EVALUATION OF THE USEFULNES AND USABILITY OF COCKPIT SITUATION DISPLAY PERSPECTIVES FOR ROV OPERATIONS IN APPROACH CIVIL AIR SPACE

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A distributed simulation of ROV operations was conducted by NASA Ames Flight Deck Display Research Laboratory (FDDRL) and the Center for Aeronautic Technologies (CSAAT) at California State University, Long Beach. The goals of this simulation were 1) to examine ROV operators' ability to maintain standard terminal separation from other aircraft and ROVs, 2) to examine the possibility of operating ROVs in terminal airspace without major disruptions in the inbound traffic flows, and 3) to evaluate proposed ROV operator tools. The current paper focuses on this third goal. Specifically the paper describes the motivation behind the development of the manipulatable 2D/3D Cockpit Situation Display (CSD), and examines its usefulness and usability. Data from questionnaires, and from observations of how the CSD was used, suggest that both the CSD format, and the ability to manipulate the CSD viewing angle, were useful and usable. However, workload appeared to play an important role in the perceived usefulness and usability of the CSD.

INTRODUCTION

In support of domestic homeland security, ROVs are being considered for a variety missions such as port, border, and waterway surveillance. While these homeland security missions may be of vital importance, they may not be allowed for fear that the ROVs will disrupt and/or pose a safety hazard to other aircraft. Prime examples of this are ROV missions proximate to major hub airports which require the ROVs to operate in terminal airspace. Presently, if these missions are allowed at all, they are required to operate during off-peak periods when airport traffic is very light or non-existent.

In response to this challenge, a team composed of researchers at California State University, Long Beach (CSULB), and at NASA Ames Research Center (Ames), has initiated a series of joint simulation studies designed to directly assess the feasibility of this most difficult ROV operation - safe and non-disrupting ROV flight in a busy terminal airspace. These are also studies which seek to develop both tools and procedures that will support safe operations. The immediate goal of this initial study was to provide a first look at this operation, and to gather data to support refinement of our operational concepts and operator tools.

The ROV's specific mission in this initial study was to safely patrol reservoirs at low altitudes within simulated airspace of the Dallas Fort Worth (DFW) terminal area, without major disruptions to the inbound flows to runways. While, as noted previously, assessments of safety, effectiveness, and feasibility were goals of the study, the adequacy of one of the operator tools is the focus of this report.

This tool, the Cockpit Situation Display (CSD), was previously developed as an advanced cockpit display of traffic information (Johnson, Battiste, & Holland, 1999), and is now being considered for inclusion in ROV workstations. The CSD provides 3D as well as 2D visualization of ownship, traffic, terrain, weather, as well as a large number of other features. Although, there are many other relevant issues of interest to the current authors and the ROV research community, the scope of this paper will be limited to the usability and usefulness of ROV navigation display – which in this case would be the CSD.

Overview of ROV Simulation

The goals of this first study were to examine three issues. The first goal, related to safety, was to examine how well ROV operators could maintain standard terminal separation (3NM and altitude of 1000 ft) from other aircraft and ROVs. The second goal, related to efficiency, was to examine how well ROVs could be flown in terminal airspace without major disruptions in the inbound traffic flows. The study's third goal was to evaluate the operator tools and determine what features need to be redesigned for more effective ROV operations in terminal airspace. This report will focus on this third goal, with specific attention given to the usability of the CSD display perspectives and view manipulation.

Motivation for CSD Development

The initial research and development for the CSD was in response to the need stated by the RTCA Task Force 3, Free Flight implementation (1995) to increase situation awareness on the flight deck in order to develop and progress the notion of free flight. Their definition of free flight was "safe and efficient flight operating capability under IFR in which the operators have the freedom to select a path and speed in real time". The NASA Ames Flight Deck Display Research Laboratory (FDDRL) has devoted several years of research into developing a CSD that provides the situation awareness required for free flight on the modern flight deck (Granada, Dao, Wong, Johnson, and Battiste, 2005; Johnson, Battiste, Delzell, Holland, Belcher, and Jordan, 1997; Johnson, Battiste, & Holland, 1999).

The CSD aids situation awareness with a battery of tools available to the pilot in a single interface. These tools, which presuppose extended and advanced surveillance capabilities such as ADS-B , include 1) the ability to view the flight plan and maneuvering intent of other aircraft (Figure 1), 2) an integrated Route Assessment Tool that allows users to view, manipulate, and revise their aircraft's flight plan (Figure 2), and 3) conflict alerting logic that automatically identifies and visually indicates impending separation violations on current and proposed flight plans (Figure 3).

Figure 1. A 2D perspective of the flight plan information for ownship and an intruder aircraft on the CSD.

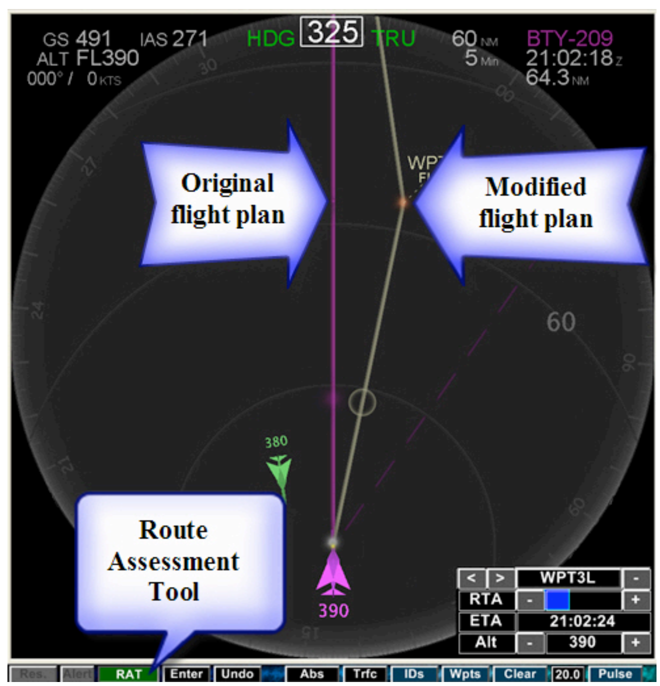

Figure 2. A 2D perspective of a route modification made with the route assessment tool (RAT).

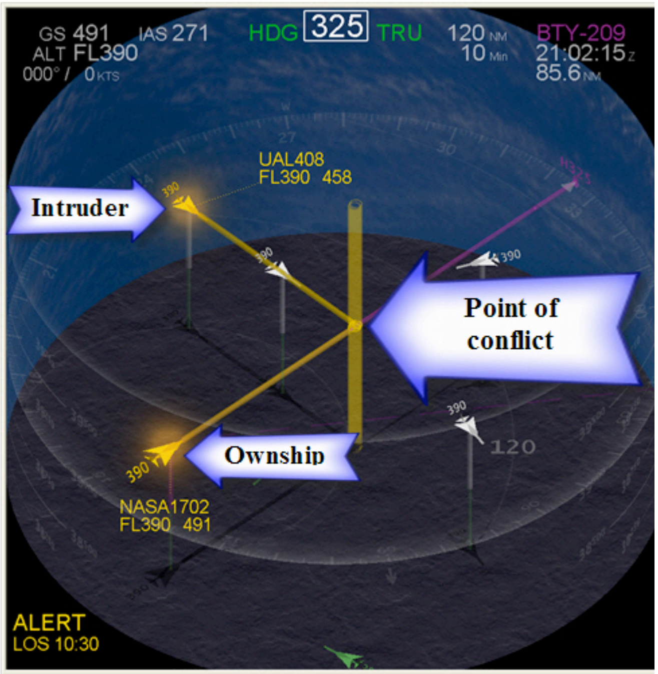

Figure 3. A 3D perspective of visual alerting invoked by conflict alerting logic.

Lastly, the CSD expands the user's awareness of the airspace by allowing pilot selected viewing of traffic relative to ownship in both 2D and 3D display modes. For more details about the above and many other tools in the FDDRL 2D/3D CSD see the Ames CSD User Guide (http://human-factors.arc.nasa.gov/ihh/cdti/download.html).

Why a 2D/3D Integrated CSD?

To achieve the situation awareness necessary for free flight pilots need vertical and horizontal information regarding ownship and traffic position and movement. Sometimes pilots need to focus on just one or the other of these two dimensions, while at still other times they need a combined or integrated view. According to the Proximity Compatibility Principle (PCP), when tasks require mental integration of two or more sources of information, the display should present the information in close proximity. If tasks require focused attention, then the information should be presented in reduced "display proximity" (Wickens & Carswell, 1995). Consistent with this, the CSD provides the flexibility to manipulate the CSD into any view from a vertical profile view to a god's eye top down view, to an integrated off-axis perspective view. Additionally, the pilot can pre-set four preferred views which can be quickly selected to support a variety of cockpit tasks. Thus the CSD is designed to satisfy display requirements when the task necessitates mental integration of 3D information, as well as when it requires focused attention on traditional 2D slices. Furthermore, the CSD moves smoothly and continuously between its different views, and does not jump between them, – effectively supporting visual momentum (Woods, 1984).

Finally, the CSD also affords viewing weather and terrain information in 3D, providing an ecological representation consistent with user expectations of how terrain and weather should be depicted.

ROV Operator Task Requirements

In the current study, 4 commercial airline pilots were recruited to fly either one or two ROVs in heavy, medium, or light traffic conditions. Using the CSD integrated with a MACS desktop flight simulator (Prevot, 2002), the pilots' task was to perform low altitude surveillance flights over lakes west of DFW. Both traffic and terrain information was available on the CSD. Figure 4 shows that the

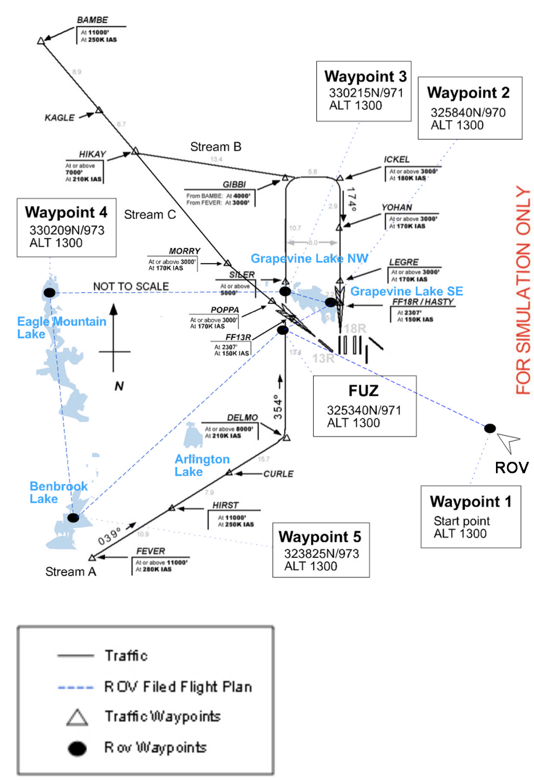

Figure 4. The DFW approach airspace and ROV filed flight plan.

filed flight plan covers surveillance over three main bodies of water north and west of the DFW runways. In order of priority, pilots were required to 1) maintain 3 nm horizontal and 1000 ft vertical separation from all other aircraft; 2) only change their route by using the CSD to modify their flight plan; and 3) fly the ROV over these lakes at altitudes between 1300 ft and 4000 ft. On half of the flights the pilots were required to manage a single ROV, while on the other half of the flights the pilots were required to simultaneously manage two ROVs. This manipulation reflects the desire in the ROV community for systems where a single pilot can manage multiple ROVs. For more details regarding the ROV demonstration see Vu, Dion, Chambers, Ngo, Nelson, Kraft, and Strybel (2006).

RESULTS

ROV Operator Response to 2D/3D CSD

The study lasted five days. Participants received four hours of training on the first day, and then flew experimental scenarios for four hours each of the remaining four days (totaling 24 trials). At the end of each day pilots rated the subjective usability and usefulness of the CSD 3D perspective view and 2D to 3D perspective manipulation on a 5-point scale (1 = very difficult, 2 = difficult, 3 = acceptable, 4 = easy, 5 = very easy). Based on average ratings from the 4 pilots recruited for this study, the CSD's 3D perspective view was determined to be between acceptable and easy to use (M = 3.5). Similarly, pilots rated the ability to change from 3D to 2D viewing modes between acceptable and easy to use as well (M = 3.5). Usefulness was also rated on a 5-point scale (1 = absolutely useless, 2 = useless, 3 = adequate, 4 = useful, 5 = extremely useful). On average, pilots felt that the CSD's 3D perspective viewing was useful (M = 4) as was the ability to manipulate the CSD into 2D and 3D views (M = 3.75).

Table 1. Percent Frequency of CSD Perspectives Used During Periods with No Conflict and Periods with Conflicts

Use of CSD Perspectives					
	2D only	2D/some 3D	Both	3D/some 2D	3D only
No Conflict	34.8	24.7	24.7	2.2	13.5
Conflict	30.2	27.9	23.3	4.7	14

Observed CSD Perspective Usage

In addition to the subjective ratings, each pilot was observed by a single researcher who judged if the pilots viewed the CSD in 2D only, primarily 2D and some 3D, 3D only, primarily 3D and some 2D, or a balance of both views. Results were averaged across both 1 and 2 ROV operating conditions. Table 1 demonstrates that across both periods with and without conflict alerts, pilots used the 2D perspective most often. There was however, a tendency to use the 3D perspective a bit more when pilots were only controlling a single ROV (Table 2), suggesting that pilots were more willing to switch to the 3D perspectives under a lighter workload.

Table 2. Percent Frequency of CSD Perspectives Used Across 1 ROV and 2 ROV Conditions

Use of CSD Perspectives					
	2D only	2D/some 3D	Both	3D/some 2D	3D only
1 ROV	17.2	34.5	25.9	8.6	13.8
2 ROV	40.2	22.2	23.0	0.8	13.7

In summary, the pilot questionnaire data shows that most of the pilots thought that having the ability to switch between various perspectives on the CSD useful. All of the pilots thought that it would be useful to have a 3D perspective available. However, comparison of the observer judgments of CSD use, with the subjective ratings, shows that the pilot's *perceived* usefulness of the CSD perspectives may have been influenced by the amount of workload – in this case, whether they were operating only 1 or 2 ROVs simultaneously. Under conditions where pilots were responsible for only 1 ROV they were observed using primarily a 2D perspective and switching to the 3D perspective some of the time. When pilots were operating 2 ROVs simultaneously pilots were observed staying in the 2D display perspective most frequently. This influence of workload may have been a contributing factor for lower perceived 3D and 2D to 3D perspective manipulation usability ratings.

DISCUSSION

In free flight conditions aircraft separation responsibility is distributed between equipped aircraft and air traffic controllers. The CSD provides the vertical and horizontal air space information required to operate in self-separation contexts – which in turn, also support greater situational awareness. The operational flexibility of the CSD was exemplified by the ability of commercial pilots to accomplish strategic ROV missions. Preliminary data shows that the ability to manipulate an ego-centric traffic display into both 2D and 3D was useful. The frequency of observed transitions between 2D and 3D modes on the CSD and its perceived usability may have been workload dependent. Future studies will be focused on the effect of 2D to 3D display manipulation on operator conflict resolution performance and perceived workload.

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