

INFLUENCE OF COLOR COCKPIT DISPLAYS OF TRAFFIC INFORMATION ON PILOT DECISION MAKING IN FREE FLIGHT

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INTRODUCTION

Free Flight

The proposed restructuring concept for the National Airspace System generating the most discussion is called Free Flight. At the heart of the Free Flight system is an increased latitude in pilot decision making and responsibility, especially as it relates to (1) the definition and maintenance of separation, (2) the definition of preferred routes and speeds, and (3) the conduct of maneuvers relating to uncertainties and emergencies in the airspace.

The RTCA Board of Directors' Select Committee on Free Flight, a consensus building industry body, defined Free Flight as:

A safe and efficient flight operating capability under instrument flight rules (IFR) in which the operators have the freedom to select their path and speed in real time. Air traffic restrictions are only imposed to ensure separation, to preclude exceeding airport capacity, to prevent unauthorized flight through special use airspace, and to ensure safety of flight. Restrictions are limited in extent and duration to correct the identified problem. Any activity which removes restrictions represents a move toward Free Flight. (RTCA-3, 1995, page 23)

Free Flight is proposed to evolve as a function of available technologies, procedural changes, aviation community requirements, and increases in airspace capacity. The underlying assumption is that benefits will drive the necessary developments in technology and procedures, both for the aircraft flight systems and the air traffic system. The FAA is committed to a phased and incremental evolution to Free Flight. Movement through the phases of that evolution will require increasing levels of decision support to service users and providers, and increasing degrees of sophistication in the enabling technology.

Cockpit Displays of Traffic Information (CDTI)

The RTCA committee has identified accurate cockpit displays of traffic information as essential technology for the 'well-equipped cockpit' of the future. These displays are proposed to facilitate situational awareness and conflict identification by broadcasting and receiving identification, time, position, velocity and other time-sensitive surveillance information from proximate aircraft (RTCA-3, 1995). Therefore, the development of CDTI technology and display capabilities is an essential technical requirement if both near and long term benefits of Free Flight are to be realized. The content and structure of CDTI will largely be defined by the chosen role of the pilot as defined by the final implementation of Free Flight. CDTI must support the traffic monitoring, collision avoidance, navigation, and communication roles of the flightdeck (Kreifeldt, 1980).

Color

In aviation, where both the volume and rate of information transmission are high, the use of color has become an increasingly popular means to enhance the representation and organization of data. However, the emphasis of color displays has largely centered on technical issues while the numerous human factors questions are less thoroughly researched (Stokes & Wickens, 1984). While studies in the aviation domain have demonstrated that users generally prefer color displays (Mykityshyn, Kuchar, & John, 1994; Reising & Calhoun, 1982), empirical support has not been consistent (e.g., Christ, 1975; Merwin & Wickens, 1993). However, color may be an effective coding format for CDTI collision avoidance functions. Studies have demonstrated that color effectively reduces information processing time in target search tasks, especially in serial search with multiple targets (Hughes & Creed, 1994). Color has also proven effective in conjunctive search tasks where information from two or more dimensions is needed to detect the target (Kaptein, Theeuwes, & van der Heijden, 1995). Target search tasks, where pilots will

be required to integrate position data in order to identify questionable separation situations, are critical to the success of cockpit-based separation operations of Free Flight. The purpose of the present paper is to evaluate the effectiveness of a distanced-based color-coding scheme in the display of traffic information during simulated Free Flight scenarios.

METHOD

Apparatus

Glass Cockpit Instrumentation

The experimental platform has two major components, software written in the C language and hardware featuring a glass cockpit. The software enables pilots to navigate a simulated Boeing 757 aircraft and to maintain or deviate from a preprogrammed flight plan using IFR rules and procedures. Glass cockpit instrumentation includes a primary flight display (PFD), a cockpit display of traffic information (CDTI), and a flight management system (FMS) (see Figure 1).

Cockpit Display of Traffic Information (CDTI)

The CDTI display (Figure 2) is presented on the center CRT and has two views, plan view (180°) and forward view (360°), with available radii of 15, 30, 50, 100, 150, and 300 miles. Traffic information are displayed in one of two formats. The standard format displayed all traffic with an accompanying data tag indicating callsign, airspeed, heading, and altitude. The second format added a color-coded proximity warning system. Aircraft within 1000 ft vertically of the pilots' aircraft were coded blue. Aircraft within 1000 ft. vertically and 30 miles horizontally were coded yellow. Aircraft within 1000 ft. vertically and 5 miles horizontally were coded red. Aircraft not satisfying any of the above criteria were coded white.

Self-separation (free flight) scenarios

While en route, pilots encounter traffic scenarios which portray realistic conflict situations. Traffic is composed of several 'drones' (aircraft that pose no potential conflict for the ownership) and one or more intruders (aircraft that will eventually conflict with the ownership's position). Twelve scenarios investigate two complexity factors: the course of the conflict aircraft (crossing, converging-to-path and overtaking) and traffic density, operationally defined as the number of aircraft in the scenario.

Experimental Participants

Twelve (12) experienced commercial pilots participated in the experiment. Half of the pilots ($n=6$, mean=9208.3 flight hours) were randomly assigned to the standard CDTI condition (no-color group) and the other half ($n=6$, mean=14316.6 flight hours) to the color-coded CDTI condition (color group).

Procedure

Pilots received instruction on each component of the glass cockpit system and then flew a practice scenario. Each pilot then flew the twelve experimental self-separation scenarios. At the start of each scenario pilots received a high-altitude map with their flight plan and starting position identified. Pilots were instructed to maintain progress to their destination and to maintain a minimum of 1000 ft. vertical and 5 mile lateral separation. Pilots were free to select preferred altitude, heading, and speed. No ATC support was provided.

Dependent Measures

The following measures were collected for each scenario: number of separation violations, number and type of executed maneuvers, time to first maneuver, total time on task, and total time spent in each CDTI range and view setting. Simulation software also recorded and time-stamped all pilot interactions with cockpit instrumentation.

RESULTS

Performance

Effectiveness

The total number of achieved separation violations was divided by the total number of programmed violations, yielding a percentage of conflicts achieved (see Figure 3). Pilots in the color display format group achieved 33 of 88 possible conflicts (37.5%). Pilots in the no-color display format achieved 23 of 96 possible conflicts (23.9%). Totals for the groups differed due to the inadvertent corruption of some data files during post processing.

Efficiency

Time to initial maneuver, number of maneuvers executed, and total time on task are measures of pilot efficiency (see Figures 4, 5, and 6, respectively). Time to initial maneuver was calculated as the time elapsed between the start of the scenario and the execution of

the first maneuver. The average number of maneuvers was calculated by dividing the total number of maneuvers by the total number of scenarios. Total time on task was calculated as the elapsed time between the start of the scenario and the time when the pilot indicated no further maneuvers were required.

Strategy

Pilot resolution strategy was inferred by calculating the average number of maneuvers executed for each maneuver type (deviate, climb, descend, cruise, and direct-to (DTO), see Figure 7). Pilot attention strategy was inferred by calculating the percentage of total time spent in each CDTI range radii (see Figure 8). For both strategy measures, data were averaged across all scenarios.

DISCUSSION

Pilot Performance

Contrary to expectations, data for pilot effectiveness indicated that the color group were no more successful in maintaining separation than in the no-color group. The data further suggest that the color-coded display actually degraded performance. Pilot efficiency measures of time on task and number of maneuvers similarly indicated no benefit for the color-coded display format. Taken together, these effectiveness and efficiency measures are strong indicators that the proximity-based color coding of CDTI information in this experiment did not facilitate self-separation and furthermore, may have even hindered pilot performance.

The only potential benefit from color coding seen in this experiment is seen in time to initial maneuver. On average, the color group executed a maneuver approximately ten seconds prior to the no-color group. For an aircraft travelling at 300 kts, this translates to a savings of more than one mile. This benefit, however, should be interpreted with some caution, since there is no indication that the maneuvers made by the color group were any more effective than the maneuvers made by the no-color group. In this case, efficiency without corresponding effectiveness is not sufficient evidence to warrant recommendation of the color CDTI.

Pilot Strategy

Overall, pilot strategy data indicated a preference for vertical resolution strategies and an attentional focus on intermediate CDTI ranges. Vertical maneuvers accounted for approximately 46% of all maneuvers and the 30 and 50 mile ranges accounted for nearly 70% of scenario time. Specifically, maneuver type data indicate that CDTI format contributed to divergent strategies for the two groups of subjects. Pilots in the no-color group were much more likely to employ climb maneuvers and to focus attention more to the immediate proximity of their own aircraft than pilots in the color group. Conversely, pilots in the color group executed more speed maneuvers and allocated time equally to 30 and 50 mile ranges.

What accounts for these strategy differences? Because the no-color pilots tended to wait longer to start the initial avoidance maneuver, they found themselves in the position of having less time to maintain self separation. Given this constraint, vertical maneuvers are preferable to horizontal and speed maneuvers because they achieve separation more quickly. This logic is the basis current collision avoidance systems like TCAS (SAE Inc., 1993). The no-color pilots may also be employing a type of high-altitude density heuristic where, given time constraints, climb maneuvers are selected because higher altitudes are likely to contain fewer aircraft. It is difficult to determine how time constraints and heuristic factors contributed to specific strategies because, in the present experiment, pilot strategy was inferred and not directly manipulated. Future work will specifically examine pilot strategies in self-separation scenarios through analyses of concurrent verbal reports (Ericsson & Simon, 1984) where pilots overtly state goals and strategies.

Color-Coding

There are several explanations for why the implemented color coding system did not produce the expected benefits for pilot performance in the self-separation scenarios. Principal among these is that color coding is simply not an effective format for displaying information pertinent to the identification of intruders. Performance benefits were expected based on established evidence that color coding is effective in reducing information processing time in target search tasks (Hughes & Creed, 1994). It may, however, be unfair to represent the present self-separation task as a simple serial search for targets,

i.e., identifying those aircraft that will conflict with the ownship. The pilot's role is not only to respond to possible conflicts but to build and maintain a dynamic representation of the airspace. To build and update an airspace representation requires processing information for all nearby aircraft at all times, especially as the pilot evaluates how potential maneuvers may effect the particular traffic pattern. It is possible that color coding disturbs the pilots ability to process non-color coded information, especially when evaluating potential maneuvers. Thus, it is possible attention is focused on only a subset of relevant information. Even if attention is not fully captured by color coded targets, these targets may still serve as landmarks for a top-down search strategy (Todd & Kramer, 1994), potentially increasing information processing times for non-color-coded information. Previous research has identified that potential benefits for color coded displays can also be compromised when the search tasks requires elements of exhaustive search (Hughes & Creed, 1994).

The reliance on distance parameters in the color scheme may also account for the lack of performance support from the color group. Other research has indicated that pilot behavior can be interpreted with respect to variables such as time to contact, where pilots respond to information for relative velocities and changes in relative velocities when planning and executing maneuvers (Smith, Hancock, & Lewin, 1996). Data from pilot debrief sessions also supported the contention that distance alone did not account for individual maneuver decisions. Pilots often reported that distant aircraft with high relative velocities (approaching aircraft) weighed heavily in avoidance decisions while close aircraft with low relative velocities were not viewed as problematic. Alternate color coded implementation schemes, one based on relative velocity alone and one based on hybrid distance-relative velocity information, are the basis of current research.

Finally, design characteristics of the self-separation scenarios may account for the lack of performance support for the color format group. All aircraft in the scenarios maintained their pre-programmed flight plans. Only the one aircraft under the pilot's control was free to change altitude. This design makes the future position of aircraft highly predictable. It should be noted that this design feature was not made explicit to the pilots. However, concurrent verbal reports collected during the experiment indicated, without exception, that pilots quickly realized this design feature. The predictability

provided by the static altitude design feature simplifies the initial assessment of the traffic situation because the search for intruder aircraft can be limited to those aircraft at the same altitude as the pilot. To determine the extent to which the static altitude design feature accounts for pilot performance and strategy the experimental scenarios were modified so that both intruder and drone aircraft execute more dynamic flightplans. Research with these modified scenarios is currently being conducted. Preliminary data indicate that the static-dynamic distinction is considerable factor in evaluating pilot performance and strategy in self-separation scenarios.

CONCLUSIONS

- Distance-based color coding of intruder aircraft on a CDTI did not increase pilots' ability to maintain separation in Free Flight scenarios.
- Pilots employing the color CDTI executed initial maneuvers earlier than pilots without color CDTI, providing some evidence in support of increases in pilot efficiency for color displays.
- In general, pilots executed more vertical maneuvers than other maneuver types. The no-color group executed more climb maneuvers than the color group while the converse was true for cruise maneuvers.
- In general, pilots spent the largest proportion of their time with the CDTI in the intermediate (30 and 50 mile) ranges. Pilots in the color group allocated time equally in the intermediate ranges while pilots in the no-color group spent more time in the 30 mile range than in the 50 mile range.

ACKNOWLEDGEMENTS

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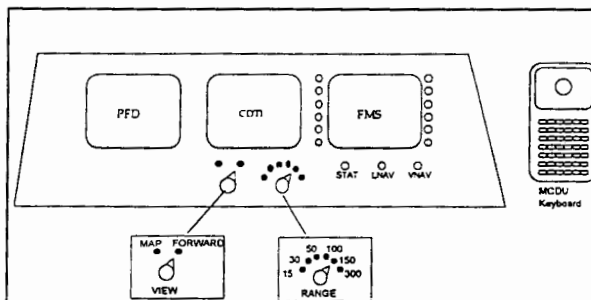


Figure 1. Layout of cockpit displays and controls.

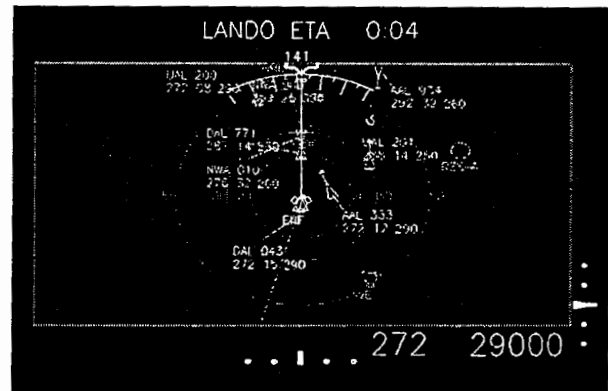


Figure 2. The cockpit display of traffic information.

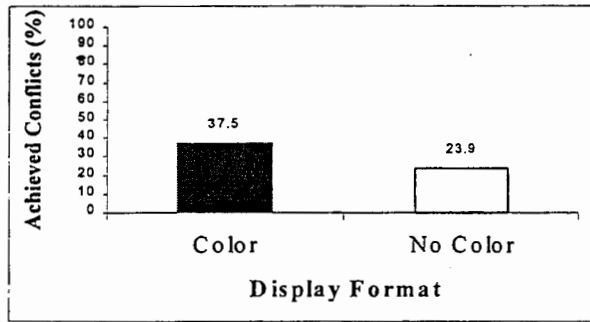


Figure 3. Overall percentage of achieved conflicts.

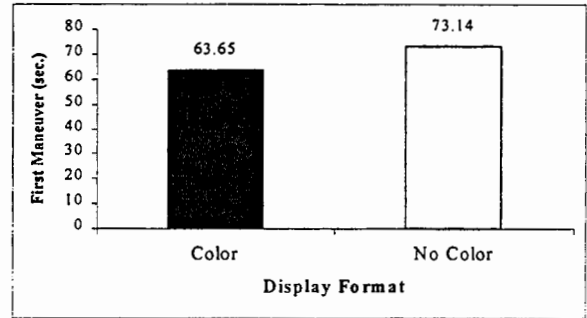


Figure 4. Average time to initial maneuver.

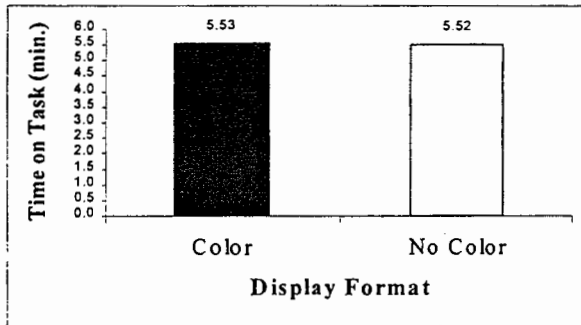


Figure 5. Average time on task

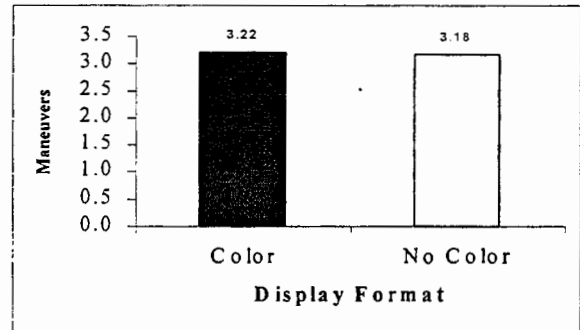


Figure 6. Average number of maneuvers.

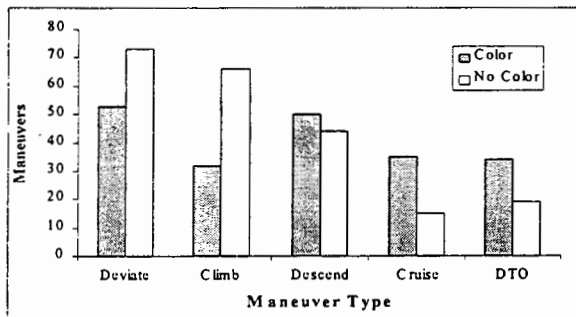


Figure 7. Number of maneuvers by type.

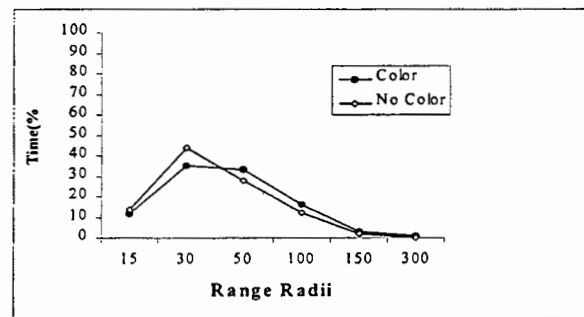


Figure 8. Percentage of time in CDTI range radii.