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CAN 3D-AUDIO IMPROVE STATE-OF-THE-ART PILOT-ASSISTANCE SYSTEMS?

Christian A. Niermann
German Aerospace Center (DLR), Institute of Flight Guidance

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Abstract

The effort to make flying safer goes parallel with the new possibilities of technology which has been made possible in recent years. With the introduction of new technologies and a variety of new assistance systems in modern flight decks, the demand of safety and efficiency of flight operations are increased.

These new cockpit designs and the increasing number of high-resolution displays in the cockpit intensely use the visual system of the pilots. The advantage of these glass cockpits tends to be impaired by constantly increasing amount of information presented. The pilot has to deal with multiple concurrent tasks, all with dominant impact on the pilot's visual perception.

The most unused audio channel in modern cockpits provided only simple warning or information sounds. In contrast to an increasing number of synthetic vision and 3D displays, audio contains no spatial information.

In our experiment, we tested the ability to localize different spatial audio files, presented via a stereo headset under varying conditions. The results show that participants are able to localize a 3D-audio presentation via a normal stereo headset adequately enough to direct their attention to a specific point. Including the head movement becomes a key feature to create a natural spatial feeling. The results allow the assumption that localization is independent of the hearing.

With a preselected assistance system, 3D-audio has the capability to support pilots during critical flight phases and potentially even decreasing the overall workload.

1 Introduction

With the introduction of new technologies in modern flight decks, the precision and efficiency of flight operations are increased. Most of the information provided to the cockpit crew is given via the human visual channel [1]. Large visual-display units in state-of-the-art head-down glass cockpits provide a considerable amount of information e.g., Primary Flight Display, Navigation Display, Systems Display, Engine and Warning Display. Additionally, helmet-mounted displays or head-up displays on the one hand increase situation awareness but on the other hand intensely consume visual resources of the pilot [2]. Unlike normal displays, head up or helmet-mounted displays are attached right in the pilot’s field of vision. They are used in military as well as in civil aircrafts.

Fig. 1 Airbus A350 cockpit, head-up display, helmet-mounted display

Compared to the multitude of visual displays in modern cockpits, audio interfaces are under-represented. Audio alerts and warnings are given to the crew via a simple loudspeaker inside the cockpit or via the pilot's headset. They are mostly a simple mono sound and convey no spatial information [3]. In present-day cockpits audio-keys are used to draw attention to a visual display [4] or as intra-crew and crew to air traffic control communication. There are minor military applications that use simple left-right-audio presentation in the pilot's headset.

In combination with increasing number of systems that have to be used, managed or monitored by the cockpit crew, this creates new operational burdens and new kinds of failure modes in the overall human-machine system [5] [6]. Following the work of Wickens and other Human Factors scientists, the cognitive ability of humans is limited [7]. Adding further more displays in front of the pilots will soon reach the human visual limit. It is plausible to use audio as an additional human-machine interface to reduce and divide the workload on multiple resources.

Audio research has been sparse in the aviation domain and mostly covered spatial audio with an array of loudspeakers around the participant's head or simple left-right-volume difference in a stereo headset [8]. As far as we know at the present time, there are minor publications about the performance and limits of 3D-audio as an additional information channel in the field of aviation. However, several studies have suggested a multitude of applications for the use of 3D-audio in the cockpit [1], [3], [4].

In this paper, we present an approach to integrate 3D-audio into future cockpits. We introduce the design and results of a psychoacoustic 3D-audio experiment. The experiment intends to test the ability of 3D-audio localization presented via a stereo headset, as it is commonly used in present aircraft cockpits. The evaluation was divided into two parts. The first one analyzed the overall direction offset in the location performance and the influence of sound and movement on the tracking performance [9]. The second part, presented in this paper, focuses on the potential of 3D-audio as an additional information channel for existing assistance systems.

This paper is organized into four parts. The first chapter *Research Question* gives a short introduction into the existing research. The Chapter *Methods* presents an overview of the experimental setup. Following in chapter *Results* the findings of the 3D-audio experiment are briefly discussed. *Conclusions* and outline of future work are given in the last chapter.

2 Research Question

The pilot's visual system is used intensely in a state-of-the-art cockpit. Besides the normal head-down instruments, additional sources like helmet-mounted or head-up displays require visual perception. Consequently, the visual channel becomes overloaded in high workload flight phases. This can happen flying at low altitudes, in a degraded visual environment such as brown-out, white-out or at night, during search and rescue or other special operations [1]. Several advanced technology concepts to support pilots during flight are integrated into the cockpits side-by-side. Each of those proven to benefit safety and/or performance. However, those systems convey no, or only limited audio information. Spatial audio as an additional information channel is not used at present time. Although it is apparent, that with a cross-modal time-sharing technology, humans divide attention between the eye and ear better than between two visual sources or two auditory sources. Previous research has shown that during high visual attention tasks, auditory presented information was better and more quickly recognized than additional visual cues [7], [10]. It becomes conceivable, that audio has a positive effect in high workload situations.

With new technology, it is now credible to bring spatial audio in addition to the well-known visual displays into the cockpit. Spatial hearing includes the perception of direction, distance and expanse of an audio source. The spatial awareness of humans is a key part of the perception and interaction with the environment.

Although humans are primarily visually orientated, auditory cues deliver additional information and play an important role considering everything that happens outside the field of view [11].

Thus, the research question is: Can 3D-audio be generated and presented to the pilots in a way, that it can be perceived precisely and accurately enough for real-time application in aviation context? In addition, which systems can be supplemented with spatial audio to support pilots during flight?

3 Methods

The experiment took place in the Institute of Flight Guidance at DLR, Braunschweig, Germany. Participants were invited from scientists of the research facility. Twenty-three people, five female and eighteen male, ranging from the age of 25 to 62 (M = 36.43, SD = 10.24) participated in the experiment. All participants were tested and passed a pure tone audiometry test with limits for pilots in the frequency 500 Hz to 3.000 Hz. The average hearing threshold, not age corrected, was at 16.03 dB (SD = 7.07) with an average left-right difference below 5 dB (M = 3.04 dB, SD = 1.88 dB). Ten participants held a pilot license and experienced an average of 478 flight hours (SD = 472.29) in total.

A 360-degree round room, normally a tower simulator, was used for the experiment. The inside simulator wall was in a monotone blue color with reference marks for 0, 90, 180 and 270 degree. As shown in Fig. 2, the participant sat on a swivel chair in the center of the room. The experiment operator sat in the same room at approximately 150 degrees, three meters away from the participant.

We created three test sounds as basic stimuli for the experiment, with sounds having a length of one second. Two sounds were designed as a technical warning sound with a frequency of 2.000 Hz and 4.000 Hz. Both are comparable to warning-sounds, used in the Airbus Helicopter H135. The third sound was a synthetic English female voice, speaking out the word *position*.

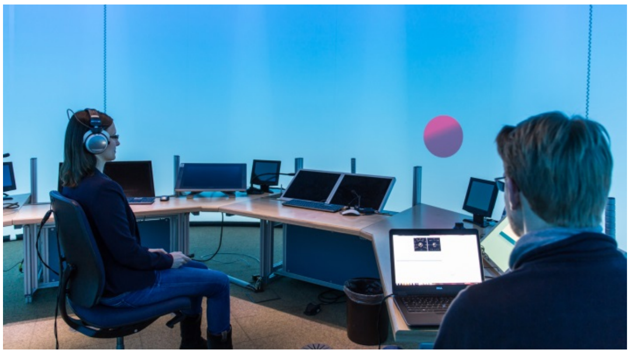

Fig. 2 The 360-degree tower simulator during the 3D-audio experiment. Participant wears a head set with attached head tracker to control the position of the sound and the digital red ball at the wall.

During the experiment, the participants had to point to the perceived position of the sound. In order to succeed, a digital ball was shown on the simulator wall. The ball was linked to the participant’s head position. They where instructed to rotate their whole body on the swivel chair to move the ball. At the perceived position, participants confirmed by clicking on a presenter-button in their hand. The participant calibrated the combination of ball and head tracker before every new audio position was played, if it was necessary.

The experiment software calculated the 3D-audio in real time. The audio corresponded in two head tracker sessions to the direction of the desired sound source position relative to the orientation of the participant's head. This was possible by combining the headset with a Carl Zeiss head tracker, continuously sending the head positions and orientations to the experiment software. Including this information, the software was able to relocate the audio in real time whenever the participant moved the head. Fig. 3 shows the structure of our experiment system. The complete real time 3D-audio system including 3D calculation, head tracker, sound source and data logging was executed on a laptop.

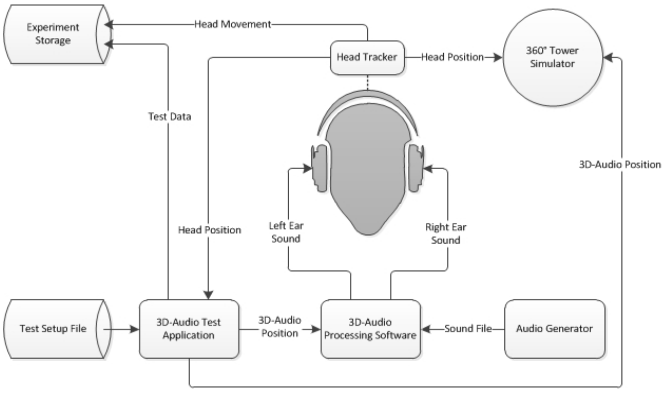

Fig. 3. Structure of the test system as it was used for this experiment

The direction in this experiment was defined like a compass, the angle rise clockwise from 0 degree to 360 degree. At angle of 0 degree for the direction straight ahead and 180 degree in the back of the participant. For the experiment 20 sound angles where defined. The first six angles always start at the positions: 90, 30, 270, 330, 150 and 210 degree. After these, the next 14 angles were defined randomly. The presented sound angle had a distance of at least 40 degree to the one given before. For the test sessions, four distinct angle-sets were defined. No correspondence between these sets was given.

The experiment was split into two parts for each participant. First, every participant was introduced to the experiment and got a short briefing. Following, the pure tone audiometry test was executed. Second, the main experiment part starts directly after. Four different sessions were created and presented to the participant in a randomized order. They were introduced to the first experiment session and what they are going to expect. In every session and for every sound angle the presenting sequence was the same. At the beginning, the sound plays two times at the 0-degree position. Then it moved to the target position and played during the movement for three times. At the target position, the test sound played either five times or until the participant pressed a button. During one session, the angle-set was presented twice. Each session took approximately 15 to 20 minutes, depending on the time, the participant needed to localize and to decide about the perceived position. Directly after each test session, participants replied to a questionnaire. They were asked how they felt after the recently conducted session and what they thought about the given sound file. After a short break the next session began, again with a briefing of the now following setup. After four sessions, the main experiment part ended and participants were asked about their overall opinion about the experiment and the 3D-audio sounds.

4 Results

The localization error was calculated as the difference between the actual and the participant-estimated direction. The distribution was assumed a normal distribution. Mean average and standard deviation were calculated from the raw directional data. During the experiment, every participant heard in total 160 sound positions.

The average location performance under all conditions in this experiment was at $M = .33$, $SD = 25.41$. The intra-participant variation was low (4.03) over all sessions. To put this relative high offset result into perspective, the results of the head tracking vs. no-head tracking sessions must be considered separately. The comparison between these two shows Fig. 4. As expected, the number of localization errors in the head tracker sessions is relatively low, compared to the no-head tracker condition. In the head tracker session, the participant perceived the sound with an average error of -0.70 degree with a standard deviation of 10.0 overall given angle. The average error rose to 1.36 degree with a standard deviation of 34.50 overall given angles without a coupled head tracker. These results are in line with previous studies [12], [13], [14].

In contrast to the studies of Parker et al., participants reported no front-back confusion or inside the head phenomenon during the experiment [15]. During sessions without head tracker, three participants were not sure at the beginning of the first sound. However, after the 2nd sound, a second later, they were assured about the heard hemisphere.

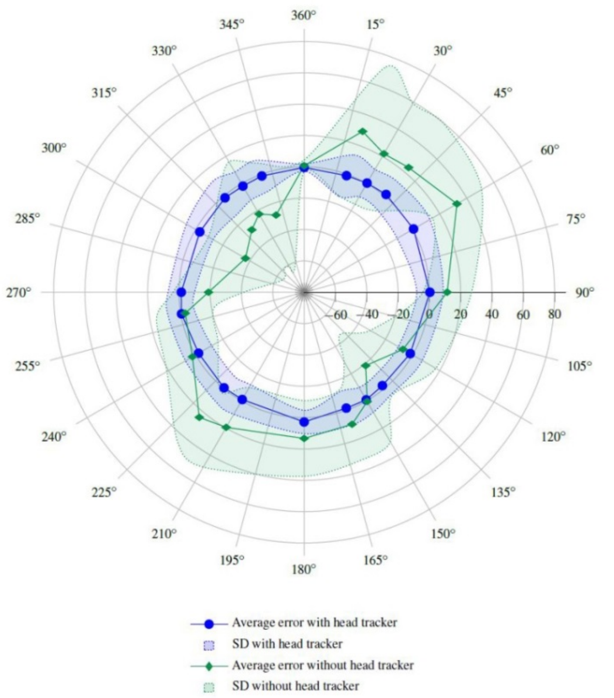

Fig. 4 Average error over all tested sessions with/without head tracker. The colored areas describe the standard deviation. Thin areas represent higher accuracy.

It was hypothesized that experience either in wearing a headphone or hearing spatial audio has a positive influence on the localization performance. To classify, participants were asked in a questionnaire if they hold a current pilot license (they regularly wear a headset), play an instrument and/or have experience with any kind of spacial audio. Furthermore, they were asked how often they use headphones in the everyday life and if they play computer games with a headphone.

Ten participants hold a current pilot license. All of them wear a headset during the whole flight so they are used to obtaining information via the audio channel by a headphone. Eight participants play an instrument (most of them play piano). Thirteen participants heard spacial audio before. All participants listened only in private context, neither gathers experience during work. Spatial audio in the cinema or as a multi loudspeaker system at home was named, both not presented via headphone. Only one participant tried a 3D gaming headset for less than 10 hours. The overall headphone use was quite rare. Nearly two-third of the participants use headphones only *sometimes* when they hear music. Only one-third use headphones when listening to audio books, watching a movie or making phone calls. Twelve participants play computer games regularly, but only three of them use headphones. Nine participants play only with normal loudspeakers or without sound. Due to the low utilization, it cannot be assumed that all participants are accustomed to using headphones caused by their normal life. This is also reflected in the results of the experiment. No significant difference in these groups compared with participants without any experience was noticeable.

At the current state of the evaluation, it looks like sound localization is relatively insusceptible for external influences. This finding becomes even clearer by looking at the tracking results in comparison to the results of the pure ton audiometry of every participant. We found no outstanding connection. There was neither a link between pure tone audiometry and tracking results, nor a link between difference in left and right hearing and the tracking. However it should be noted, that due to the experiment design, the variation in the pure tone audiometry was small.

5 Conclusion

All participants were able to localize the sounds with a good precision. During the experiment, no participants remarked that they were unable to localize the position of the given sound. The determined accuracy is high. High enough to think about further experiments and applications in the domain of aircrafts and helicopter cockpits.

In our first attempt, 12-18 different position could be determined with high correctness. Even by cutting this result down to the four different quadrants, a multiplicity of pilot-assistance systems could benefit from an extra information channel or additional information to the pilots. With head tracker, the reliability of the tracking was increased tremendously. These results are compared with the real world results of about 5 degrees from previous studies [16], [17], [18].

Participants report that in the head tracker sessions, the sound localization felt more natural and the acceptance for the sound as information channel was higher. Beyond that, we find further options to optimize the localization. These outcomes will be integrated in our ongoing experiment.

In contrast to the studies of Parker et al., participants reported no front-back confusion or inside the head phenomenon neither in the head tracker session nor without head tracker. A combination of spoken direction, as the often used *at two o'clock* for front-right, combined with a 3D-audio sound at the target position will reduce the time to orientate and creates another security layer.

Nevertheless, the positive influence of 3D-audio experience could not be clearly established. On the one hand, the participants have no outstanding real life experience with 3D-audio. The simple fact that they rarely use a headphone was not enough to produce noticeable benefits in spatial hearing. On the other hand, no significant linking between hearing threshold and localization performance was measured. This allows the assumption that spatial hearing is independent in the given limits of normal hearing. As consequence of these findings, we are going to test the ability of human to be trained at spacial audio.

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8 Contact Author Email Address

christian.niermann@DLR.de

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