A Virtual Audio Guidance and Alert System for Commercial Aircraft Operations

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Introduction

Our work in virtual reality systems at NASA Ames Research Center includes the area of aurally-guided visual search, particularly the use of specially-designed audio cues and spatial audio processing (also known as virtual or "3-D audio") techniques (Begault 1994). Previous studies at Ames reveal that, compared to a head-down map display (0.5 sec advantage) or no display at all (2.2 sec advantage), 3-D audio used in Traffic Collision Avoidance System (TCAS) advisories significantly reduce head-down time(Begault 1993, 1995; Begault and Pittman 1994; for an audio demo, see Wenzel 1994). When taxiing under low-visibility conditions, the crew must look out the window rather than at visual instruments, and the potential for accidents consequently increases. To solve this problem, two prototype information systems, an audio ground-collision-avoidance warning (GCAW) system and a 3-D audio guidance system, incorporate audio-spatial cueing. We evaluated the effectiveness of the audio-spatial cueing in these prototypes. Audio-spatial cueing yielded favorable results in the GCAW, but not in the audio guidance system.

Objectives of the Study

This study sought two objectives. One was to determine whether pilots preferred audio in a prototype 3-D audio GCAW system, intended for low-visibility conditions. We thus designed an alarm to alert pilots to the direction of a potential incursion and hypothesized that there would be a significant preference for such a system to be included in the flight deck. To test our hypothesis, we measured pilot preference with a Likert scale questionnaire that we gave during the pilot debriefing session.

The second objective was to determine whether audio improved pilot crews' ground taxi time, from the landing point to the gate. We hypothesized that a 3-D audio guidance system, announcing specific taxiway turnoffs on the route to orient and guide pilots, would reduce significantly the taxi time. To test this hypothesis, we timed pilot crews taxiing under aided (with the audio guidance system) and unaided (with only a map) conditions.

Subjects and Scenario

The experiment was conducted within a 747-400 simulator at NASA Ames; 12 crews from a U.S. carrier, all with 747-300 or -400 glass cockpit experience, served as subjects. We designed the flight plans, communications and procedures to be realistic as possible. A total of 7 routes (6 orientation routes and 1 incursion route) were based on normal routes used at O'Hare Airport in Chicago. Each crew taxied three of the six orientation routes twice (once with and once without the guidance system) to enable a within-subject evaluation. The order and assignment of routes was randomized so that the crews ran each route an equal number of times. To evaluate preference for GCAW, each crew ran the same 7th route that included a potential conflict from another aircraft. To preserve the realistic element of surprise, the crews had no previous knowledge of the total number of routes or which route included a potential incursion.

Stimuli

The audio hardware for producing the stimuli consisted of pre-spatialized 3-D audio cues stored within an audio sampler (Roland

S-760), which was connected to a stereo headset (Sennheiser HME 1410-KA). For the GCAW system, the stimuli consisted of an alert signal. We designed the signal to be noticeable but not as loud as typical alarms by (1) using significant frequency energy from 0.3-13 kHz and (2) including a "transient" (fast rise time) amplitude envelope. For the guidance system, the stimuli consisted of a synthetic "pre-alert" alarm followed by a female voice that announced taxiway crossing names (e.g., "A 15").

Results of the GCAW

In the preference evaluation, all 11 questions that related to the GCAW system yielded significant results. Given the possibility of the following responses

strongly disagree__
disagree__
neither agree nor disagree__
agree____
strongly agree____

the following questions yielded a significant response of "agree" (chi-square test, a = .05):

- A system using an audio incursion alert like that heard in the last run would be useful for avoiding a potential incursion under low visibility (300 RVR) conditions.
- The audio incursion alert would also be useful under normal visibility conditions.
- An auditory system presenting incursion alerts would be a useful adjunct to a moving map display.
- An auditory system presenting incursion alerts would be useful on its own.
- The incursion alert probably allowed me to stop sooner than I would have without it.
- The beeping sound of the incursion warning was comfortable to listen to.
- The audio level of the incursion warning was "comfortable."

Interestingly, a significant number of pilots responded "neither agree nor disagree" regarding whether the spatial quality, in particular, of the alert helped them to locate visually the other aircraft. A probable explanation is that each crew experienced only one possible incursion and that several were taxied as fast as 27-30 knots. Because our implementation was based on distance and not time-until-impact, like TCAS systems, taxiing at high speeds could thwart the alert's effectiveness. Our future implementation of the GCAW system will incorporate an estimation of time-until-impact to determine when to activate the alarm. Previous data (Begault 1993) suggest that the spatial element aids target acquisition. Unlike TCAS, however, the primary task upon receiving a GCAW alert is to stop the plane—a non-spatial task. In other words, acquisition follows stopping. Whether the spatial quality of the alert benefits GCAW will require evaluation of a redesigned, time-until-impact system, which we are currently designing and testing.

A question related to the design of the auditory alert revealed less decisive group opinion. The question "an incursion alert using speech would have been preferable to the use of a non-speech alarm" elicited responses split between "neither agree nor disagree" and "agree." During the debriefing, some pilots expressed strong desire for a verbal STOP command in conjunction with the alarm, as if a third crew member had noticed the potential incursion.

Results of the 3-D Audio Guidance-System

There was no significant difference in the time needed to complete taxi routes under spatial-audio assisted and non-assisted conditions. After disposing of one outlier (in which a crew became completely lost), an ANOVA revealed no significant difference as a function of individual routes, crews, or their interaction overall. Figure 1 shows the similarity of taxi times under both conditions for each crew. Overall, the mean duration for completion of the taxi routes was 5 minutes, 48 seconds, and 5 minutes, 44 seconds under unassisted and assisted (3-D audio) conditions. Table 1 summarizes, for both conditions, the mean duration (in sec) and standard deviations as a function of the individual routes. The large standard deviations indicate the wide variability of taxi times for each route.

Route	Condition	Mean	SD
1	unassisted 3-D audio	410.2 416.1	94.8 56.2
2	unassisted 3-D audio	365.1 408.6	52.0 72.7
3	unassisted 3-D audio	384.2 374.4	55.6 81.5
4	unassisted 3-D audio	297.9 30	65.0 34.7
5	unassisted 3-D audio	234.4 234.1	39.8 53.7
6	unassisted 3-D audio	394.1 369.1	60.7 69.6

Table 1: Data from 3-D audio guidance study. Means and Standard Deviations (sec) for the six different routes tested. No significant difference was found between conditions. Note the high standard deviations for each combination of route and condition as well as the similarity of the means between conditions for each route.

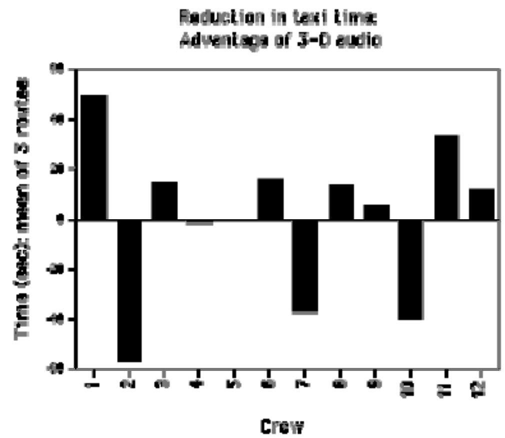

Figure 1: Data from the 3-D audio guidance study. The time difference between unassisted and 3-D audio assisted conditions is shown by crew. The graph includes the mean value of the three routes taxied by each crew; positive values indicate an advantage when using 3-D audio. No statistically significant difference was found between unassisted and 3-D audio conditions. The time value was measured from the first turn-off of the high speed runway until the parking brake was set at the last turnoff (pilots were instructed to "hold short").

A total of 5 out of 9 questions related to preference for the guidance system cues yielded a significant statistical response of "neither agree nor disagree," i.e., no opinion:

- Audio taxiway alerts would also be useful in navigating around an airport under normal visibility conditions.
- An auditory system presenting taxiway alerts would be a useful adjunct to a moving map display.
- The spatial quality of the taxiway alerts, in particular, helped me to navigate around the taxiways.
- The speech messages for the taxiway alerts should have occurred more often.
- The alert should have occurred earlier than it did, with

respect to visual acquisition of the taxiway.

Pilots reached a strong consensus, however, on the issue of male vs. female voice announcements. In response to the question of whether "It would have been better to use a male voice rather than a female voice for the taxiway alerts," the majority indicated "disagree."

Summary

This experiment, in short, proved audio-spatial cueing as effective in the GCAW and as ineffective—contrary to our hypothesis—in the audio guidance system. In their evaluations, pilots indicated that the GCAW system efficiently warned of potential incursions and was thus desirable. We currently are conducting a follow-up experiment to test a more sophisticated GCAW system design that accounts for time-until-impact information. This experiment will allow more detailed evaluation of crew avoidance of collisions, particularly whether the spatial aspect of the audio cues improves flight performance or safety. Meanwhile, the audio guidance system did not reduce taxi time and elicited an indifferent response from pilots. Adjusting the system to announce information by pilot request, rather than automatically, might lessen auditory "clutter" and thus improve the system's effectiveness.

References

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