ownship and is presented initially as non-directional diamonds. Changes in threat levels are presented by changes in the shape, color, and fills of these symbols.

The CDTI has been described as being "...perceptually a more complicated display than those used by air traffic controllers" (Palmer, Jago, Baty, & O'Connor, 1980, p. 606). On an ATC display, the map shows a fixed area of the world, and the aircraft symbols move with respect to the fixed background. With a CDTI, pilots view a display having a continuously moving background, as well as moving aircraft. While this ownship-referenced, or relative display is perceptually more complicated than ATC's

world-referenced displays, the movement on the display parallels the pilot's ego-centered mental model of the traffic flow in the airspace. For example, a well-known navigational concept that pilots use to identify conflicts is relative bearing (Litchford, 1975). Pilots know that a collision will occur if an aircraft in view remains in the same position out the window while increasing in size. If the bearing-angle continues to be unchanging, the aircraft are on a collision course. Similarly, if the angle between ownship and another aircraft symbol on the display remains constant while the aircraft symbol is closing on ownship, a collision will ensue. So, while the display may appear to be complicated, the movement of traffic depicted on the display is similar to what the pilot would see out the window if the aircraft were in view.

Traffic depiction on the CDTI is made possible due to air-to-air data exchange between TCAS-equipped aircraft. The system has a limited surveillance range, though, so its functionality is also limited. With the newly developed Automatic Dependent Surveillance Broadcast system (ADSB) an increase in the surveillance range up to and possibly exceeding 120 nautical miles (NM) is made possible. At this range, the CDTI and its associated tools could change from being a last minute tactical alerting and resolution system into a system that will allow strategic self-separation.

The Task of Self-Separating

To maintain self-separation with a TCAS like display, the pilot will have to determine the speed and path of an aircraft considered problematic, predict the future position of that aircraft, determine if a maneuver is necessary, and determine when that action will need to be initiated to maintain a safe distance from the aircraft. Several things

could make this task very difficult. First, the movement visible on a cockpit display when set at a large range is small and slow. While the mental extrapolation of a single object moving at a fast, constant velocity has been shown to be quite accurate, performance is severely degraded when the movement is relatively slow (Finke & Pinker, 1983; Rosenbaum, 1975). Second, when considering possible maneuvers, it may be necessary for the pilot to estimate the future positions of several aircraft simultaneously to determine how the new route would impact other aircraft. It is reasonable to expect that the error in extrapolation performance will be compounded when multiple aircraft are considered.

To compensate for any limitations in the pilots' ability to self-separate, an early alerting logic is expected to be incorporated into the CDTI software. One of the benefits of an early alerting system is that pilots can choose to make preemptive resolutions, which in most cases will require smaller maneuvers resulting in better fuel efficiency. An early alerting system may not be enough for the pilot to make well-informed decisions, though. Alerting systems will most likely present the most fuel-efficient maneuver to avoid a potential conflict, while other factors may require the pilot to consider or choose an alternate route change (e.g., ultimate flight destination or weather). Additionally, it has been found that pilots generally want to be able to check the validity of computer generated avoidance maneuvers (Palmer & Ellis, 1983). Therefore, pilots will need to have information regarding the surrounding traffic in a format that allows accurate and efficient processing, even when the system has an early alerting logic. This study

examined methods of presenting (1) the current state of the airspace and (2) an estimated future state (prediction) by which pilots may anticipate and prepare for events.

Previous Studies on the Presentation of Information on a CDTI

A considerable body of work examining the presentation of traffic information on a cockpit display was conducted at NASA research centers in the 1970's and 1980's (e.g., Connelly, 1977; Hart & Loomis, 1980; Jago & Palmer, 1980; Palmer, 1983; and Palmer & Ellis, 1983). The CDTI was seen as a means for improving pilot situational awareness, with potential for some of the responsibility for the following tasks to be transferred to the cockpit: blunder detection and recovery, merging and in-trail following in the terminal airspace, the maintenance of primary separation, and collision avoidance (Verstynen, 1980). All of these things were contingent on the pilot's ability to understand and cognitively process the information presented on the CDTI.

TCAS's display symbology incorporates essential information for tactical collision avoidance. If the CDTI is to be used as a strategic tool, more information will need to be present on the display. Hart and Loomis (1980) asked pilots to select the display features that would incorporate all information essential for monitoring the traffic situation, detecting blunders, maintaining in-trail separation, and merging. Pilots were presented displays that incorporated different categories of information (e.g., heading, flight history, and altitude) with varying levels of complexity and different symbology.

For the representation of aircraft position, the pilots reported a preference for a directional traffic symbol, but were willing to give up the directionality for a graphical encoding of relative altitude (i.e., same, above, and below). This choice may have been

influenced by the availability of two other symbols providing flight path information (i.e., path history and predictors). History and predictors are both spatio-temporal path indicators, the former showing where the aircraft has been relative to the ground for a specified amount of time and the latter estimating where the aircraft will be with the provision that it maintains its current velocity and heading. Examples of the relative-altitude traffic symbol, predictors, and history can be seen in Figure 1. In addition to selecting these symbols, pilots also selected ground speed and climb or descend arrows for aircraft changing altitude. In an experiment using the pilot-preferred displays, Hart and Loomis (1980) found that flight path predictors greatly contributed to the pilot's ability to perceive a traffic conflict correctly. The other pilot-selected information was not found to improve speed or accuracy for the task of determining if an intruding aircraft would pass in front of or behind ownship.

Palmer et al. (1980) also investigated flight path predictors and histories. They found that pilots could only make accurate judgments of future position consistently when predictor symbology was provided. Participants in this study also judged whether an intruding aircraft would pass in front of or behind the ownship. The study presented participants with a relative display set at 20 NM and the scenarios simulated tactical situations in terminal area operations. Two aircraft were presented, including ownship, with ground-referenced predictors. While predictors significantly improved pilots' judgments of future position, there was evidence that pilots did not accurately take into account differences in the speed of ownship and the intruder. Flight path history, while its presence was preferred by some pilots, did not improve prediction performance.

Figure 1. Examples of the ownship symbol, non-directional traffic symbols that incorporate relative altitude information, predictor lines, and history.

Palmer (1983) also investigated the impact of predictors on pilots' abilities to make small maneuvers to prevent collision avoidance advisories. The amount and quality of predictive information on the CDTI was manipulated, along with the amount of time the participants had to view the encounter. Palmer hypothesized that high quality predictive information would be required for pilots to make maneuvers that would uniformly increase separation. Although the mean difference in achieved separation was not statistically significant for conditions with and without prediction information, when the pilots had predictors, collision avoidance advisories were avoided 90% of the time while they were avoided 78% of the time without predictors. On the no predictor display, twice as many maneuvers were made that did not increase "miss" distance. On the other hand, further analysis indicated that with the high quality predictors the resulting maneuvers might have been larger than necessary.

The Frame of Reference for Prediction Information

While the usefulness of prediction information has been well documented, the frame of reference in which prediction information should be presented has not yet been determined. There are predominantly two presentation modes in which predictor lines have been investigated: relative to the ground or relative to ownship. For the ground-referenced mode, all aircraft on the display, including ownship, have predictor lines extending from them (see Figure 2 top) showing their path along the ground. Since predictors are based on speed and trajectory, an additional benefit of this display is that line orientations and lengths can be compared to get an understanding of relative velocities. This feature of the absolute reference frame may make the assessment of a

Figure 2. Experimental CDTI display set at 80 NM range. The top display shows three minute ground-referenced predictors. The bottom display depicts the same prediction information in the ownship-referenced mode.

proposed avoidance maneuver quick and accurate. The problem with this presentation is in the assessment of the conflict. Since both aircraft have predictors, pilots will have to make spatio-temporal estimations of future positions for both the ownship and the suspected intruder to determine if a spacing violation will occur.

For the relative prediction mode, ownship's movement is subtracted from all elements on the display. All aircraft on the display, except for ownship, have predictor lines extending from them (see Figure 2 bottom) and the predictor line points in the direction that the aircraft symbol will travel across the display. For the relative prediction display, assessment of a probable intruder requires the directional extrapolation of only one aircraft. If an aircraft's predictor line is pointed at ownship, they will violate each other's airspace. There are some inherent problems with the relative prediction display, though, when more than traffic information is present on the display. Impossible configurations of stationary objects on the display (e.g., airports, waypoints, terrain) may occur when the predictor lines are present (see Figure 3). That is, depending on how the designer decides to depict the stationary objects when in prediction mode, either (1) immobile objects will be depicted as having moved or (2) the projected future positions of the aircraft will show inaccurate positions relative to the stationary objects.

Studies on Reference Frame for Predictors

Some of the early studies on the presentation of prediction information also investigated whether information should be presented ground-referenced or ownship-referenced, and the results were somewhat mixed. Lester and Palmer (1983) had pilots determine if an aircraft would pass within 3 NM of ownship. In the ownship-referenced

Figure 3. Predicted future position in the ownship-referenced mode causes either a misrepresentation of the airspace or movement of world-referenced, stationary objects (e.g., waypoint SMOGI) resulting in clutter.

condition, any time the predictor pierced a 3 NM range ring surrounding ownship, the aircraft was in violation. Since most of the trials started with the intruder already in violation, it is not surprising that performance with the relative predictors was faster and more accurate. Error rates with both the ownship and ground-predictors did increase as the number of aircraft on the display increased from one to four. One possible explanation for the increase in error rates in the ownship-referenced groups was that the experiment presented mixed symbologies (i.e., 60 second ownship-referenced predictor lines for traffic and a 60 second ground-referenced predictor for ownship) which caused confusion for some of the pilots. The pilots in the Lester and Palmer study reported preference for the ownship-referenced predictor for a quick check of horizontal traffic separation. They also stated that the ground-referenced information would be helpful at certain times, such as when approaching the terminal area and merging with arriving traffic.

Type of predictor presented has also been shown to influence the type of maneuver taken and the timing in which that maneuver is made. Palmer, Jago, and DuBord (1981) studied the types of maneuvers pilots would make when the only information they had about the other aircraft was that presented on the CDTI. Both ground-referenced and ownship-referenced predictors were examined. The pilots with the ownship-referenced predictors made fewer turns to pass behind the intruder, a common maneuver that was evident in the ground-referenced group in this study, and in other studies (Smith, Ellis, & Lee, 1982, 1984). While the ownship-referenced group waited longer to make their first maneuver, they achieved about the same separation at closest approach as the ground group. The longer reaction times and the difference in the type of

maneuver suggests that it may be harder to understand the traffic situation with ownship-referenced predictors.

A general conclusion drawn from these studies is that the best predictor type (ground- or ownship-referenced) may depend on the task the pilot is asked to perform. Thus, it might seem appropriate to provide the pilots with a tool allowing them to select between the two reference frames. There are problems with this approach, however. First, requiring the pilot to manually switch between displays could increase pilot workload. Switching between reference frames would make it necessary for the pilots to process the new presentation of information and synthesize it into their understanding of the traffic situation. And in specific circumstances, it may be difficult for the pilot to decide which mode is more appropriate. In either case, the required actions would demand more heads-down time, possibly detaining the pilots from more important tasks.

Second, the two display presentations look similar. Under stress, confusion over which prediction mode is being displayed may occur, potentially causing the pilot to misinterpret the traffic situation. For example, if the pilot incorrectly determined that the ownship-referenced predictors had been selected, they may consider an aircraft to be problematic because the pilot would be using the rules associated with the wrong predictors. Seeing that an aircraft's "ownship-referenced" predictor is pointing at the ownship, the pilot would expect a conflict alert. Since a separation violation would not actually be developing, the automation would not deliver the expected alert. This violation of expectation would draw on the pilot's attentional resources and could possibly cause the pilot to mistrust the automation.

The Present Study

Most of the early studies on reference frame for prediction information presented non-directional aircraft symbols along with the predictor lines. The symbol in most of the studies was like those used on the TCAS display, while some of the studies presented a non-directional symbol which also incorporated relative altitude information. In the present study, a relative altitude symbol was used that also contained directionality. By doing this, the simultaneous presentation of ground-referenced and ownship-referenced traffic information (viz., traffic symbol and predictor lines) was possible.

Although the presentation of mixed reference frames was not successful in previous research (e.g., Palmer, Jago, & DuBord, 1981), the reason may be that prediction information was presented in different reference frames, simultaneously. That is, Palmer, Jago, and DuBord presented an ownship-referenced predictor line on the traffic and a ground-referenced predictor line on ownship. This mixture required the pilots to apply different rules for prediction information appearing in very similar formats.

In this study, participants were presented CDTIs that contained directional traffic symbols and predictor lines. Both types of traffic information were presented ground-referenced and ownship-referenced. The crossing of the traffic variables results in one condition containing only ground-referenced information and one containing only ownship-referenced information. The other two mixed conditions showed (1) ownship-referenced traffic symbols with predictor lines referenced to the ground and (2) ground-referenced traffic symbols with predictor lines referenced to ownship (see Figure 4).

Figure 4. The four displays resulting from the crossing of traffic symbols and prediction information.

Since the ability to detect a conflicting aircraft is an essential part of the cockpit display, the four display formats were compared on the basis of how well they supported this task. The conflict detection task required participants to determine if a spacing violation would occur and with whom it would occur. Since ownship-referenced traffic information has been shown to assist in the detection of a conflict, it was expected that performance would be better for conditions containing this information. More precisely, conditions containing ownship-referenced predictor lines were expected to result in quicker, more accurate performance than the conditions containing ground-referenced predictors.

An additional way to assess how well pilots are able to extract information about the airspace from the display is to assess their ability to judge the effectiveness of an avoidance maneuver. Since fuel efficiency is one of the main considerations behind the initiation of the free-flight program, it is essential that the cockpit display support the pilot's ability to select minimum safe maneuvers. Due to this, the effectiveness of the proposed safe maneuvers was manipulated in terms of the distance that would be achieved between ownship and the primary target and the distance achieved between ownship and a second aircraft on the display.

This complexity in the proposed avoidance maneuvers was designed to help determine (1) if the display would support pilot acceptance of minimum safe maneuvers and (2) how well pilots are able to consider other aircraft in the airspace when evaluating a proposed maneuver. The minimum distance conditions were also used to ensure sufficient error rates, allowing the better symbology to have an observable effect. Overall,

scores were expected to reflect some conservatism in separation judgements, with more of the minimum separation avoidance maneuvers being rejected than the large. Since ground-referenced information has been shown to support the pilot's ability to maneuver, it was also expected that the conditions containing ground-based information would result in better performance. In particular, conditions containing ground-referenced predictors are expected to result in the best performance, especially when comparing the minimum separation conditions.

A combined task overall error measure was also calculated for each display condition. The score reflected the number of trials on which a participant followed a correct identification of the conflict aircraft with an accurate judgement of the proposed avoidance maneuver. This measure would help decide which display supported both tasks with the least amount of error. It was expected that the presentation of the ownship-referenced traffic symbol and the ground-referenced predictor lines would prove to be the most effective presentation for both tasks. With the ownship-referenced traffic symbol, the participants would have to extrapolate from one point to determine if the aircraft would come within 5 NM of ownship. Then, when it is time to judge the usefulness of the proposed avoidance maneuver, the participants' evaluations could be based on small mental adjustments to their own ground-referenced predictor line.

Method

Participants

Twelve pilots, currently employed as active flight-crew members and who have experience with Electronic Flight Instrument System and TCAS equipped aircraft, were

recruited from major passenger airlines. Participants were paid an hourly rate, administered by Raytheon Corporation, acting under a human research contract with 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 participants prior to the experiment.

Apparatus

The experiment was administered using an IBM PC-compatible computer based workstation. The workstation included a 17 inch monitor with a resolution of 1024 X 768 and a P-6 200 MHz processor with audio feedback capabilities. Participants were positioned 61 cm from the display and entered their responses using the left button on a two-button mouse.

The simulated CDTI screen measured 10 inches diagonally (17.96 by 17.96 cm). The display was always presented in map mode at a range of 80 NM. Ten NM at this range measures 2.41 cm and subtends 2.26 degrees of visual angle. Format and display conventions were nearly identical to the map mode of the 747-400 navigation display, except that most navigation functions were removed and the initial range setting was unalterable.

Since responses to each task were expected to average less than 15 seconds (s), and the visible movement of traffic symbols on a display set at an 80 NM range is minimal within this time period, static depictions of the traffic flow were used in this

experiment. The trials were generated using in-house computer software developed to allow the experimenter to create conflict situations according to specific criteria (e.g., distance at point of closest approach, speeds, and encounter geometry) and additional context traffic.

Design

Conflict Detection Task. The design for the conflict detection task was a 2 (Predictor Type) x 2 (Symbol Type) x 2 (Trial Type) x 24 (replications) within subject design. The levels for the two factors, which define the appearance of the traffic information on the CDTI, were (1) referenced to the ground and (2) referenced to ownship. The levels of the trial type were conflict and no conflict.

The participant's task was to determine if an aircraft would violate ownship's airspace. In the conflict trials, one aircraft was programmed to have a point of closest approach of 2.5 NM that would occur between 3 min 30 s to 4 min 30 s in the future. In the no conflict trials, a distractor aircraft was programmed to have a point of closest approach of 7.5 NM, within this time interval. No other aircraft came closer than this to ownship. The dependent measures for this task were (1) the accuracy in determining if an aircraft would cause a spacing violation and (2) the response time.

Errors could occur by (1) selecting an aircraft when a conflict was not programmed to occur, (2) selecting the wrong aircraft when a conflict was programmed to occur, and (3) responding that no conflict would occur when a spacing violation was programmed. Since the avoidance maneuver assessment task was performed only on trials where a spacing violation had occurred, feedback was given for all errors on the first task.

If the participants did not select the target on the conflict trials, the target was subsequently highlighted and an aural warning sounded. All participants then progressed to the avoidance maneuver assessment task with the same information. When a false identification of a conflict occurred, an error message saying that all aircraft maintained separation was displayed.

Avoidance maneuver assessment task. Performance on the avoidance maneuver task was evaluated in two parts. The first part examined performance on trials in which the proposed maneuver resulted in a spacing violation. The second part examined performance on trials in which the proposed maneuver cleared the initial conflict and maintained separation from all other aircraft. In both cases, the separation distances that would result if the pilot were to make the proposed maneuver were manipulated on the primary threat and a second aircraft in each trial. The design for the avoidance maneuver assessment task with a violation was a 2 (Predictor Type) x 2 (Symbol Type) x 2 (Violation Type) x 4 (replications) within subject design. The aircraft with which ownship would have a spacing violation if the proposed avoidance maneuver were incorrectly accepted defined the two levels of violation. The trials either (1) sufficiently separated ownship from the primary (initial) threat but caused a violation with the secondary aircraft or (2) failed to separate the ownship from the primary threat aircraft.

The design for the avoidance maneuver task with separation was a 2 (Predictor) x 2 (Symbol) x 2 (Primary Separation) x 2 (Secondary Separation) x 4 (replications) within subject design. The levels for the two separation factors were minimum safe (7.5 NM)

and large safe (12.5 NM). [The proposed avoidance maneuver, which was always some degree of heading change, was presented as a heading bug (see Figure 5).]

The participant's task was to assess the effectiveness of the proposed avoidance maneuvers. The correct responses for the avoidance maneuver task were to "accept" the proposed maneuver resulting in separation and "reject" the violation trials. A description of all proposed avoidance maneuvers can be found in Figure 6. The dependent measure for this task was the accuracy at assessing the effectiveness of the proposed avoidance maneuver by correctly accepting or rejecting the maneuver. Reaction times were also collected for this task. Again, feedback was given in the form of a text box when an error occurred.

The combination of the traffic information factors resulted in four CDTI presentations (i.e., all ownship-referenced, all ground-referenced, and the two mixed-modes). The trials for these four conditions were presented in blocks that were counterbalanced using an incomplete counterbalancing technique controlling for pairwise sequencing. For the conflict detection task, each block contained 8 practice (4 conflict and 4 no conflict) and 48 experimental trials (24 conflict and 24 no conflict). The 28 conflict trials (practice and experimental) were immediately followed by the avoidance maneuver task. The presentation order of the proposed avoidance maneuvers was completely randomized, with the provision that equal numbers of each type of maneuver was presented in each block. For the experimental trials, 16 of the proposed avoidance maneuvers presented a clear path and eight would have resulted in a spacing violation.

Figure 5. The avoidance maneuver was presented with a heading bug (triangle on range arc) and a textual instruction of the new heading.

Separation Trials:	Primary Target Separation	
Correct Response	Minimum Safe	Large Safe
Accept	Minimum Safe	16 trials
	Large Safe	16 trials
Secondary Target Separation		
Violation Trials:	Violation Primary Target	16 trials
Correct Response	Violation Secondary Target	16 trials
Reject		

Figure 6. The two factors defining the proposed avoidance maneuver with separation trials resulted in four separation conditions varying in separation distances (top panel). The proposed avoidance maneuver trials with a violation were defined by the aircraft with which ownship would have a violation (bottom panel).

To prevent practice effects from repeated exposure to a trial, 192 unique test scenarios were developed for the execution of this experiment. The scenarios were divided into four groups, and the presentations of these groups were counterbalanced using an incomplete Latin Square. No participant ever responded to the same test stimuli across the four CDTI conditions and each block of scenarios was presented an equal number of times in each of the four CDTI conditions.

Procedure

The experiment was conducted in a well-lit room with low noise. The experimenter was in the adjoining room, separated from view during the experiment. One participant ran at a time, and each participant was told that the experiment would take more than 2 hours but no longer than 3 hours to complete.

The participants were first given a written description of a world-referenced, ATC type display and a relative, CDTI type display. Then a simplified traffic example was presented involving four objects: ownship, a second aircraft, and two objects fixed to the world (i.e., waypoint and terrain). The two aircraft, both flying towards the waypoint, were shown on a collision course. This scenario was presented first on the world-referenced display and then on the relative display, both with ground-referenced traffic symbols. The pilots were shown how the traffic representations varied while maintaining the same relative positions of the traffic symbols. Additionally, the pilots were shown how the movement of the aircraft across the relative display would not follow its ground-referenced path, but an ownship-referenced one. Then, the relative display was presented again with ownship-referenced traffic information.

The pilots were then shown traffic symbols and predictor lines presented in the ground-referenced and ownship-reference frames on a relative display. The inconsistency problem that results from the simultaneous presentation of world-referenced objects and ownship-referenced prediction information was described to the participants, but they were also told that no world-referenced objects would be presented in the experiment. Finally, four displays resulting from a crossing of the two traffic symbol and prediction information modes were presented. How each display mapped onto the other was described in detail to the participants. The participants were then asked to look at pictures of the four conditions and tell the experimenter what condition they were being presented. Correct identifications were required before the participants were permitted to proceed with the experiment.

Participants were then given written instructions for the two tasks. The instruction packet contained several printed versions of the tasks to be performed. For the conflict detection task, the participants were instructed to select the aircraft that would come within 5 NM of ownship. Participants were given a picture depicting the 5 mile separation standard which they could reference during the experiment. For the second task, they were asked to determine if the proposed avoidance maneuver would allow them to maintain separation from all aircraft on the display. The instructions emphasized that while accuracy was most important for both tasks, timeliness was also essential.

For all of the test scenarios, the participants were presented a CDTI with ownship (i.e., white triangle) in a fixed position 5.93 cm from the bottom of the display. Chevrons were used to depict traffic aircraft position. For ownship and traffic, the apex of the

symbol represented the current position of the aircraft. A 2.5 min temporal predictor line extended from each aircraft, with the exception of ownship in the ownship-referenced condition. The physical length of the predictor line depended on the speed of the aircraft and the frame of reference in which it was presented.

In each test scenario, there were 5 to 8 aircraft “flying” straight and level at constant speeds. Included in that number were the ownship, the target aircraft, the distractor aircraft, and a secondary threat aircraft. Ownship was assigned a random heading (0-360 degrees) but always traveled at a speed of 450 knots and at an altitude of 31,000 feet (ft). The targets were programmed to violate the 5 NM separation standard in 3.5 to 4.5 min, passing either in front or behind ownship and having a point of closest approach of 2.5 NM. The point of closest approach for the distractor was 7.5 NM. To ensure that an equal number of targets approach from the front, sides, and back, the approach angle for the target aircraft was selected using a partial random assignment technique (see Figure 7). In each test scenario, the secondary threat aircraft was programmed to satisfy the requirements of the proposed avoidance maneuver condition.

The target, distractor, and secondary aircraft all “flew” at the same altitude as ownship but had randomly assigned speeds between 300 to 480 knots. All of the context aircraft had randomly assigned headings (0-360 degrees), altitudes (27,000 to 37,000 ft assigned in 2000 ft increments) and speeds (300 to 480 knots), with the provision that none of these aircraft came within 15 miles of ownship at any time. The only spacing violation that occurred in each scenario was between ownship and the threat aircraft.

Figure 7. The approach heading for the intruding aircraft will be equally distributed over the front, the back, and the combined right and left sides .

A trial started when the participants clicked the mouse on the preview screen. The preview screen informed the participants of the experimental condition and of the trial number. For the first task, conflict detection, the participants made a "violation" response by selecting with the mouse the aircraft that they believed would violate ownship's airspace. If "no violation" was the response, the participants were instructed to click on the ownship. After the response was made on the no violation trials, text appeared on the display indicating if the response was correct or incorrect and the participants had 5 s to review the screen before the computer advanced to the next trial preview screen. On the violation trials, the correct target aircraft was highlighted for the participants and the proposed avoidance maneuver (heading bug) appeared on the range arc. The participants then judged if they should accept or reject the proposed maneuver. The participants "accepted" or "rejected" the advisory by clicking on the appropriate text box presented in the corner of the display. After that response was made, the participants again received feedback and had 5 s to review the display before advancing to the trial preview screen.

The first 8 trials in each block of 56 test scenarios were designated practice trials. Each block of trials was followed by a 3 min break. Immediately following the completion of the fourth block of trials, the participants were fully debriefed.

Results

The dependent variables analyzed in this study were accuracy and reaction time for both the conflict detection and avoidance maneuver tasks. Prior to analysis, reaction times for incorrect responses and outliers were replaced using one of two missing value

replacement techniques. For the conflict detection task, in which there were 24 replications per condition, missing data was replaced with an average of the participants valid data by condition. For the avoidance maneuver tasks, in which there were four replications, the replacement method used an average of (1) valid responses by participant across all conditions, (2) valid responses by condition across all participants, and (3) the overall mean for reaction time. This replacement technique was used due to several conditions in which no valid responses were obtained by participants. For the twelve participants, there were three conditions out of 192 without valid data for the avoidance maneuver task with separation. There were 15 conditions out of 96 without valid data for the avoidance maneuver task with a violation.

Before replacing the missing values, accuracy and reaction times for each of the three data sets were analyzed using a pairwise Pearson correlation coefficient to determine if participants were getting more accurate scores by spending more time on trials. The resulting correlations indicate that a speed-accuracy trade-off may have been occurring for the avoidance maneuver task with a violation. The result of this correlation was $r(94) = .25$, $p < .05$. For the other two analyses, the direction of the correlation showed that participants were getting better scores with shorter reaction times. For the conflict detection and the avoidance maneuver task with separation data, the resulting coefficient were $r(94) = -.48$, $p < .01$ and $r(190) = -.11$, $p > .05$, respectively.

Conflict Detection Task

Mean scores and standard errors are presented for the conflict detection in Table

1. It can be seen that the conflict detection task was performed with higher accuracy and

Table 1.

Means and Standard Error for the Conflict Detection Task (N=12)

		Predictor Type			
		Ground		Ownship	
Symbol Type	Trial Type	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
Accuracy					
Ground	No Conflict	.76	.04	.90	.03
	Conflict	.76	.04	.92	.03
Ownship	No Conflict	.76	.04	.87	.03
	Conflict	.80	.03	.88	.03
Reaction Time					
Ground	No Conflict	15.36	1.74	10.16	.80
	Conflict	15.19	2.04	9.32	.64
Ownship	No Conflict	16.78	1.51	10.02	.51
	Conflict	15.49	1.36	9.41	.45

speed with the ownship-referenced prediction information. With ownship-referenced predictors, spacing judgments (violation or no violation) were made with 12% more accuracy and these judgments were made at a pace that was on average 5.8 s faster.

For the conflict detection task, a 2 (Predictor Type) x 2 (Symbol Type) x 2 (Trial Type) within subject analysis of variance (ANOVA) was conducted on both the accuracy and reaction time data. The results are presented in Table 2. The procedure for accuracy indicated that there was a significant main effect for predictor type, $F(1, 11) = 10.96$, $p < .01$, $\eta^2 = .50$. As was hypothesized, ownship-referenced predictors were better than ground-referenced predictors for determining if a spacing violation would occur. No other significant effects or interactions were found.

The results from the three-factor (Predictor Type x Symbol Type x Trial Type) ANOVA for reaction time data are consistent with the findings for the accuracy data (see Table 2). A main effect for predictor type showed that participants were significantly faster at this task when presented the ownship-referenced predictor, $F(1, 11) = 26.43$, $p < .001$, $\eta^2 = .31$. No other effects were found in this analysis.

Avoidance Maneuver Assessment Task

Trials Resulting in a Violation. Table 3 presents accuracy and reaction time summaries for the avoidance maneuver tasks in which the maneuver would result in a spacing violation. Performance appears to be better when the traffic information was presented relative to the ground, but the overall means show that performance was not strong for this task. On average, participants only correctly rejected the proposed maneuvers that would result in a violation on 12 out of 32 trials.

Table 2.

Analysis of Variance for the Conflict Detection Task: Predictor Type by Symbol Type
by Trial Type

Source	df	<u>F</u>	
		Accuracy	Reaction Time
Predictor Type	1	10.96**	26.43**
Symbol Type	1	.18	.170
Trial Type	1	.96	1.53
Predictor x Symbol	1	2.23	.28
Predictor x Trial	1	.00	.00
Symbol x Trial	1	.15	.54
Predictor x Symbol x Trial	1	.28	1.10

** $p < .01$

Table 3.

Means and Standard Error for the Avoidance Maneuver Task with a Spacing Violation(N=12)

		Predictor Type			
Symbol Type	Target	Ground		Ownship	
		<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
Accuracy					
Ground	Primary	.42	.09	.33	.06
	Secondary	.46	.09	.42	.08
Ownship	Primary	.35	.10	.19	.06
	Secondary	.50	.10	.40	.07
Reaction Time					
Ground	Primary	14.19	1.14	13.59	1.92
	Secondary	14.20	1.70	16.78	2.77
Ownship	Primary	12.93	1.02	11.59	.59
	Secondary	12.51	1.19	11.99	1.00

Before presenting the results for the ANOVAs performed on the avoidance maneuver with a violation task, it should be stated that the interpretation of the accuracy data should be made with caution, since the correlation coefficient suggested the possibility that a speed-accuracy tradeoff was occurring. Additionally, since there were such a large number of replacements for the reaction time data, increasing the probability of getting a significant effect, a more stringent alpha level (.01) was used for this analysis.

For the 2 (Predictor Type) x 2 (Symbol Type) x 2 (Violation Type) within subject ANOVA performed on accuracy data (see Table 4), there again was a significant main effect on accuracy for predictor $F(1,11) = 5.09, p < .05, \eta^2 = .32$. The ground-referenced predictor was better than the ownship-referenced predictor for identifying continuing or newly created spacing violations. No other effects or interactions were significant. The ANOVA performed on reaction time data resulted in no significant effects, even at the .05 level.

Trials Maintaining Separation. Table 5 presents summaries from the avoidance maneuver trials in which the proposed maneuver would have resulted in a clear path varying in separation distance. With the ground-referenced predictors, errors appear to be as expected if pilots were more conservative when responding to the minimum versus the large separation condition. With ownship-referenced predictors, performance appears to be equal if not better when the avoidance maneuver only gives minimum clearance.

Table 6 presents the results from the 2 (Predictor Type) x 2 (Symbol Type) x 2 (Primary Separation) x 2 (Secondary Separation) within subject ANOVAs performed on accuracy and reaction time data. There were no main effects for the analysis on accuracy

Table 4.

Analysis of Variance for Avoidance Maneuver Task: Predictor Type by Symbol Type by Violation Type

Source	df	F	
		Accuracy	Reaction Time
Predictor Type	1	5.09*	.00
Symbol Type	1	.46	4.71
Violation Type	1	3.59	1.64
Predictor x Symbol	1	.45	1.05
Predictor x Violate	1	.18	1.19
Symbol x Violate	1	1.52	1.54
Predictor x Symbol x Violate	1	.01	1.22

* $p < .05$

Table 5.

Means and Standard Error for the Avoidance Maneuver Task Resulting in Separation(N=12)

Symbol Type	Separation	Predictor Type			
		Ground		Ownship	
		<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
Accuracy					
Ground	MM ^a	.52	.07	.73	.07
	ML ^b	.69	.08	.71	.07
	LM ^c	.73	.08	.67	.07
	LL ^d	.83	.06	.75	.05
Ownship	MM	.69	.07	.81	.05
	ML	.77	.08	.65	.06
	LM	.52	.10	.73	.07
	LL	.81	.06	.65	.07

Table 5.

Means and Standard Error for the Avoidance Maneuver Task Resulting in Separation
(continued)

Symbol Type	Separation	Predictor Type			
		Ground		Ownship	
		<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
Ground		Reaction Time			
	MM	12.94	1.30	9.29	.78
	ML	11.68	1.26	10.94	1.24
	LM	10.03	.79	9.48	.66
	LL	8.98	1.18	10.04	.97
Ownship					
	MM	10.87	1.41	9.12	.82
	ML	12.56	1.90	8.23	.75
	LM	11.83	1.54	7.35	.71
	LL	11.55	2.02	9.77	1.44

^aMM = minimum separation primary and secondary. ^bML = minimum separation primary and large separation secondary. ^cLM = large separation primary and minimum separation secondary.

^dLL = large separation primary and secondary.

Table 6.

Analysis of Variance for Avoidance Maneuver Task: Predictor Type by Symbol Type by Primary Separation by Secondary Separation

Source	df	F	
		Accuracy	Reaction Time
Predictor	1	.28	6.51*
Symbol	1	.00	.07
Primary	1	.22	3.00
Secondary	1	3.90	.81
Predictor x Symbol	1	.02	2.54
Predictor x Primary	1	1.88	3.22
Predictor x Secondary	1	7.17*	2.59
Symbol x Primary	1	5.65*	2.81
Symbol x Secondary	1	.45	1.10
Primary x Secondary	1	2.01	.01
Predictor x Symbol x Primary	1	3.37	5.83*
Predictor x Symbol x Secondary	1	8.21*	4.42
Predictor x Primary x Secondary	1	.04	1.32
Symbol x Primary x Secondary	1	.63	.28
Predictor x Symbol x Primary x Secondary	1	1.53	6.09*

*p < .05

data. Two significant 2-way interactions (Predictor Type x Secondary Separation, $F(1,11) = 7.17$, $p < .05$, $\eta^2 = .39$; Symbol Type x Primary Separation, $F(1,11) = 5.65$, $p < .05$, $\eta^2 = .34$) as well as one three-way interaction (Predictor Type x Symbol Type x Secondary Separation, $F(1,11) = 8.21$, $p < .05$, $\eta^2 = .43$) were found.

To evaluate the interaction between predictor type and secondary target separation, simple effects were calculated at both levels of each variable. A significant difference for performance was found between the minimum and large separation distances when the predictor was ground-referenced, $F(1, 11) = 10.88$, $p = .01$, $\eta^2 = .497$. In that condition, participants were more likely to correctly accept the proposed avoidance maneuver that would result in a large separation distance than a minimum safe distance. This effect indicates that pilots are more conservative when considering minimum safe maneuvers. This effect for separation distance for the secondary aircraft did not affect performance when the predictor was presented relative to ownship.

Further analyses of the three-way interaction revealed that this effect also depended on which orientation the traffic symbol appeared (see Figure 8). When the traffic symbol was oriented relative to the ground, no effects were found for the predictor type by separation secondary analysis. When the symbol was ownship-referenced, performance was better for the large separation trials only when the predictor lines were oriented relative to the ground, $F(1,11) = 9.58$, $p < .01$. There was no difference in performance when the predictors were presented relative to ownship. Additionally, whether or not minimum and large proposed avoidance maneuvers were accepted

Predictor by Secondary when the Symbol is Ground-Referenced

Predictor by Secondary when the Symbol is Ownship-Referenced

Figure 8. The effect of symbol on the predictor and secondary aircraft in the avoidance maneuver task with separation.

depended on the orientation of the predictor line. Minimum safe maneuvers were accepted more often in the ownship-referenced predictor condition, $F(1,11) = 16.00$, $p < .01$. Large maneuvers were accepted more often when pilots were presented ground predictors, $F(1,11) = 5.23$, $p < .05$. This crossover in results showed that for the ownship-referenced condition, performance was the opposite from what was expected for the minimum and large separation judgments.

The significant two-way interaction between symbol and primary target separation reveal that the ownship-referenced traffic symbol exerted the same type of effect on performance as the ownship-referenced predictor, $F(1,11) = 5.35$, $p < .05$, $\eta^2 = .33$. Again, when performance is expected to be worse for the minimum rather than the large separation condition, better performance is seen for the minimum separation condition with the ownship-referenced traffic symbol (see Figure 9). Performance is as would be expected with the ground-referenced symbol.

The 4-way (Predictor Type x Symbol Type x Primary Separation x Secondary Separation) analysis on reaction time data had a main effect for predictor type, $F(1,11) = 6.51$, $p < .05$, $\eta^2 = .37$. Responses were faster with the ownship-referenced predictor than with the ground predictor. There also were two significant interactions. The first was a three-way interaction involving predictor, symbol, and primary separation. Follow-up analyses performed on predictor by primary separation for both levels of symbol indicated that the orientation of the symbol had an impact on reaction time inconsistently over the other conditions (see Figure 10). When the symbol was ownship-referenced, predictor type was the only reliable effect, $F(1, 11) = 6.20$, $p < .05$. Ground-referenced predictors

Symbol by Primary Two-way Interaction

Figure 9. Interaction between the traffic symbol and the primary aircraft for the avoidance maneuver task with separation.

**Predictor by Primary when the Symbol is
Ownship-Referenced**

**Predictor by Primary when the Symbol is
Ground-Referenced**

Figure 10. The effect of symbol on the predictor by primary separation interaction for the avoidance maneuver with separation reaction time data.

were studied longer before a response was made. When the symbol was oriented relative to the ground, several effects were obtained. With the predictor referenced to the ground, reaction times were different for the minimum and large separation distances, $F(1, 11) = 12.89, p < .01$. Large separation distances were judged at a faster pace. Reaction times for minimum separations were different across the two prediction conditions, with the ownship-referenced predictors resulting in quicker judgments $F(1, 11) = 5.15, p < .05$.

There was also a significant 4-way interaction, $F(1, 11) = 6.09, p < .05, \eta^2 = .36$. The impact of secondary target separation in the previously described 3-way interaction was different at the minimum separation level than the large. When the separation for the secondary aircraft was minimal, no effects or interactions among the other three variables were found. At the large distance, the pattern of results was the same as for the three-way.

Overall Accuracy

One additional accuracy score was calculated to determine if, in a real-world setting, pilots would be able to transition from the conflict detection task to the avoidance maneuver task without switching between display modes. An overall performance score was calculated on the conflict trials that transitioned to the avoidance maneuver task by summing the number of times the pilots correctly responded to both tasks. Participants accurately performed both tasks a little more than 50% of the time. The totals were analyzed in a 2 (Predictor Type) x 2 (Symbol Type) ANOVA and the results indicate that there was no difference on overall performance among the four conditions.

Finally, the last analysis performed was to investigate if there were differences in the overall reaction times for completing both tasks by condition. Average reaction times

were calculated by summing the times for the conflict detection, avoidance maneuver pair and then dividing that amount by the total number of valid response pairs. The data was analyzed using a 2 (Predictor Type) x 2 (Symbol Type) within subject ANOVA. Overall, participants responded quicker with the ownship-referenced predictor ($\underline{M}$ = 20.35) than the ground predictor ($\underline{M}$ = 28.42).

Discussion

The purpose of this study was to investigate the usefulness of mixed-reference frame displays in order to determine if a combined presentation could produce the same results seen with ownship- and ground-referenced single-mode displays. If the mixed-mode display were able to produce the same results as the single-mode displays, the necessity for a tool allowing pilots to switch between displays in order to perform different tasks would be eliminated. This, in turn, would eliminate some of the problems with having multi-mode tools. Two primary tasks were examined to determine if a mixed-mode display could produce better performance than the single-mode displays. The first was the conflict detection task, and the second was the avoidance maneuver task.

Evaluation of Hypotheses

For the conflict detection task, it was proposed that traffic conditions containing ownship-referenced predictors would result in better performance than the ground-based ones. The main effects for predictor type for both the accuracy and reaction time data support this hypothesis.

For the avoidance maneuver task, it was proposed that ground-referenced traffic information would result in the best performance. For the avoidance maneuver task resulting in a violation, the main effect of predictor type supported this hypothesis. The overall performance and the evidence suggesting that a speed-accuracy tradeoff may have been occurring, indicate that pilots will need some other type of information to make these judgements with higher accuracy and speed. Both the error rates and the participants' reports show that the task was very difficult.

For the avoidance maneuver task with separation, performance improved. Separation distances were manipulated in order to determine which display would support pilots' acceptance of minimum safe maneuvers. It was proposed that the ground-referenced prediction information would result in better performance, especially when comparing conditions with minimum separation distances on the primary and secondary target. This hypothesis was not supported. In the ground predictor conditions, performance was as expected with better performance in the large separation condition. Predictors exerted this effect on the secondary aircraft and the traffic symbols exerted this effect on the primary aircraft. Several effects were contrary to the hypothesis though. First, performance was better in the minimum separation condition of the secondary aircraft with the ownship-referenced predictors versus the ground predictor. Second, when ownship-referenced predictors were examined, no differences were found between the minimum and large separations for the primary and secondary aircraft. While not significant, in one condition, the scores were actually better in the minimum separation condition than in the large. Third, the predictors did not appear to have any effect on the

primary aircraft. While more attention may have been given to this aircraft, since it had been identified in the conflict detection task, more errors in the minimum separation conditions would still be expected.

The reaction time data also presented some problems for the hypothesis that ground predictors would result in better performance for the avoidance maneuver task. For this data, the three-way interaction included predictor type, symbol type, and primary aircraft separation. For the conditions in which a ground-based predictor and symbol were presented, the reaction times for the large separation trials were faster than the minimum separation trials. This implies that participants studied the more difficult, minimum separation condition longer before making a response only when given the ground-referenced information. With the ownship-referenced predictor, though, there was no difference in reaction times between the minimum and large separation conditions. The overall reaction times were also faster with the ownship-referenced predictors.

In sum, the ownship-referenced predictors appeared to support the avoidance maneuver task more than the ground predictors. Before accepting this result as being valid, one limitation of this study should be mentioned. Since there were unequal numbers of trials in which the correct response was to accept versus reject the proposed avoidance maneuver and feedback was given on the task, response bias in the direction of accepting the maneuver may have been produced. If response bias was occurring, more correct responses on the avoidance maneuver task with separation would be coupled with more errors on the avoidance maneuver with a violation. This happened for the ownship-referenced predictor condition. Additionally, with the ownship predictors, more minimum

separation trials were correctly accepted than the large separation conditions. This could possibly mean that the participants did not have a clear understanding of the traffic situation with these predictors. These events may indicate that a more structured avoidance maneuver task should be performed to fully understand how well ownship predictors can be used when evaluating a proposed avoidance maneuver.

The final hypothesis to be evaluated was that one of the mixed-presentations would result in better overall performance than either of the single-mode conditions. The analysis performed on the accuracy data indicated that none of the display conditions outperformed any other. Participants were only able to correctly respond to both tasks on about half of the trials. Reaction time results indicated that with the ownship-referenced predictors, the combined task was performed eight seconds faster on average. How meaningful this is cannot be determined due to the limitations previously identified.

Additional information was obtained through pilot reports during the debriefing that could add to the understanding of the usefulness of these displays. Pilots were asked which presentation they would most prefer if they had to choose one display, without having the ability to switch between presentation modes. Seven of the participants selected the display containing only ownship-referenced information. Interestingly, the other five participants selected the mixed-mode display presenting the ownship-referenced predictor and the ground-referenced traffic symbol. When asked their overall impression of the tasks, all of the participants reported that more information would be required to make the avoidance maneuver task less difficult.

In summary, ownship-referenced prediction information does allow for quick, accurate identification of a conflict. Since no interactions were found for this task, though, the proposal that a mixed-reference display with a ground-referenced predictor line and an ownship-referenced traffic symbol was not supported. No difference between conditions may indicate that the mixed display did not cause confusion or hinder performance, though. Whether a mixed- or a single-mode display is used, the ownship-referenced predictor is definitely a preferred component of this type of display. For the avoidance maneuver task, the results do not point to which information was most reliably used. Due to the limitations already discussed and the overall poor performance on the avoidance maneuver task, no recommendations can be made on how to enhance the pilots' understanding of a traffic situation to the point that they could accurately judge an avoidance maneuver. Since the real world conditions will not be too dissimilar from the conditions presented here, more work into what will need to be presented to allow the pilot to understand a proposed avoidance maneuver is recommended.

Future Research

The importance of understanding the effectiveness of a proposed avoidance maneuver requires further examination of various presentations of traffic information. One way to isolate how well the traffic situation is understood using a task similar to the one presented here would be to ask participants to define the closest proximity between the ownship and each individual aircraft on the display if a proposed avoidance maneuver were accepted. This would also allow for the comparison of trials that would and would

not result in a spacing violation. While this task would be time consuming, the information that could be gained would greatly assist in the design of future displays.

Motion is another factor that needs to be investigated to fully understand which presentation of information will provide pilots an understanding of their environment. In this study, static depictions were presented since within the time frame that participants were making their responses, the traffic situation would have changed only a very small amount. This lower fidelity presentation of information allowed for more information to be gathered. A higher fidelity part-task simulation with motion would allow the experimenter to gather information on (1) when the pilots feel it would be necessary to maneuver away from a traffic situation, (2) how the pilot would maneuver away from the situation, and (3) how these judgements will be affected by the mode in which the traffic information is presented.

Even with the best combination of traffic information on the display, it might be determined that pilots will need an addition tool to evaluate the safety of proposed course changes. Johnson et al. (1997) gave pilots such a tool in a demonstration of a prototype free-flight cockpit display. The Route Assessment Tool (RAT) allowed pilots to probe the horizontal and vertical planes to identify clear paths. The tool showed the pilots why certain maneuvers would be preferential to others by visually highlighting aircraft that would be deemed too close if the maneuver were to be executed. The results of the demonstration indicated that maneuvers were made earlier and generated larger separation distances when the crews used the RAT tool. It was not clear how this type of tool would affect workload in a real world situation.

Conclusion

The advances in technology and the additional information that will be available to the flight deck will permit many enhancements to the current cockpit displays. These enhancements hopefully will improve safety while increasing the efficiency of the air-traffic management system. To ensure that this happens, designs must increase the avenues for delivering information without making too many demands on pilot workload. While the technology will allow ever increasing amounts of information transfer, it is the presentation of the information that will ensure continued safety in an ever-expanding traffic environment.

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Appendix

HSIRB Approval

**Office of the Academic
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Sacramento, San Bernardino, San Diego,
San Francisco, San Jose, San Luis Obispo,
San Marcos, Sonoma, Stanislaus

TO: Sheila Holland
42 Arch Street, Apt. #E
Redwood City, CA 94062

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

DATE: June 4, 1998

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

**"Conflict Detection and Assessment of Proposed
Avoidance Maneuvers with Combined Ground
and Ownship Referenced 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)

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