# Enhanced Audio for NextGen Flight Decks

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## ABSTRACT

Implementation of the Next Generation Air Transportation System (NextGen) will require shifting more roles to the flight deck. The proposed tools and displays for facilitating these added tasks primarily deliver information through visual means. This saturates an already loaded channel while perhaps underutilizing the auditory modality. This paper describes audio enhancements we have developed to compliment NextGen tools and displays, and reports on preliminary observations from a simulation incorporating these enhancements. Pilots were generally receptive to the broad concept, but opinions diverged regarding specific features, suggesting potential for this strategy, and that user defined settings may be important.

**Keywords**: NextGen, aurally enhanced flight deck, CDTI, synthetic voice

## 1 INTRODUCTION

It is envisioned in the Next Generation Air Transportation System (NextGen) that flight decks will take on some of the responsibilities traditionally associated with Air Traffic Control (ATC). Specifically, Air Traffic Management (ATM), once under the sole purview of ATC, will be increasingly integrated into the flight deck as the automation necessary to implement NextGen becomes operational. This shift in roles and responsibility on the flight deck will drive a need for new equipage and capabilities. For example, pilots will manage new tools and ATM procedures such as conflict detection and resolution (CD&R), and arrival interval management. They will also have the responsibility to reroute themselves around weather and other hazards. While emerging technologies would allow these new tasks to be entirely controlled on the flight deck, these new roles will likely impose additional challenges for pilots whose existing responsibilities are already demanding.

A primary purpose of this simulation study was to explore the use of audio technologies to mitigate some of the burdens placed on the NextGen flight deck. In the following sections, we will first discuss our view of some specific challenges posed by the new role of the NextGen pilot, followed by a summary of possible mitigations for these challenges through the use of sound as an information source. We will then discuss our concept of the aurally enhanced NextGen flight deck, followed by a description of a simulation that implemented these new technologies in a NextGen operational environment. We conclude with a general discussion of pilots' experiences with these technologies and implications for future development.

# 2 NEXTGEN FLIGHT DECK CHALLENGES

## 2.1 Delegation of ATM Responsibilities

One challenge faced by the NextGen flight deck concerns responsibility for separation. In the current National Airspace System (NAS), aircraft separation and sequencing is the exclusive purview of ATC. Pilots today have need of these services provided by the controller, and are obliged by regulation to use them. There is no display on the flight deck capable of facilitating these tasks, nor are today's pilots trained to accomplish them except in the narrow sense of maintaining visual, out-the-window separation in the vicinity of airports.

Under a number of proposed new applications (oceanic in-trail procedures – ITP, closely spaced parallel approach operations – CSPA, and flight deck interval management – FIM), limited delegation of separation responsibility will be placed on flight crews to maintain a safe distance from other aircraft. The implementation of this shared responsibility will require greater predictability which will be provided through the use of Trajectory Based operations (TBO), tighter required navigation performance (RNP), flight deck interval management tools, and onboard conflict detection and resolution (CD&R) tools, to name a few.

## 2.2 Increased Use of Data Link Communications

A related challenge arising from the delegation of separation responsibility is the expected increase in the use of Controller Pilot Data Link Communications (CPDLC). This increased use of data link will be driven by saturation of existing VHF radio networks as both the number of aircraft increases, and the number of coordination tasks between each flight deck and ATC increases. Data link communication offers a viable solution for this frequency congestion, but has some possible disadvantages. As data communications increase, the information available through an open-circuit with human talkers is eliminated. This potentially disrupts one of the primary means through which pilots obtain situational awareness (SA).

Indeed, in the results of several surveys administered to pilots on party line information, Pritchett, Hansman and Midkiff (1995) found that traffic and weather information obtained from radio party line communications was rated critical for maintaining SA. Pilots' subjective assessment of the importance of party line information was confirmed in a recent study by Boehm-Davis, Gee, Baker, and Medina-Mora (2010), who found that the use of data link not only reduced SA but also increased workload in some cases. Boehm-Davis et al.'s results again attest to the importance of party line information to pilots and suggest the need to replace this information where data link is implemented.

## 3 SOUND AS AN INFORMATION SOURCE

There is a large body of research that indicates multi-modal presentation, specifically aural enhancement of visual displays may be effective in improving human performance in applied settings (for a review, see Proctor & Vu 2010). For example, Ho and Spence (2005) assessed auditory cues as a means for capturing a driver's attention to relevant events. Auditory cues were presented either as semantically meaningful verbal cues (i.e., spoken words) or directional sonifications (i.e., the sound of squealing brakes). They found improved reaction time and accuracy in drivers' responses when aural cues were added to simulated driving scenarios. Ho and Spence attributed the effect to the ability of the aural cues to help orient visual attention to critical visual stimuli.

Additionally, three-dimensional aural augmentation of visual displays has been shown to successfully focus user attention to specific tasks and has proven to improve reaction times in locating visual targets. Begault (1993) showed a 2.2 second improvement in out-the-window visual acquisition of targets when target presentation was augmented by spatial 3D audio. Tannen, Nelson, Bolia, et al. (2000) found a significant reduction in head movement when visual search targets were accompanied by spatially corresponding audio cues. Veltman, Oving and Bronkhorst (2004) reported similar improvements in performance during pursuit and intercept tasks conducted in a simulated fighter cockpit.

In addition to its innately spatial nature, the sound itself can also convey information about the world. A small pebble hits the water with a splash; a large rock hits the water with a thump. Graver (1986) used the term "auditory icons" to describe those kinds of informative sounds. Graver suggested that the principles behind auditory icons could be used to provide supplemental, descriptive information about computer generated objects rather the arbitrary and metaphorical relations often employed in designing sound alerts in computer interfaces.

In environments involving multiple speech sources, Ericson, Brungart and Simpson (2004) found that subjects were better able to attend to, and differentiate content if different voices were spatially separated. They also found notable effects by differentiating the multiple speakers by gender and by sound level.

# 4 AN AURALLY ENHANCED NEXTGEN FLIGHT DECK

The aforementioned research shows that sounds when used appropriately can not only deliver messages without disrupting ongoing visual processing but also convey spatial information. On NextGen advanced flight deck displays where traffic and aircraft system information abounds, we believe pilots can benefit greatly from carefully designed auditory enhancements to visual stimuli. In the following we describe several proposed NextGen flight deck tools and the types of audio enhancements that could potentially improve the efficiency of their use. In addition, we describe a potential solution to the loss of party line information through the use of synthetic speech.

## 4.1 Advanced NextGen Flight Deck Tools

The platform on which we implement proposed NextGen flight deck tools and audio enhancements is the Three-Dimensional Cockpit Situation Display (3D CSD), an advanced version of a cockpit display of traffic information (CDTI). This experimental prototype was developed by the Flight Deck Display Research Laboratory at NASA Ames Research Center (Granada et al. 2005). The CSD provides displays of traffic, weather, and flight trajectory information. Several tools supporting ATM capabilities are provided. Among them are the Route Assessment Tool (RAT), a graphical tool used for in-flight trajectory modifications, and a Conflict Detection and Alerting (CD&A) tool which graphically alerts the crew to conflicts with other aircraft. In conjunction with the RAT, the CD&A tool assists the crew in finding conflict free routes. The CSD also has a Spacing Tool that provides automation (with a graphical user interface) for performing interval management. Using the tool a pilot can select a lead aircraft that is then followed on the arrival. The tool calculates a speed which is delivered to the aircraft autothrottle. In addition to the 3D CSD, an enhanced data link interface was provided to allow data link to be used for all communications.

## 4.2 Proposed Audio Enhancements

Figure 1 illustrates our proposed audio enhancements to the CSD tools and how they are designed to be delivered to the crew. These enhancements fall into the five categories summarized below:

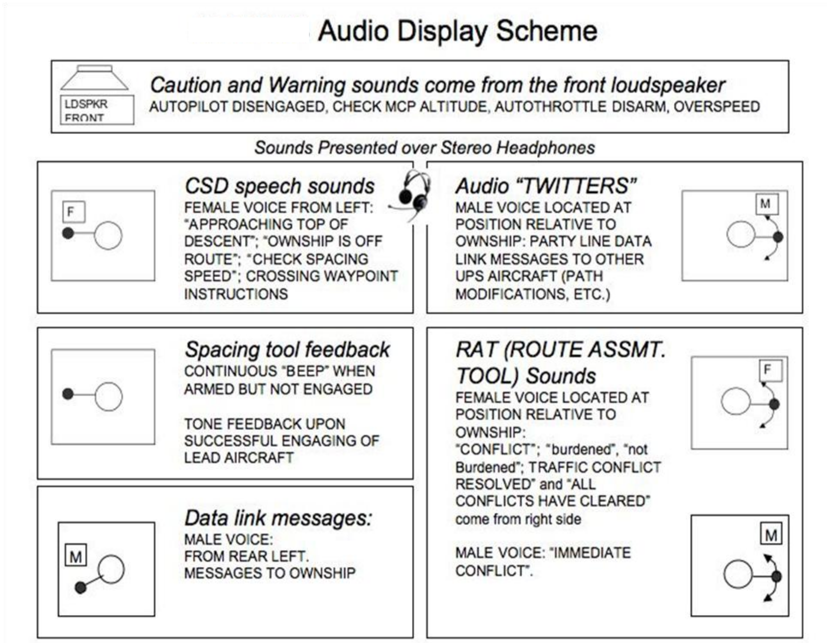


Figure 1 Auditory enhancements to CSD tools and data communications including delivery mode.

1. **Audio feedback on tool usage**: In a multi-tasking environment, users can be distracted and forget to resume interrupted tasks. In those cases, providing aural feedback with tool usage to signify step completion or incompletion can help users stay on task (e.g., Brewster 1998). We propose adding such feedback to the spacing tool which requires the pilot to perform a sequence of actions on multiple objects to complete the task.
2. **Spatially localized voice messages accompanying visual alerts**: Previous research suggests that spatially localized sounds can help users detect and orient attention toward visual events in the world (Begault 1993; Ho & Spence 2005). We propose to capitalize on this finding by adding spatially localized voice messages to traffic conflict alerts that have only been represented visually in the past. Synthetic voice messages carrying information on the conflicts are presented along with visual alerts. They are heard in the direction of the intruding aircraft in the physical airspace. The degree of urgency is conveyed by the gender of the voice: female for non-urgent and male for urgent.
3. **Voice reminders of procedural compliance**: Maintaining compliance with flight procedures often requires pilots to routinely monitor numerical changes in different parts of the displays (e.g., distance from waypoints). In emergencies, routine monitoring may be disrupted leading to procedure noncompliance that will not be corrected until visual monitoring is resumed. We propose to use synthesized voice messages as reminders to

nominal and off-nominal indications so that pilots can be notified of noncompliance as soon as it occurs even in the absence of monitoring.

4. **Voice augmentation for data link messages**: It can be anticipated that increasing the use of data link messages will lead to more head down time for the crew. This disadvantage of data link usage can be potentially remedied by narrating DataText information from uplinked data messages.
5. **Voice replacement of party line information**: We propose the use of an aural enhancement that we call audio "twitter" to replace the loss of party line information due to the use of data comm. The idea is for the system to generate synthetic voice messages approximating radio transmissions that might occur as the result of changes in the states of one aircraft (e.g. a course change, or the start of a descent), and to allow pilots of other aircraft to monitor those changes through a subscription-based mechanism. In theory, the selection of which aircraft to monitor could be initiated by the pilot or pre-determined by the airline or other stakeholders. As an initial demonstration, we propose to select only ownship's lead aircraft in an arrival interval management pair, and all other aircraft ahead on the arrival that fall within certain range limits. Audio feeds are triggered when a subscribed aircraft changes route (as in a weather deviation or a conflict resolution) or begins descent.

# 5 SIMULATION

To demonstrate the utility of these proposed audio enhancements, we implemented them in a research simulator which incorporated the CSD display with the aforementioned flight deck tools. We contrasted this *enhanced audio* environment with a *minimal audio* environment representing the current-day flight deck aural environment. In both audio environments the simulator modeled other standard transport aircraft controls and displays.

## 5.1 Method

### 5.1.1 Participants

Ten transport category aircraft pilots familiar with Flight Management Computer (FMC) operations and glass cockpit procedures participated in the simulation and were compensated for their time at a rate of $25/hr.

### 5.1.2 Apparatus

The simulation utilized a mid-fidelity fixed-based research simulator consisting of a two person cab configured as an advanced transport category flight deck. Four 50 inch plasma displays presented out-of-window views of weather and traffic. Most flight deck controls and auto-flight capabilities were modeled to provide an immersive and physically realistic environment to the participants. Pilots occupied the left (captain) seat of the simulator and used an autopilot mode control panel (MCP), a flight management system (FMS) with a control display unit (CDU), and a computer mouse to interact with simulation software and displays.

A real-time signal processing engine referred to as CrewSound supported the generation of audio and voice cues (Begault et al. 2010). Hardware included a fully configurable 24-channel audio interface (MOTU 24 I/O core system PCIe), multiple loudspeakers, and supra-aural stereo aviation headsets with active noise cancellation and a customized push-to-talk capability (Sennheiser HMEC46-BV-K). Software included a custom graphical user interface enabling up to 24 channels of synthesized speech messages and/or non-speech alerts.

Airspace and traffic for the simulation was generated using the Multi-Aircraft Control System (MACS) software (Prevot 2002). This software package allows creation of an accurate three dimensional airspace model which can be populated by a variety of controllable simulated aircraft.

### 5.1.3 Design and Scenarios

Eight 20-minute traffic scenarios, four in each of the two audio conditions were presented to allow pilots to experience these enhancements in a variety of situations. Pilots flew aircraft arriving into Louisville International Airport (SDF). Each scenario was a 20 minute segment of a nominal arrival trajectory that began in the en route environment approximately 90 minutes west of SDF at a cruising altitude of 33000 to 35000 feet. The route included a planned optimal profile descent (OPD) into the airport. Convective weather cells were placed at a location about l50 NM from the starting point along route. To maximize the opportunity for exposure to a variety of audio events during different phases of flight, each of the four scenarios in a given audio condition started at a different point on the nominal trajectory (150 NM from weather, 50 NM from weather, passing abeam weather to the north or south, and past the weather near the top-of-descent). The two audio conditions were counterbalanced across participants.

Planned traffic conflicts were engineered to occur with the experimental aircraft at specific times during a particular scenario, generated either by the simulation software or by confederate pseudo-pilots according to scripted timing. Confederate pseudo-pilots also handled additional air traffic to bring the total traffic load up to approximately 1.5 times of current day traffic.

### 5.1.4 Procedures

The simulation was conducted during ten, daylong sessions each lasting eight hours. The pilots were instructed that their primary responsibilities included guiding their simulated aircraft though an OPD, maintaining a temporal interval from an assigned lead aircraft, and avoiding other aircraft and hazardous weather exclusively through use of onboard tools (i.e. without contacting ATC). A confederate “co-pilot” was present to aid the subject pilot as necessary.

In both audio conditions, the pilot received an arrival clearance message that included a scheduled time of arrival, a speed profile, and an interval management clearance related to an assigned lead aircraft. During pilot initiated route changes for weather or traffic conflicts, communication with ATC was discouraged.

After completing the scenario runs, pilots completed a 79-question post-simulation questionnaire that asked them to use a 5-point scale to rate a variety of aspects of the simulation such as training, displays, tools, controls and tasks, as well as provide written comments on these topics. Space for written comment was provided for feedback on areas not directly queried.

Finally, pilots also participated in a twenty to forty minute verbal de-briefing. One interview was lost due to recording equipment malfunction.

## 6 OBSERVATIONS AND DISCUSSION

Due to the wide range of audio enhancements and the areas to which they were applied, it was difficult to access their utility individually. However, opinions expressed by the participants through their questionnaire responses offer a glimpse of how well these audio enhancements facilitated the use of various tools and compliance with procedures as a whole. Ratings from the questionnaire showed that participants, in general, had positive impressions of the auditory display and the types of messages that were presented. The use of synthesized text-to-speech messages for alerting, merging and spacing, data link, and situational awareness ("twitter") messages was rated highly (4.4/5). Participants expressed clear preference for the text-plus-speech display over the text-only one. Participates also responded positively to the general quality and acceptability of the acoustic simulation environment and audio presentation (4.3/5). One area that did not fare well and perhaps requires further refinement in its implementation was the use of spatial location cues (3.8/5).

Opinions volunteered in written comments echoed rating responses, favoring the concept of enhanced voice information and audio cueing. A typical respondent stated: "Some radio chatter can help with w/x avoidance and situational awareness." However, there were exceptions to this general trend. Specifically, the overlap of audio cues and recurring alerts in this simulation were mentioned as areas needing improvement, with one subject stating: "I would prefer only one message at a time."

While a majority of opinions favored the enhanced audio concept in general, there was not clear consensus on what form that should take. Divergent views of participants emerged during conversations during post-simulation debriefing sessions. Seven of the ten subjects seemed to agree with the notion that some form of audio enhancement will be necessary to augment the advanced NextGen flight deck. Two participants specifically liked the "twitter" information that was received from other arrival aircraft. One participant listed the audio feedback paired with the spacing tool and the RAT as the best of the enhancements, stating that it saved him from making sequencing mistakes with those tools on more than one occasion.

However, two subjects preferred to just use advanced visual display to gain and maintain situation awareness. Their comments suggested that too much audio was actually detrimental to their level of performance. Both stated that, to a great extent, the advanced aspects of the CSD made up for any audio information they were potentially missing by not having the open radio circuit available. They acknowledged that audio enhancements would be needed, but that the ones they were exposed to in this study may not have been ideal for them.

This divergence of opinion concerning the utility of specific features, and in two cases the entire concept as presented, suggests that a high degree of user-selected flexibility in flight deck audio presentation may be necessary. As with current flight deck visual displays, users may need the ability to fit the audio "display" to their situation. This idea is borne out by the answers volunteered when the subjects were asked about a future ability to filter or select what they could listen to with the "twitter" function. Eight of the subjects felt that customizing the audio presentation to their own preferences and needs would be highly desirable. Four expanded their answer to include the ability to adjust features for the entire audio suite.

Parallels to existing visual alerting systems, such as EICAS (Engine Indication and Crew Alerting System), were drawn by two participants. Both the logical hierarchy, and the ability to cancel and recall an alert or synthesized voice message were listed as features that would be desired as future audio enhancements. In addition, two comments suggest that concurrent and integrated audio and visual alerts were quite helpful when presented correctly. The visual flashing of a target on the CSD while receiving an audio "twitter" about that aircraft was suggested as a good example of this type of integration during the current study.

When asked about audio features the subjects would like to have in the future, pilots suggested that they would like information about changes in airport status, changes in expected routing, and changes in enroute weather. Additionally they listed other considerations such as holding or diversions in progress a their airports of interest. It was further suggested that these aural notifications would be particularly useful for information that was beyond the range of the visual display.

## 6.3 Final Thoughts

The present simulation represents a preliminary effort in exploring the use of auditory technologies to aid pilots in managing their new roles and responsibilities on the NextGen flight deck. Subjective evaluations from the pilots showed that they were receptive to the audio enhancements in general and found many of the individual features to be highly useful. While pilots preferred the enhanced audio concept in general, their evaluations of specific tools varied widely. Their diverse preferences suggest that future audio environments can benefit from allowing user-customized settings to meet individual needs and preferences in varying situations.

## ACKNOWLEDGMENTS

This work was supported by NASA’s Aviation Safety Program, Integrated

Intelligent Flight Deck Technologies (IIFDT) Project and Airspace Systems Program, Concepts and Technology Development Project. Jimmy Nguyen, now at Gulfstream, was supported in part by a NASA cooperative agreement (NNX09AU66A) with the Center for Human Factors in Advanced Aeronautics Technologies at California State University – Long Beach, awarded as a part of NASA Group 5 University Research Center Program by NASA's Office of Education. Michael Politowicz, now at GE Aviation Systems, was supported by an internship from NASA's Undergraduate Student Research Program. We thank Jonathan Luk, Summer Brandt, Sarah Ligda, Dominic Wong, George Lawton, Tom Quinonez, and Patrick Cravalho for their help as well.

## REFERENCES

Begault, D.R. et al., 2010. Applying Spatial Audio to Human Interfaces: 25 Years of NASA Experience. In *Proceedings of the 40th International Conference: Spatial Audio: Sense the Sound of Space*. New York: Audio Engineering Society. Available at: http://www.aes.org/e-lib/browse.cfm?elib=15546.

Begault, D.R., 1993. Head-Up Auditory Displays for Traffic Collision Avoidance System Advisories: A Preliminary Investigation. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 35(4), pp.707–717.

Boehm-Davis, D.A. et al., 2010. Effect of Party Line Loss and Delivery Format on Crew Performance and Workload. In *Human Factors and Ergonomics Society Annual Meeting Proceedings*. pp. 126–130.

Brewster, S.A., 1998. Sonically-enhanced drag and drop. In *Proceedings of the International Conference on Auditory Display*. pp. 1–7.

Ericson, M.A., Brungart, D.S. & Simpson, B.D., 2004. Factors That Influence Intelligibility in Multitalker Speech Displays. *The International Journal of Aviation Psychology*, 14(3), pp.313–334.

Gaver, W.W., 1986. Auditory icons: Using sound in computer interfaces. *Human-Computer Interaction*, 2(2), pp.167–177.

Granada, S. et al., 2005. Development and Integration of a Human-Centered Volumetric Cockpit Situation Display for Distributed Air-Ground Operations. In International Symposium on Aviation Psychology.

Ho, C. & Spence, C., 2005. Assessing the effectiveness of various auditory cues in capturing a driver's visual attention. *Journal of experimental psychology: Applied*, 11(3), p.157.

Prevot, T., 2002. Exploring the many perspectives of distributed air traffic management: The Multi Aircraft Control System MACS. In *Proceedings of the HCI-Aero*. pp. 149–154.

Pritchett, A., Midkiff, A. & Hansman, R.J., 1995. Party line'information use studies and implications for ATC datalink communications. In *Digital Avionics Systems Conference, 1995., 14th DASC*. pp. 26–31.

Proctor, R.W. & Vu, K.-P.L., 2010. Cumulative Knowledge and Progress in Human Factors. In *Annual Review of Psychology*. Palo Alto: Annual Reviews, pp. 623–651.

Tannen, R.S. et al., 2000. Adaptive integration of head-coupled multi-sensory displays for target localization. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. pp. 77–80.

Veltman, J.A., Oving, A.B. & Bronkhorst, A.W., 2004. 3-D Audio in the Fighter Cockpit Improves Task Performance. *The International Journal of Aviation Psychology*, 14(3), pp.239–256.