A virtual audio guidance and alert system for commercial aircraft operations

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• Background

Our work in virtual reality systems at NASA Ames Research Center includes the area of aurally-guided visual search, using specially-designed audio cues and spatial audio processing (also known as virtual or "3-D audio") techniques (Begault, 1994). Previous studies at Ames had revealed that use of 3-D audio for Traffic Collision Avoidance System (TCAS) advisories significantly reduced head-down time, compared to a head-down map display (0.5 sec advantage) or no display at all (2.2 sec advantage) (Begault, 1993, 1995; Begault & Pittman, 1994; see Wenzel, 1994, for an audio demo). Since the crew must keep their head up and looking out the window as much as possible when taxiing under low-visibility conditions, and the potential for "blunder" is increased under such conditions, it was sensible to evaluate the audio spatial cueing for a prototype audio ground collision avoidance warning (GCAW) system, and a 3-D audio guidance system. Results were favorable for GCAW, but not for the audio guidance system.

• Objectives of the current study

There were two specific experimental objectives in the current study. The first objective was to determine pilot preference for a prototype **3-D audio ground collision avoidance warning system** (GCAW) for use in low-visibility conditions. An alarm was designed for alerting pilots to the direction of a potential incursion. We hypothesized that there would be a significant preference for such a system to be included in the flight deck. The dependent variable for the GCAW study was a measurement of preference on a Likert scale questionnaire, given during the pilot debriefing session. The second objective was to determine ground taxi time from landing to the gate, under aided and unaided conditions. The aided condition featured a **3-D audio guidance system** for orientation and guidance that announced specific taxiway turnoffs on the route. We hypothesized that this system would significantly reduce the time required for taxiing to the gate, compared to the unaided condition, where the crew is dependent solely on the map. The dependent variable for 3-D audio guidance system was the time necessary to complete tax route under aided and unaided conditions.

• Subjects and scenario

The experiment was conducted within a 747-400 simulator at NASA Ames; we used 12 crews from a U.S. carrier as subjects, all with 747-300 or 400 glass cockpit experience. All flight plans, communications and procedures were designed to be realistic as possible. A total of 7 routes (6 orientation routes and 1 incursion route) were designed based on normal routes used at O'Hare Airport (Chicago). Each crew taxied 3 of the 6 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 such that each route was run an equal number of times by all crews. Additionally, each crew ran the same 7th route, which included a potential conflict from another aircraft, to evaluate preference for GCAW. To insure a realistic condition that included the 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), connected to stereo headset (Sennheiser HME 1410-KA). An alert signal was synthesized for the GCAW system that was designed to be noticeable without being as loud as typical alarms, through (1) use of significant frequency energy from 0.3-13 kHz and (2) inclusion of "transient" (fast rise time) amplitude envelope. A female voice preceded by a synthetic "pre-alert" alarm was used for the guidance system; it would call out taxiway crossing names, e.g., "A 15."

- **GCAW results**

All of the 11 questions related specifically to the GCAW system yielded significant results in the preference evaluation. 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, $\alpha = .05$):

- 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 or not the spatial quality, in particular, of the alert helped them to visually acquire the other aircraft. This is probably due to the fact that each crew only experienced one possible incursion, and that several were taxiing as fast as 27-30 knots. Since our implementation was based on *distance* and not *time until impact* (like TCAS systems), it was possible to thwart the utility of the alert by taxiing at high speeds. Our future implementation of the GCAW system will be redesigned to use an estimation of time to impact to determine when to activate the alarm. Previous data (Begault, 1993) suggest that the spatial element helps in target acquisition, but unlike TCAS, the primary task upon receiving a GCAW alert would be to stop the plane—a non-spatial task. In other words, acquisition follows stopping. Whether or not the spatial quality of the alert is useful for GCAW will require evaluation of a redesigned, "time until impact" type of system, which we are currently designing and evaluating.

Two questions related to the design of the auditory alert resulted in less decisive group opinion. The data came out mid-way between "neither agree nor disagree" and "agree" for the question "an incursion alert using speech would have been preferable to the use of a non-speech alarm." Some pilots during the debriefing strongly desired a verbal STOP command in conjunction with the alarm (as if a 3rd crew member had noticed the potential incursion).

• 3-D audio guidance system results

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 (where 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 the mean duration (in sec) and standard deviations as a function of the individual routes, separated by condition. The large standard deviations indicate the wide variability between crews in running the same route.

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.

Interestingly, a strong consensus was reached 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

Based on the data and from comments during the debriefing sessions, an automated audio guidance system is probably best implemented so that one's current location and the next gate is given "on demand," in order to lessen auditory "clutter." On the other hand, the use of a GCAW system for warning of a potential incursion is indicated as desirable by pilots. We are currently running a follow-up experiment using a more sophisticated GCAW system design that accounts for "time until impact." This will enable evaluation of crew avoidance of collisions in greater detail, including whether or not the spatial aspect of the audio cues contributes anything to improved performance or safety.

• References

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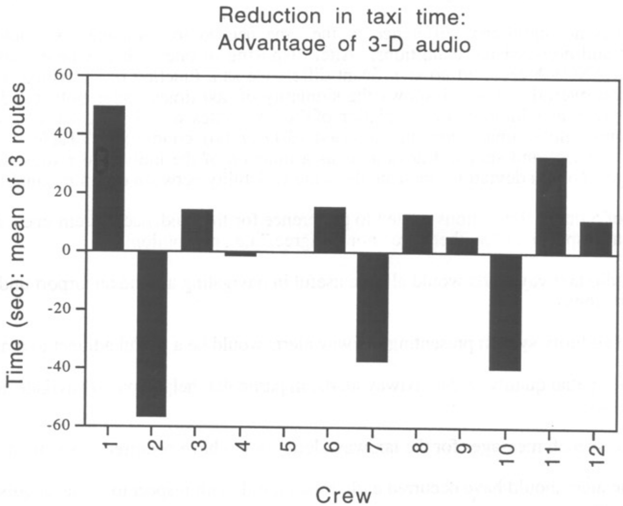

FIGURE 1. Data from 3-D audio guidance study. *Time difference between unassisted and 3-D audio assisted conditions shown by crew. The mean value of the three routes taxied by each crew is shown; positive values indicate an advantage when using 3-D audio. No statistically significant difference was found 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").*

Route	Condition	MEAN	SD
1	unassisted	410.2	94.8
	3-D audio	416.1	56.2
2	unassisted	365.1	52.0
	3-D audio	408.6	72.7
3	unassisted	384.2	55.6
	3-D audio	374.4	81.5
4	unassisted	297.9	65.0
	3-D audio	304.6	34.7
5	unassisted	234.4	39.8
	3-D audio	234.1	53.7
6	unassisted	394.1	60.7
	3-D audio	369.1	69.6

TABLE I. 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–condition and the similarity of the means between conditions for each route.*