# SEPARATION MONITORING WITH FOUR TYPES OF PREDICTORS ON A COCKPIT DISPLAY OF TRAFFIC INFORMATION

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The concept of a cockpit display of traffic information (CDTI) includes the integration of air traffic, navigation, terrain and weather information in a single electronic display in the cockpit. The present study was conducted as part of a research project designed to develop a clear and concise display format for use in later full mission simulator evaluation of the CDTI concept. This experiment required airline pilots to monitor a CDTI and make perceptual judgments concerning the future position of a single intruder aircraft in relationship to their own aircraft (ownship). The main experimental variable was the type of predictor used to display future position of each aircraft. Predictors were referenced to the ground or to ownship and they either included turn rate information or did not. Other variables were the aircraft's separation distance when the judgment was required and the type of encounter (straight or turning). Results indicate that under these experimental conditions fewer errors were made when the predictor included turn rate information. There was little difference in overall error rate for the curved ground referenced and the ownship referenced predictors.

## INTRODUCTION

Projected estimates of air traffic indicate a marked increase in congestion occurring over the next 20 years. This increase is expected to create a demand for greatly improved air traffic control services to maintain or improve present levels of safety. Relevant to the area of safety are concerns dealing with efficiency of flights into and out of capacity limited terminal areas. The concept of a cockpit display of traffic information (CDTI) is presently being considered to determine its role in the air traffic system.

The CDTI is displayed on a cathode-ray tube (CRT) located in the aircraft cockpit with a display created by a computer. The display allows the pilot to see other aircraft's position in relation to the pilot's own aircraft. The pilot's own position and direction of travel with respect to area navigation routes and terrain features are indicated by a heading-up moving map.

Prior experiments in this project were directed toward developing a clear and easy to use display (ref. 1, 2, 3, 4). Questions concerning the generic CDTI display were directed toward the display symbology and factors affecting perception of motion. Such variables as update rate, viewing time, background and methods of displaying past and future position of the aircraft have been considered. Additional studies have been made on how to display vertical situation information on a map display (ref. 5, 6).

The object of this experiment was to evaluate different predictors of aircraft motion in the horizontal plane. Four predictors were used. These were either ground referenced or ownship referenced with or without turn rate information. Also of interest was whether there was a difference in learning with the different predictors.

## METHOD

Subjects. Sixteen airline pilots were paid to participate in this experiment. No pilot had prior experience using CDTI symbology, eliminating the possibility of previous learning affecting the results.

Apparatus. The pilots were seated in a two-place, fixed-base transport simulator. The only functioning parts of the simulator were the CRTs that displayed the traffic information. Responses were made on a hand-held instrument.

Visual display. The CDTI was displayed on a 18 cm X 18 cm CRT. The center of the screen was located 25 deg. (.44 rad) below the horizontal on the pilot's center line and .87 m from the subject's eye reference point. The width of the terrain displayed on the CRT was 10 nautical miles (18.5 km). With this map scale, 1 nautical mile (1.85 km) on the ground equals 1.2 cm on the display. The ownship was represented by a chevron symbol with the exact location of ownship being the top point of the symbol. The intruder was represented on the display by a circular symbol with a dot in the center indicating its present location. Both ownship and intruder were displayed with ground referenced history dots. Each of the eight dots indicated the past position of the aircraft over the ground at 4 sec intervals. These symbols were preferred by most pilots in Hart's studies of pilot preference for various types of CDTI symbols (ref 7, 8). An area navigation route map provided ground objects for the background.

Encounter variables. There were 48 different encounters. Figure 1 shows 12 of the 48 encounters. For example, encounter 1 displays the ownship in a heading up position. The intruder is approaching from the right. In Figure 1 all sketches show curved ground referenced predictors for the purpose of illustration. In 24 of the encounters the intruder ultimately passed in front of ownship. In the remaining 24 the intruder ultimately passed behind the ownship. In 24 of the encounters, both aircraft went straight and in the remaining 24 one or both aircraft turned. In 24 encounters the display stopped at 44 sec to the point of closest encounter. The remaining 24 encounters stopped at 28 sec to the point of the closest encounter. The parameters for the encounters are found in Palmer et. al.

Constant encounter parameters included: viewing time, 8 sec, separation distance at encounter, 3000 ft (.91 km), and update rates for ownship and intruder. Ownship's position and heading was

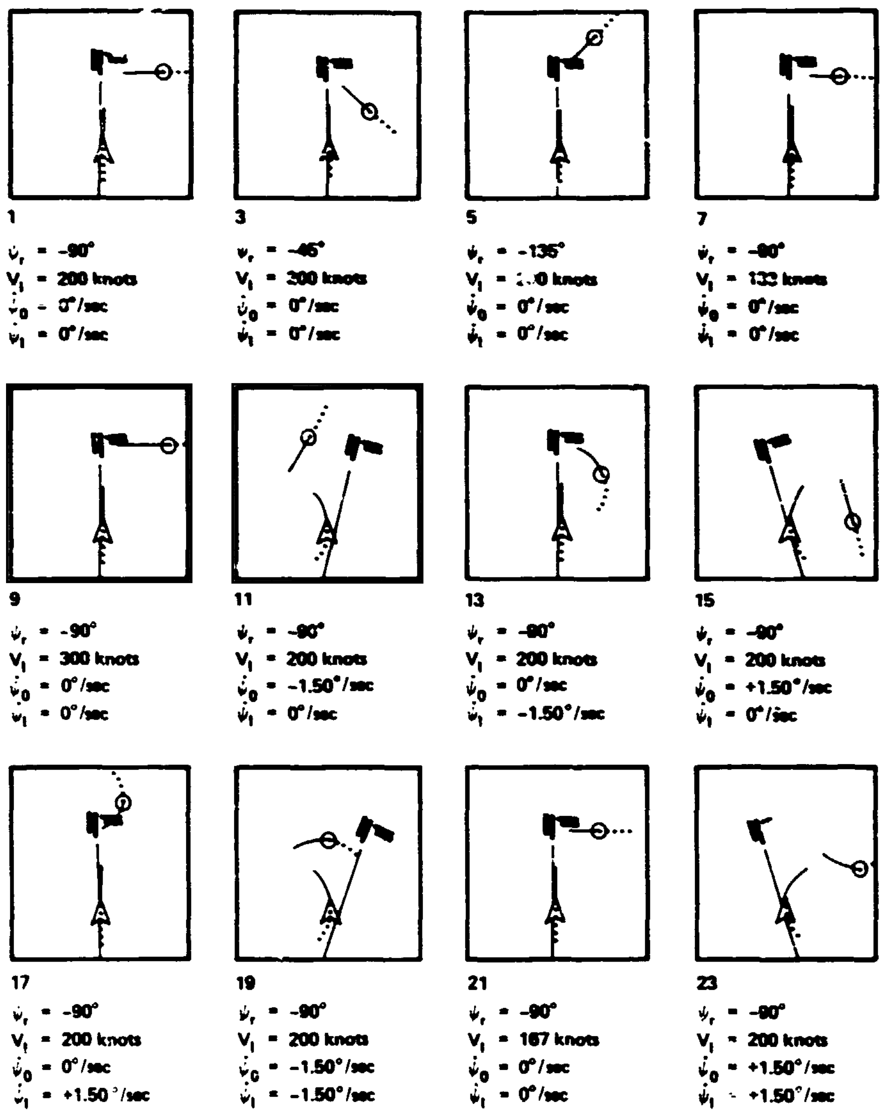


Figure 1 Twelve of the 48 encounters in which the intruder would ultimately pass in front of ownship. All displays show curved ground referenced predictors.

updated every .1 sec, while the intruder's position and heading was updated every 2 sec.

<u>Display variables</u>. There were four conditions of display predictors: (a) straight ground referenced, (b) curved ground referenced, (c) straight relative, and (d) curved relative. In the straight ground referenced predictors, the end of the vector indicated the projected position of the aircraft over the ground in 32 sec, assuming the aircraft maintained its current instantaneous ground track. The curved ground referenced predictor indicated the position of the aircraft in 32 sec, assuming the aircraft maintained its current turn rate. In curved encounters this predictor curved in proportion to the turn rate. With the straight relative predictor the end of the predictor indicated the intruder's position relative to the ownship position, direction, and speed if both aircraft maintain their current ground track. With the curved relative the end of the predictor predicts the position of the intruder relative to ownship if both aircraft maintain their current turn rates. In encounters where both aircraft are going straight the display appears the same with both straight and curved predictors. Figure 2 shows the same encounter with each of the four predictors. No radar noise or tracker lag were simulated.

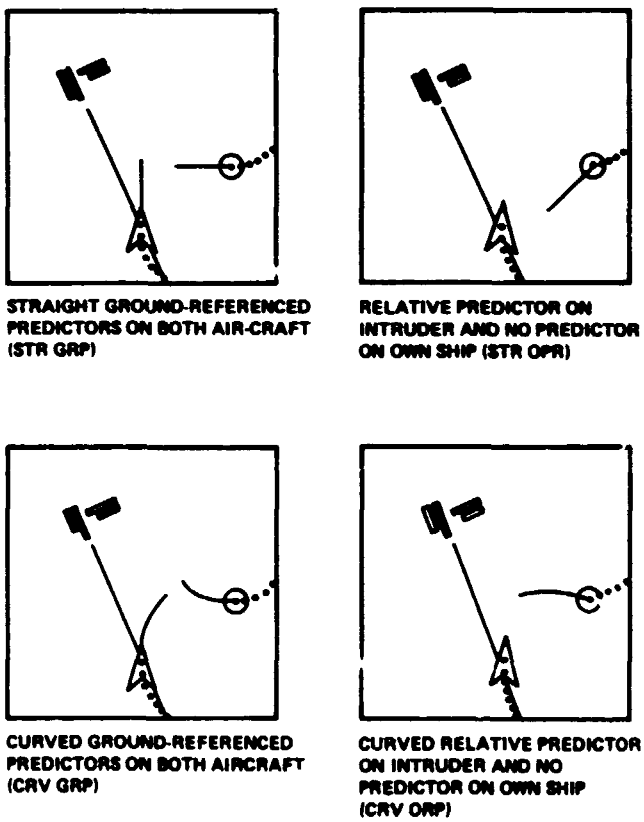


Figure 2. The four display formats used in the experiment.

Procedure. The task for this experiment was to monitor the CDTI for 8 sec and predict whether the intruder aircraft would ultimately pass in front of or in back of the ownship. The subjects indicated their decisions by pressing the appropriate button on the hand held response switch. Two seconds after the initiation of the run, the intruder appeared on the CDTI with a position, velocity, track angle, and turn rate calculated so that the intruder ultimately passed either directly in front of or in back of ownship in 52 or 36 sec. After 8 sec of viewing time the CRT was blanked and replaced with a message asking whether the intruder would pass in front or in back of ownship. The pilot responded. The words "IN FRONT" or "IN BACK" then appeared on the screen indicating the correct judgment.

Four subjects were assigned to each of the four conditions. Initial oral instructions concerning the concept of the CDTI and the meaning of the various display symbols were given. After approximately one half hour of training, all pilots underwent a pretest block of 48 encounters with no predictors. At the conclusion of the pretest trial there was a 10-minute break. The pilots received additional training specific to the experimental condition. On Day 1, three blocks of the experimental condition of the 48 encounters were administered with a 10-minute break between blocks. On Day 2, the subjects received instructions on the meaning of the CDTI symbols for the experimental condition and three more blocks of 48 encounters of the experimental condition were given. The experiment concluded with a posttest block identical to the pretest block with no predictors. Presentation order was randomized. In addition, whether the subject saw a specific encounter or its mirror image was also randomized.

## Results

Table 1 shows the percent error for each of the predictor conditions for straight and curved encounters at both distances. It can be seen in Figure 3 and Table 1 that fewer errors were made on curved encounters when the predictor indicated the future joint effect of current turn rate of both aircraft. Both ground referenced and ownship referenced predictors resulted in equally good performances on straight encounters. However the error rate on curved encounters was consistently lower for the conditions with curved ground or ownship referenced predictors that provided turn rate information. With turn rate information the error rate on the curved encounters was comparable to the error rate on straight encounters. The highest error rates occured when both aircraft were turning and the predictors did not include turn rate information.

An analysis of variance was conducted on transformed percent error rate over the four predictor conditions, separation distance at encounter and type of encounter (straight or turning). Table 2 shows the results of the ANOVA. Performances over the four predictor types, two separation distances and encounter types were significantly different as were the interactions of predictor type and separation distance and the interaction between predictor type and encounter type.

| Predictors | Encounters | | | |
|---|---|---|---|---|
| | Straight | | Curved | |
| | 28 | 44 sec | 28 | 44 sec |
| None (pretest) | 31 | 42 | 23 | 35 |
| None (posttest) | 23 | 29 | 25 | 35 |
| Straight ground ref. | 1 | 11 | 27 | 30 |
| Curved ground ref. | 2 | 10 | 2 | 7 |
| Straight ownship ref. | 1 | 8 | 14 | 35 |
| Curved ownship ref. | 0 | 0 | 0 | 10 |

Table 1. Percent error averaged over subjects and replications for straight and curved encounters. There were 95 trials each per cell for the pretest and posttest no predictor conditions and 238 trials each per cell for the four predictor conditions.

| Source | SS | df | MS | F |
|---|---|---|---|---|
| P | 3215.5 | 3 | 1071.8 | 20.2 * |
| D | 1605.3 | 1 | 1606.3 | 178.3 * |
| E | 1557.2 | 1 | 1557.2 | 75.6 * |
| P X D | 13.2 | 3 | 4.4 | <1 |
| P X E | 1292.6 | 3 | 430.8 | 20.9 * |
| D X E | 2.6 | 1 | 2.5 | <1 |
| P X D X E | 298.2 | 3 | 99.4 | 6.5 * |

* $p<0.01$

Table 2. ANOVA over predictor conditions (P), separation distance (D), and encounter type (E).

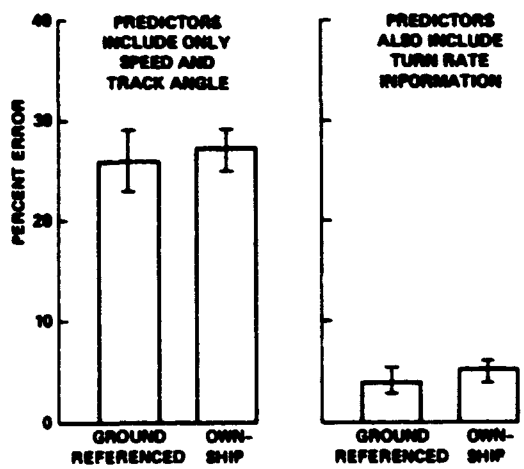


Figure 3. The effect of adding turn rate information to the predictor.

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Figure 4 shows percent error collapsed over subjects for each of the predictors. The data are shown for each of the replications averaged over the two distances. It can be seen that replications with predictors do not improve performance on the no predictor posttest. There was no significant difference between the pretest and posttest means. There was evidence for learning for all predictors except the curved ownship referenced predictor which maintained an average error rate of 3%.

At the conclusion of the experiment the pilots were allowed to view the other predictor conditions. Their predictor preference was requested. All pilots preferred predictors with turn rate information included. The preference was evenly divided between ground referenced and ownship referenced predictors.

## DISCUSSION

The main objective of this experiment was to investigate performances using different types of predictors. Evidence clearly shows that the addition of a predictor reduced the error rate. The percent error was further reduced when turn rate information was added to the predictor.

There still remains a question whether ground referencing or ownship referencing is the best method. The percent error data on the replications showed that there was little learning with the curved ownship referenced predictor. Although after six replications both curved ground referenced and curved ownship referenced predictor conditions had similiar low error rates.

The question of which method of referencing is best is further clouded by the fact that 50% of the error with the curved ownship referenced predictor was accounted for by two encounters. These two encounters (#11 and #19) are both encounters where the ownship is turning. Thus the curved ownship referenced predictor condition had a very low overall error rate when these two encounters are not considered. One could argue that ownship referencing is the best method. On the other hand, the curved ground referenced predictor condition had a more even distribution of error. One must also question how good a referencing method is if it can be so confusing on two of the encounters and not confusing on all the other encounters.

Results from the subjective data suggest that the method of referencing is an individual preference and not based on performance.

## CONCLUSION

This experiment adds to a series of experiments designed to evaluate CDTI display symbology in a dynamic but controlled environment. The following are general observations based on the data from this experiment. 1) The addition of predictive information reduces error. 2) The best results were obtained when turn rate information was included in the prediction.

It is important that any conclusion the reader may draw from

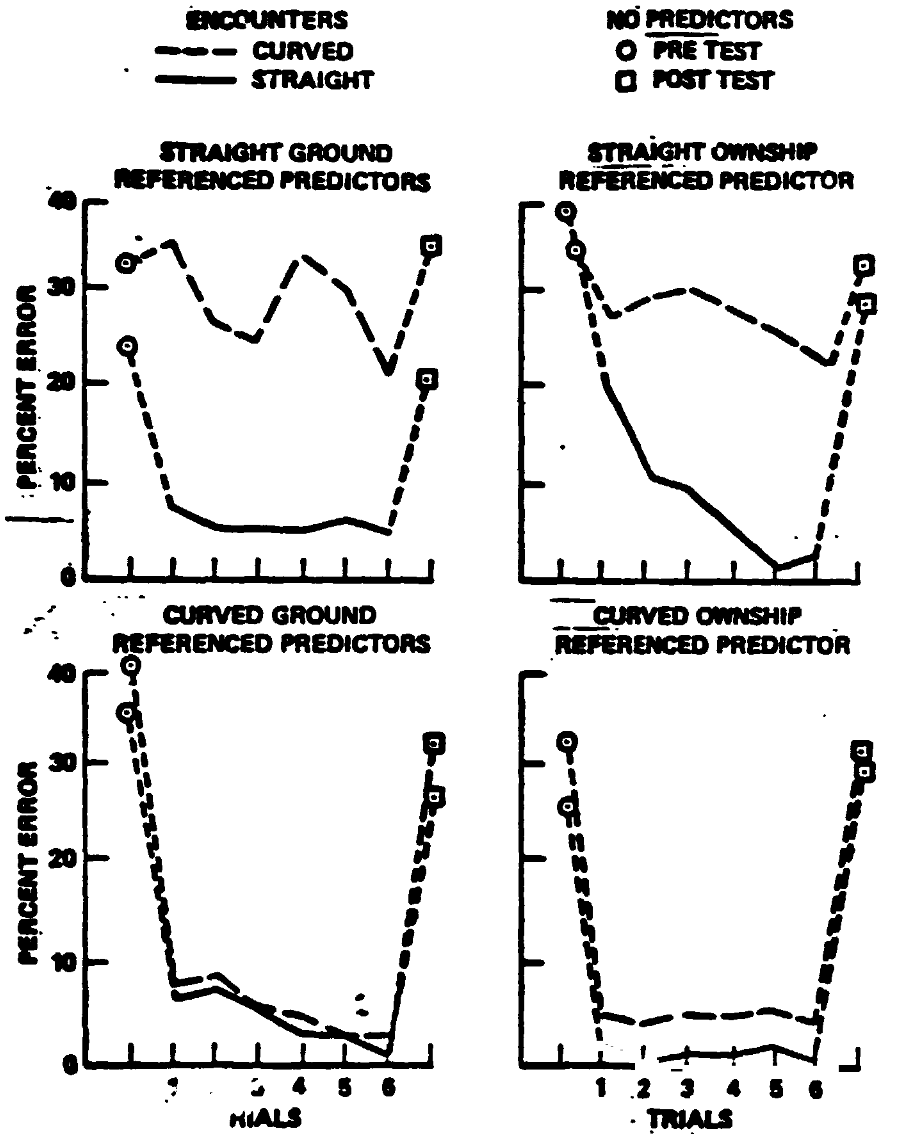


Figure 4. Learning performance with each predictor type. Percent error collapsed over subjects.

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these results take into account the following limitations of the research method: (1) The pilots could devote their uninterrupted attention to the task for 3 sec; (2) neither aircraft changed its speed or turn rate during an encounter; (3) although the display was dynamic, the pilots could not interact with the display to ask for more information about the intruder or change the map scale; (4) pilots could not take over manual control of the aircraft; (5) the passive nature of the task and the large number of trials resulted in a task that quickly became routine. The first two items should lead to fewer errors than would be expected in a real aircraft. The last three items should lead to more errors than in a real aircraft. It is felt, however, that the relative difference between the displays will remain the same as the task is made more realistic.

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