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Noise annoyance caused by continuous descent approaches compared to regular descent procedures

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ABSTRACT

During Continuous Descent Approaches (CDAs) aircraft glide towards the runway resulting in reduced noise and fuel usage. Here, we investigated whether such landings cause less noise annoyance than a regular stepwise approach. Both landing types were compared in a controlled laboratory setting with a Virtual Community Noise Simulator (VCNS), using four audio samples: an overflight during a regular approach (2000 ft altitude) and three aircraft performing CDAs at respectively 3000, 4000 and 5000 ft. The samples at 2000 ft and 4000 ft were recorded at a countryside road, a 360° photo of which was used for the virtual visuals. The other two CDA samples were derived from the recording at 4000 ft. Participants were asked to rate all flyover samples twice while being immersed in the virtual environment. The CDA at 3000 ft was rated as most annoying, likely due to a longer overflight duration, followed by the regular descent and then the CDAs at 4000 and 5000 ft. As CDAs follow a fairly steady trajectory, it was estimated that they will increase annoyance within an area of approximately 2.5 km^2, as compared to regular landings. Outside of this area, CDAs may instead result in less annoyance than regular landings.

1. Introduction

Aircraft noise can be a burden for communities and individuals living in the vicinity of an airport, especially at night time. As noise annoyance is a key component in airport capacity discussions, any measure to aid noise abatement is welcome.

During regular landing procedures, the aircraft approach the runway in a stepwise manner: alternately descending and flying at steady altitudes depending on e.g. the route, the distance to the runway and traffic situation. To maintain a steady height, extra thrust and therefore more fuel is needed, which in turn leads to extra noise. In the last 15–20 years, many airports worldwide have commenced with using Continuous Descent Approaches (CDAs) in addition to regular procedures. During CDAs, the aircraft stay at their cruising altitude as long as possible [1], and then glide towards the landing strip with an angle of approximately 3° [12] in a vertically optimized route [1]. The amount of drag that is needed to maintain a steady height is reduced in CDAs [10,18] allowing the engines to operate at near idle thrust [1]. Compared to regular landing procedures, a CDA results in reduced fuel burn, lower emissions and noise reduction [5,6,7,8,18,19], until the CDA intercepts the Instrument Landing System (ILS) after which there is no difference between a CDA and a regular landing anymore. In one study, A-weighted peak noise was found to be 3.9–6.5 dB(A) lower at seven locations underneath the flight path. As a 1–3 dB is the Just Noticeable Difference (JND) for noise, this can be called a significant noise reduction. Accordingly, Wubben and Busink [19] reported less noise annoyance around Amsterdam Airport Schiphol after CDAs were introduced at night time. In 2000, it was even suggested that, concerning aircraft noise, CDAs were the most effective noise abatement technique [13].

While previous studies [5,18,19] have consistently shown that both noise and fuel consumption are reduced, no controlled study has, to our knowledge, shown that using CDA procedures leads to a decrease of noise annoyance. With this study, we aimed to compare noise annoyance generated by CDAs and regular landing

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procedures. We hypothesized that annoyance would be lower during CDAs than during regular descent approaches.

For this study, we made use of a Virtual Community Noise Simulator (VCNS). This virtual reality (VR) device allowed us to address noise annoyance by different types of landings in a controlled laboratory environment. Participants experienced flyovers of CDAs at three different heights (resp. 5000, 4000 and 3000 ft), and of regular landings at 2000 ft (the typical altitude which aircraft approaching Amsterdam Airport Schiphol maintain until they intercept the ILS for the final approach (see Fig. 1)). Participants were standing on a virtual quiet countryside road, and were asked to rate their noise annoyance after each flyover.

It was expected that noise annoyance ratings would be lower for all CDA flyovers compared to the regular landing procedures.

2. Methods

2.1. Participants

Twenty-seven healthy volunteers with a mean age of 24.4 years old (SD = 8.8, 11 females) were recruited from the Vrije Universiteit Amsterdam student body, and participated in this study after giving informed consent. Cash money (6 euros) or academic credits were offered as a reward for participation. This study was conducted in accordance with the norms of the Helsinki Declaration.

2.2. Materials

Four one-minute audio samples of descending Airbus 330 (A330) flyovers were used: one regular descent approach at 2000 ft and three CDAs at respectively 3000, 4000 and 5000 ft at the moment of closest vertical proximity to the listener. Both the regular flyover at 2000 ft (before intercepting the Instrument Landing System (ILS)) and the CDA at 4000 ft were recorded in the province of Noord-Holland (near Castricum) in the Netherlands with a Bruel and Kjaer type 4189 microphone. By applying digital signal processing tools, gain and FIR filters [2], that reflect the change in distance, the recorded signal at 4000 ft was made representative for the 3000 ft and 5000 ft flight path. As no change in source noise was applied, all resulting samples contain the same geometric characteristics (directivity and Doppler shift) as the 4000 ft sample. This was done because it was judged that differences due to changes in directivity and Doppler shift would be much smaller than the difference caused by the distance effects. The flyover characteristics are shown in Table 1. In Fig. 2, the loudness curves over time of all overflights are portrayed. All of these samples are representative of procedures that are common for Amsterdam Airport Schiphol (AAS) in the Netherlands.

Table 1
A-weighted maximum sound level (LAmax), A-weighted Sound Exposure Level (ASEL) and minimum vertical distance (the shortest distance between the aircraft and the listener during the flyover) of the four audio samples.

Procedure/altitude	LAmax	ASEL	Minimum distance, m
Regular, 2000 ft	70.6	79.3	1033
CDA, 3000 ft	67.6	79.5	1211
CDA, 4000 ft	65.5	77.1	1460
CDA, 5000 ft	63.3	75.2	1727

The Netherlands Aerospace Centre's (NLR's) VCNS [2] was used to create a virtual environment in which the experiment was conducted. The VCNS, a copy of NASA's CNoTE system [16], sends real-time visuals and audio to a Head-Mounted Display (HMD, eMagin Z800 3D visor) and head tracked headphones (Sennheiser EH250), allowing the participant to hear and look around in the virtual environment. Ambient noise was recorded on site and played as background noise to strengthen the immersion. The real-time audio rendering functionality (AuSim's GoldServer, Chapin, 2001) provided real-time binaural effects dependent on the orientation of the participant with respect to the simulated aircraft.

The virtual visual environment consisted of a 360° photo of the recording site: a small countryside road next to a canal. Both the visuals of the virtual environment and the aircraft were rendered with OpenSceneGraph (OSG, www.openscenegraph.org). The head tracking device on the headphones ensured that the audio and virtual aircraft visuals were in sync.

Measurement of the headphone frequency response using a white noise source, revealed the non-flat behavior of the headphone. The difference with respect to the desired flat response was used to define an FIR-filter ([2], Chapter 5.2). This filter was applied to the audio signals to correct for the non-flat headphone frequency response.

A demographic questionnaire was used to ask specifics such as age, gender, education, hearing proficiency and home environment.

One question (in Dutch) was used to assess annoyance: "Thinking about the last minute, what number from zero to ten best shows how much you are bothered, disturbed, or annoyed by the aircraft noise you just heard?". With this question we stayed as close as possible to the standardized question proposed by Fields et al. [9].

2.3. Procedure

Participants first read an information folder, signed an informed consent and filled out the demographics questionnaire. They were then led into a sound-insulated room where the HMD-visor and headphones were adjusted to fit. A piece of black plastic blocked the peripheral view so the participant could not see the laboratory room.

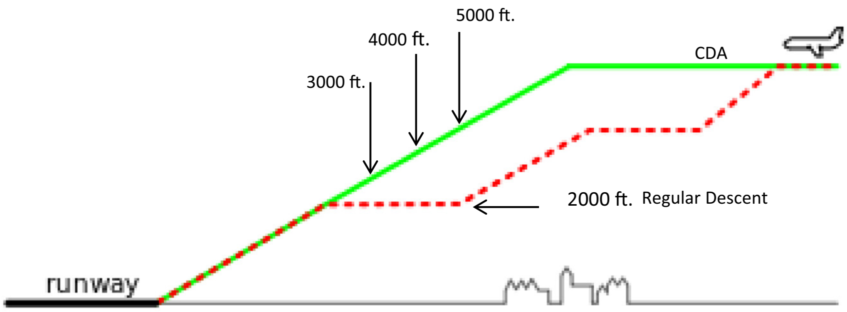

Fig. 1. Flight paths of regular descents and Continuous Descent Approaches (CDAs). Arrows indicate the respective locations of which audio samples were used. Copyright of this schematic profile: Gijs, Wikipedia 2012.

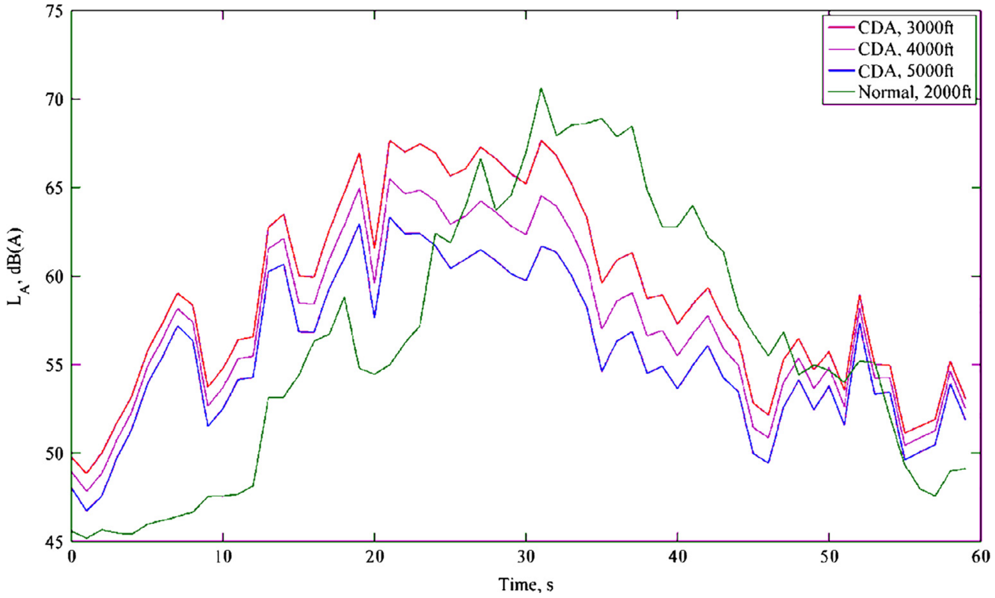

Fig. 2. LA levels per sample over time.

The first task consisted of exploring the virtual scene for 90 s without noise, to get familiar with the environment. The second task was the actual experiment during which every flyover was administered twice. As randomization of the flyover simulations was not possible in the VCNS, two counterbalanced orders were used to minimize the possibility of order effects. Specific flyovers were never presented twice consecutively. Participants were free to explore the environment during the experiment and search for the aircraft if they felt like it. After every flyover participants rated their noise annoyance with the noise annoyance question. This question was prerecorded and presented on the headphones. The answers were given verbally and entered into the computer by the experimenter. The next sample followed directly after a response was given. The experiment lasted approximately 40 min.

3. Results

Fig. 3 shows the mean annoyance ratings given by the participants for the four flyover samples. Analyses with a repeated measures Analysis of Variance (ANOVA) showed a main effect of condition, $F(3,78) = 15.685$, $p =< 0.001$, $r = 0.41$. Follow-up analyses using simple contrasts revealed that the regular descent was rated as less annoying than the CDA at 3000 ft, $F(1,26) = 5.162$, $p = 0.032$, $r = 0.41$, but as more annoying than the CDAs at 4000 ft, $F(1,26) = 5.679$, $p = 0.025$, $r = 0.42$, and at 5000 ft, $F(1,26) = 15.390$, $p = 0.001$, $r = 0.61$.

As all CDA flights more or less use the same horizontal ground track towards the runway, these results can be extrapolated to estimate annoyance experienced along the whole flight path of a descending aircraft. To do this, we computed how the noise experienced at different locations below and alongside the flight path would compare to the three CDA samples used in the experiment. Then using linear inter- and extrapolation, we estimated the annoyance that would be experienced at those locations from the three CDA conditions included in the experiment. This resulted in the map shown in Fig. 4, in which the color indicates where more or equal amounts (orange) or where less annoyance (blue) is to be expected underneath the flight path. Our analysis showed that there is an area underneath the flight path where more noise annoyance may be experienced from CDAs as compared to when

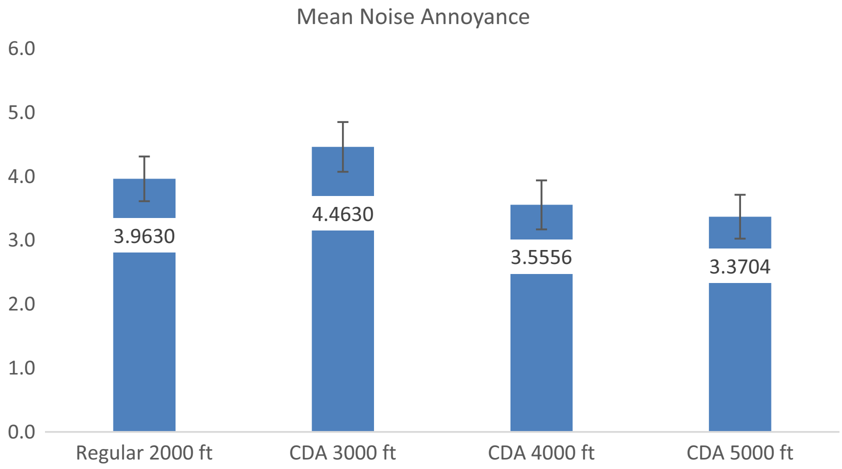

Fig. 3. Mean noise annoyance levels for the regular descent at 2000 ft and the CDAs at respectively 3000 ft, 4000 ft and 5000 ft. Error bars show the standard error of the mean.

regular descents are used. This area is approximately 2.5 km^2 in size and at a distance of 17–22 km from the runway. The results depicted by Fig. 4 only show the effects due to the difference in propagation characteristics between the flight paths. Changes in geometrical characteristics, i.e. directivity and Doppler shift, were not considered in the underlying analyses.

4. Conclusions and discussion

Using a virtual environment, we compared noise annoyance caused by a CDA with that caused by a regular landing procedure. In line with expectations, participants rated audio samples representing a CDA at 4000 ft and 5000 ft as less annoying than the sound from an A330 flying a regular descent. Against expectations, however, it was found that the CDA at 3000 ft was considered as more annoying than the regular descent procedure. This is a notable finding because the regular descent has the highest LAmax level, which is often reported as a predictor for noise annoyance [3,4,17] as is the number of events [3,4,15], although the latter effect was not found in all studies [17]. The 3000 ft CDA and the regular descent did show similar ASEL values due to the longer flyover duration of the CDA (see Table 1). Increased duration of sound is also known to result in higher annoyance levels [11,20]. In a laboratory study on noise annoyance by helicopter noise, an increase of annoyance was found for increased durations, supporting the conclusion that ASEL is a better index for helicopter noise than LAmax [14]. A longer duration of above-background level noise could thus explain why the CDA at 3000 ft resulted in more annoyance than the regular landing, even though the LAmax level was lower for the CDA. We therefore conclude that ASEL was a better predictor of annoyances in this study than LAmax, but that ASEL may not represent duration sufficiently to predict noise annoyance in general. We therefore recommend using ASEL for annoyance predictions to take the duration of flyovers into consideration as well.

Our results indicate that CDA procedures results in reduction of annoyance when the aircraft are still flying at high altitudes, but may increase annoyance closer to the runway, when the aircraft are lower. Taking into account that aircraft flying CDA procedures generally use similar horizontal flight paths, this could result in increased annoyance ratings in specific areas below the flight path. We calculated that this is likely to be the case in an area of approximately 2.5 km^2 underneath the flight path at about 17–22 km distance from the runway (see Fig. 3). In areas farther away from the runway, on the other hand, residents would profit from the CDAs as noise levels there are reduced compared to when regular landing procedures are used. Moreover, also at locations that are horizontally more than one kilometer away from the flight path, CDAs should, according to our calculations, result in a decrease in noise annoyance.

A consideration here is that, at some airports (including the main international airport in the Netherlands), CDAs are executed during the night with a flight path (or ground track) that has to be adhered to by all aircraft. Hence, residents underneath that flight path are subjected to a higher number of flyovers than would be the case if regular landing procedures were used. Curved CDA approaches, if safety protocols allow it, could be a solution for this additional burden for those residents [12]. Future research is necessary to address the issue of fixed tracks and effects of the number of CDA flyovers.

The overall mean annoyance ratings were not very high in this study. The fact that most participants were students, not necessarily living close to an airport, was possibly of influence in this matter. Another possibility is that annoyance levels were relatively low because the VR experience was novel and exciting for the participants. Because we have used a within-subject design and were predominantly interested in relative differences between annoyance ratings, we do not think that these possible biases have affected the main findings of this study.

All in all our results indicate that the use of CDAs will lead to a reduction of noise annoyance except for a small area underneath the flight path. The calculated area is only representative for the measured aircraft and cannot directly be generalized to other aircraft or routes as, for instance, flight velocities can greatly differ in other situations. Even though precise calculations and measurements should be made for different aircraft, it is not unthinkable that different types of aircraft have their own area where CDAs may lead to more annoyance or less annoyance. When areas with more expected annoyance have been identified, it would be wise to communicate about it with the inhabitants.

A general caveat concerning our results and those of several studies cited above is that they are based on laboratory experiments. Although we have tried to come close to a real-life experience, using a virtual audiovisual environment which was found to be truly immersive by most participants, it remains to be tested in future research whether actual field studies will indeed confirm our results and predictions. For now we can conclude that CDAs are likely to lead to more noise annoyance in certain small areas underneath the flight path, but that inhabitants of the surrounding areas are likely to experience some relief from aircraft noise.

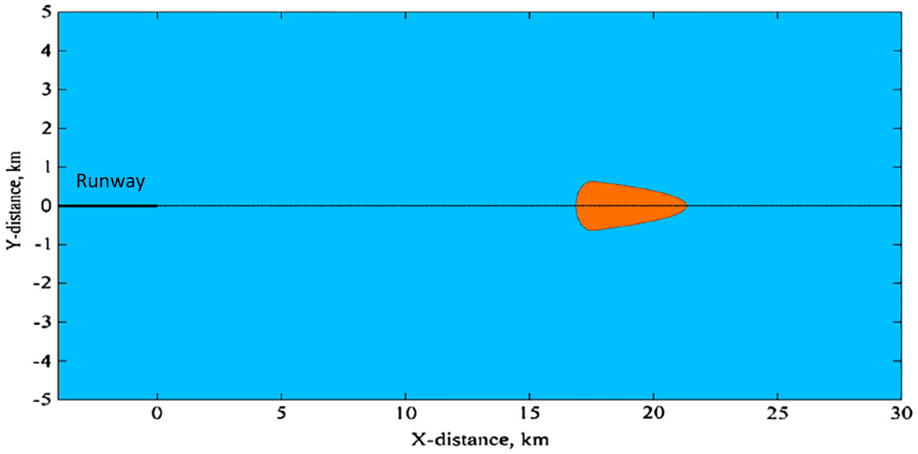

Fig. 4. The orange area is the area where equal amounts or more annoyance is expected when CDAs are used. For the blue area less annoyance is expected for CDAs compared to regular descents. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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