EVALUATING VISUALIZATION MODES FOR CLOSELY-SPACED PARALLEL APPROACHES

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Raytheon's TACEC (Terminal Area Capacity Enhancement Concept) proposes to increase airspace capacity by using closely-spaced formations of arriving and departing aircraft to greatly increase airport capacities. However, a blunder in a tightly-spaced formation could cause a collision with another aircraft or its wake vortices. Therefore, humans need tools and visualization aids to detect and respond to blunders. This paper is the first in a series of experiments to evaluate the ability of different visualization modes to enable detection of lateral blunders. We tested four viewpoints, one warning aid, and three blunder speeds in a within-subjects design. This study had twelve participants. The main result was that changing the viewpoint made a large difference; the cockpit view was by far the worst. Blunder detection varied by speed and was difficult in the presence of noise. Future experiments should use more realistic simulators and pilots as participants.

INTRODUCTION

The capacity of the United States' National Airspace System (NAS) must at least double to handle the projected increase in passenger demand by 2020. To address this challenge, NASA initiated the Virtual Airspace Modeling and Simulation (VAMS) project in 2002 with the goal of generating new Air Traffic Management (ATM) concepts that can provide the needed capacity. One of these concepts is Raytheon's Terminal Area Capacity Enhancement Concept (TACEC), which is based on formation approaches and departures (Rossow, 2003). Major airports do not have enough runways to support the departures and landings required to dramatically increase NAS capacity. Expanding airports by building new runways is often prohibitively expensive and politically difficult. Wake vortices limit how often a runway can be reused. TACEC proposes to overcome these problems by building several closely-spaced parallel runways in the area where one or two runways exist today. Aircraft would arrive and depart in tightly spaced formations to avoid wake vortex hazards between adjacent aircraft (Miller et. al., 2005). If three aircraft and runways could exist in the space occupied by one runway today, capacity could triple.

Initial simulation runs suggest that TACEC can dramatically increase capacity, but it requires new human roles and interfaces before the ATM community accepts this concept. A blundering aircraft (e.g., one that incorrectly turns left or right) can quickly cause a safety hazard, due to a potential collision with another aircraft or its wake vortices. While automation will play a key role in ensuring safety, human pilots and controllers must also have interfaces that keep them aware and involved and able to detect and respond to blunders. This paper describes the first in a series of experiments designed to measure the ability of visualization modes to convey aircraft blunders. The results from this experiment will guide the selection of cues to test in subsequent studies.

Space limitations prevent us from thoroughly covering previous works on closely-spaced parallel approaches, such as the Airborne

Information for Lateral Spacing program (Abbot, 2002), so we instead mention a few with significant visualization components. Jennings, et al. (2002) used a synthetic vision system with a "3D tunnel in the sky" to demonstrate paired approaches with actual aircraft. However, this was not conducted as a controlled experiment. Hardy and Lewis (2004) modified a standard plan view CDTI (Cockpit Display of Traffic Information) display to include representations of wake vortex hazard regions for aircraft in paired approaches. Landry and Pritchett (2002) summarize the results of several studies, including their own experiment where pilots viewed a "safe zone" graphic that represented the in-trail spacing that a pilot must maintain with respect to the other paired aircraft. Our work differs in measuring the sensitivity of different visualization modes to detect slow blunders, while previous works select one visualization mode and use that to warn against a blatant blunder (e.g., a 30 degree turn). Also, our work is intended to support TACEC formations that may have 3 or 4 aircraft, while all previous works assume paired approaches (2 aircraft).

METHOD

The purpose of this initial experiment was to begin the search for the specific visualization that would most enhance a pilot's ability to detect a blunder in another aircraft. We varied the viewpoint, the presence of one warning cue, and the speed and direction at which blunders occurred. We hypothesized that both the warning cue and a modified viewpoint (from the normal cockpit view) would improve blunder detection.

This experiment was run on a Windows PC with a Xeon CPU and an NVIDIA Quadro4 900 XGL graphics card. We wrote custom display and data collection software, using Open Scene Graph and Tcl/Tk. We used a large projection screen as the display where the two windows (mimicking an "out the window" view and a Multi-Function Display [MFD] view) were rendered to match the field of view covered by those displays in a 747 (Figure 1) when seen at our 42" viewing distance.

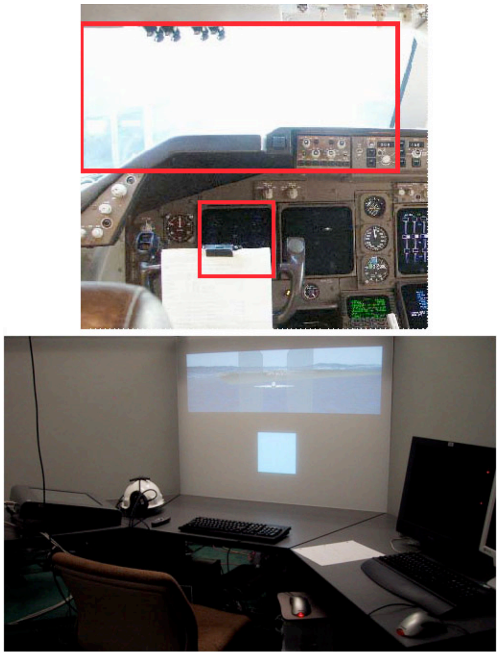

Figure 1: (Top) Measurements from 747 simulator. (Bottom) Equipment and display used in experiment.

Stimuli: Stimuli were animated sequences of one aircraft presented in real time at 30 Hz. We rendered only one aircraft to avoid the variability introduced by distracting user attention amongst several aircraft. Each sequence lasted 10 seconds. There were four types of viewpoints (cockpit, rear "out the window" view, rear MFD view, top-down MFD view), one type of warning (vertical barriers), and three blunder speeds (none, 5 feet/sec, 10 feet/sec). A blunder was a consistent motion left or right for several seconds. Figure 2 shows four examples of stimuli. Each trial had a different amount of noise in the aircraft motion. This noise was the sum of two sources: actual error in the aircraft's ability to fly the ideal course (Flight Technical

Error) [vertical □=2.5m, max=10m; horizontal □=3m, max=12m] and errors in measuring aircraft position with an augmented GPS system [vertical □=1m, max=5.3m; horizontal □=3.1m, max=15.5m].

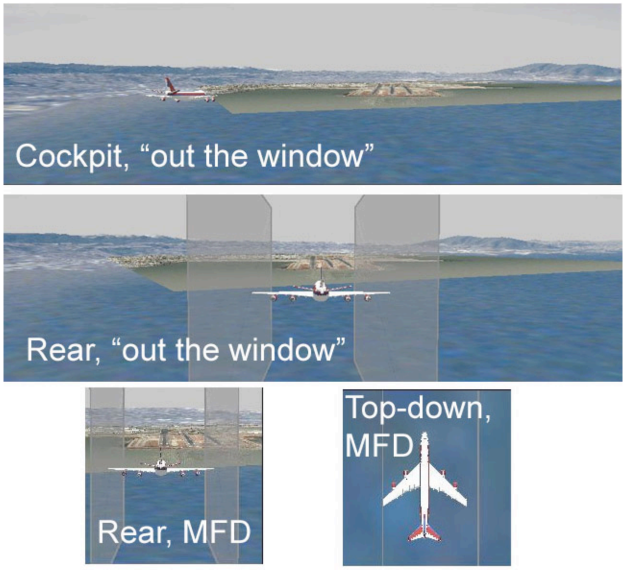

Figure 2: Examples of four stimuli, where viewpoint is either behind aircraft or above aircraft

Design: This experiment was a 4 x 2 x 3 within subjects design. The independent variables were the four viewpoints, the presence or absence of the vertical warning barriers, and the 3 blunder speeds, generating 24 unique trial types. Each trial type was repeated 10 times for a total of 240 trials (each of the 240 trials had a unique noise characteristic). There were 24 practice trials before the actual trials. The practice trials were not included in the analyses. The presentation order was counterbalanced by first randomly shuffling the 240 trials to produce a random order. Then half the participants saw the trials in the order of trial 1 to 240, while the other half saw them in order of trial 240 to 1. The dependent variables were accuracy (correct identification of the presence of a blunder and its direction) and reaction time from the onset of a blunder (if identified correctly). Lateral distance traveled before successful detection was computed from RT.

Procedure: Participants read a sheet of instructions. For each trial, the participant started the trial by pressing the space bar. The participant could take a break at any time by not pressing the space bar. After a trial began, the participant had eight seconds to indicate a blunder and its direction by pressing the left or right arrow keys, or “no blunder” by pressing the up or down arrow keys. Since the default answer was “no blunder,” participants need not press any key if no blunder was observed. Participants could change their answer up until the eight second mark. At the end of each trial, participants were told whether their choice was correct or not (this is how they learned what motions were considered blunders). The data collection software recorded all keystrokes, scored the results and measured the reaction time. Participants were 12 HRL technical staff members (10 male, 2 female); none were pilots.

RESULTS

A factorial ANOVA was run with blunder detection accuracy as the dependent variable and three independent variables: 4 viewpoints, 3 blunder speeds, and 2 warning conditions (vertical lines present or absent). There were main effects with viewpoint [F(3, 2856) = 131.122, p <= .0009] and blunder [F(2, 2856) = 76.316, p <=.0009]. There was also a significant interaction between viewpoint and blunder [F(6, 2856)=12.819, p <= .0009] and blunder, viewpoint and warning [F(6, 2856) = 3.058, p <= .006].

Viewpoint: The cockpit viewpoint yielded the lowest detection accuracy (μ=50.28%, □=5.00), and Tukey’s test showed the cockpit viewpoint to be significantly different from the other 3 viewpoints [“out the window” rear display (μ=81.11%, □=3.92), MFD rear (μ=86.67%, □=3.40) and MFD top-down (μ=82.36%, □=3.81)] at p < .0009.

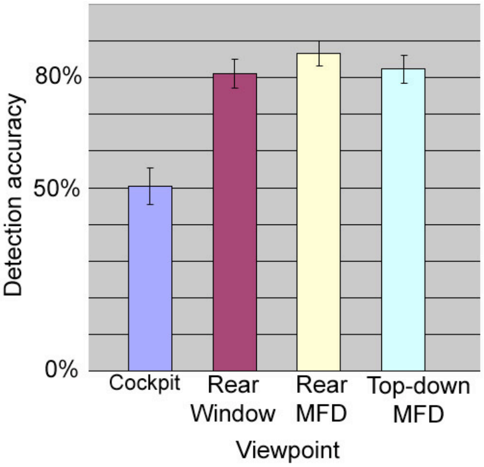

Table 1: Detection accuracy by viewpoint

Blunder speed: Participants were least accurate with slow (5 feet/sec) blunders (μ=63.85%, □=4.81), followed by no blunder (μ=75.52%, □=4.30), and were most accurate with fast (10 feet/sec) blunders (μ=85.94%, □=3.48).

Warnings: There was no overall significant difference between the presence and absence of vertical barriers. There was no clear trend over all 24 combinations of the interaction between blunder, viewpoint and warning, but warnings may be beneficial in certain MFD viewpoint conditions. For the MFD top-down viewpoint and a slow blunder, using warnings (μ=76.67%, □=4.25) yielded a higher detection rate than no warnings (μ=57.50%, □=4.96). Similarly, in the MFD rear viewpoint with no blunder, warnings (μ=92.50%, □=2.64) had a higher rate than no warnings (μ=82.50%, □=3.82).

Reaction time and distance effects: We also ran a factorial ANOVA with reaction time as the dependent variable and three independent variables: 4 viewpoints, 2 blunder speeds (reaction time is valid only when a blunder occurred and the user answered correctly), and 2 warning conditions. There were main effects with viewpoint [F(3, 1422)=12.931, p <= .0009] and blunder [F(1, 1422)=76.963, p <= .0009]. There was a significant interaction between blunder and warning [F(1, 1422) = 24.954, p <= .0009], and blunder and viewpoint [F(3, 1422)=11.157, p <= .0009]. The viewpoint main effect is due to the bad performance in the cockpit viewpoint. Participants responded more quickly with fast blunders (μ=2.51 sec, □=1.29) than with slow blunders (μ=3.25 sec, □=1.58). However, the lateral distance traveled with a fast blunder (μ=25.12 feet, □=12.95) tended to be larger than with a slow blunder (μ=16.27 feet, □=7.95).

DISCUSSION

Detecting the blunders presented in this experiment was a difficult task because the lateral displacement due to noise could be as large as a blunder (over six seconds, a 5 feet/sec blunder covers 30 feet, and 10 feet/sec covers 60 feet). This difficulty was intentional. While the “blunders” presented here are too small to cause problems in a real TACEC formation, they were usually large enough to be detectable and enabled us to measure the sensitivity of the different visualization modes (by measuring differences in accuracy and reaction time). Participants had to detect a blunder by observing trends and recognizing the consistent lateral motion in the presence of confounding noise, rather than by following some simple, easily automated rule like “crossing a threshold.”

The main result is that the viewpoint clearly makes a difference. The view that a pilot would normally see out of a cockpit was by far the worst option. Any of the other visualization modes that changed the viewpoint would be preferable, supporting the hypothesis. Surprisingly, the rear viewpoint generated different results when viewed in the “out the window” display vs. the MFD display. It is unclear what causes this difference; one possibility is that the MFD display is closer to an orthogonal view than the "out the window" display. The results do not support the hypothesis that the vertical barriers improve performance.

Participants were less accurate and took longer to detect slow blunders than fast ones, but the total lateral distance traveled by the aircraft was longer with fast blunders.

The total duration of the experiment was too long. Participants completed all the trials in about one hour, but they tended to become fatigued and bored and usually required several breaks. Future experimental designs should have shorter exposure times (30 minutes) and use more participants.

We could not enable antialiasing (reducing scintillation artifacts that unduly attract user attention) with this graphics card and software. This meant that aircraft motions were easier to perceive than they should have been.

Existing aircraft position measurement systems operate at low update rates (1-2 Hz). We did not operate under such a limitation, since high accuracy, high update rate measurement systems will be needed within a formation to make TACEC feasible.

The results of this experiment guided our design of the second experiment. We chose to focus on MFD displays and to explore several different visualization aids that could be added to a top-down viewpoint.

In future studies, we intend to work with NASA Ames and run experiments using their flight simulators, with more realistic controls and models, and multiple aircraft. We would also like to use pilots as participants. This experiment is the first in a series of experiments and will be reevaluated with other statistical approaches (e.g., signal detection methodology) as part of the larger series.

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