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Interactive simulation of aircraft noise in aural and visual virtual environments

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ABSTRACT

This paper describes a novel aircraft noise simulation technique developed at RWTH Aachen University, which makes use of aircraft noise auralization and 3D visualization to make aircraft noise both heard and seen in immersive Virtual Reality (VR) environments. This technique is intended to be used to increase the residents' acceptance of aircraft noise by presenting noise changes in a more directly relatable form, and also aid in understanding what contributes to the residents' subjective annoyance via psychoacoustic surveys. This paper describes the technique as well as some of its initial applications. The reasoning behind the development of such a technique is that the issue of aircraft noise experienced by residents in airport vicinities is one of subjective annoyance. Any efforts at noise abatement have been conventionally presented to residents in terms of noise level reductions in conventional metrics such as A-weighted level or equivalent sound level L_{eq}. This conventional approach however proves insufficient in increasing aircraft noise acceptance due to two main reasons – firstly, the residents have only a rudimentary understanding of changes in decibel and secondly, the conventional metrics do not fully capture what the residents actually find annoying i.e. characteristics of aircraft noise they find least acceptable. In order to allow least resistance to air-traffic expansion, the acceptance of aircraft noise has to be increased, for which such a new approach to noise assessment is required.

1. Introduction

It is of interest currently to both aircraft manufacturers as well as to policymakers, how reductions in aircraft noise via continually improved designs and operations are communicated to residents in airport vicinities. From a policy making perspective, it is desirable to have a means of presenting aircraft noise to residents in a means beyond numbers, which they can easily relate to and understand. From an engineering perspective however, it is still necessary to be able to express noise reduction potential in numbers which can be minimized for optimized aircraft designs and flight procedures. The metrics currently used however are seen to be lacking when expressing noise characteristics beyond intensity and with the returned focus on newer propulsion technologies such as Counter Rotating Open Rotor (CROR) engines, a need for metrics that better capture aircraft noise spectral characteristics has been identified [1–3]. Furthermore, the turbofan engines currently used with all the noise reduction technologies they employ such as fan liners and chevron nozzles have achieved much lower levels compared to their counterparts from older generations and it might not be physically possible to continue attempting to just lower the noise levels. A generalized approach at overall Sound Pressure Level (SPL) reduction now thus proves lacking as the residents have become accustomed to quieter aircraft and their tolerance for noise acceptance has decreased.

To attempt to address these issues, a new aircraft noise simulation technique was developed, which could be used to increase the residents' acceptance of aircraft noise and which would also aid in investigating what contributes to their subjective annoyance. It could aid in learning via psychoacoustic surveys of virtual aircraft and engines how the aircraft noise annoyance could be minimized and how the results could be demonstrated in a clearer and more understandable way. The use of both VR acoustics for aircraft noise auralization (i.e. aural simulation) as well as VR visualization has been made via an interdisciplinary specialized collaboration of three institutes – Institute of Aerospace Systems (ILR) for aircraft design, flight path and noise modeling; Institute of Technical

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Acoustics (ITA) for auralization of the modeled aircraft noise; Virtual Reality Group (VRG) for interactive 3D visualization of complete aircraft scenarios coupled with the auralized audio. The auralization methodology of the ITA is capable of real-time auralization and when the combined VR simulation is performed in an environment capable of handling very high computational costs such as RWTH Aachen University's CAVE (Cave Automatic Virtual Environment) facility [4,5], then the changes in aircraft or observer position can be both seen and heard in real-time.

The developed technique has the advantage of being capable of producing not just a combined aural and visual VR simulation but also separate aircraft noise auralization and visualization capabilities, which may be used for different individual purposes. Aircraft noise auralization for instance allows the effects of a new aircraft, engine, flight procedure or route to be made audible, including aircraft and propulsion technologies which have till now only been tested in wind-tunnels or as prototypes. The synthetic audio can be used for demonstration purposes as well as to perform psychoacoustic studies for investigating the annoyance of different aircraft as well as different noise sources.

The 3D visualization enhances the aurally simulated results and provides a way of making the observer feel immersed in an environment, having the possibility to move in or interact with this environment. The 3D visualization capability allows visualization of aircraft and their noise impact both in larger VR facilities such as the CAVE or also locally on a desktop computer, which allows the technique to be made portable. The capability of an interactive simulation is important as it gives the users of the technology the option of not just being static observers watching recordings but interactively finding out as much as they can.

2. VR simulation of aircraft noise – state of the art

VR technology has been used for aircraft noise simulation so far by a limited number of organizations and consortiums. Two European Commission sponsored projects SEFA (Sound Engineering for Aircraft) [6], and COSMA (Community Oriented Solutions to Minimize Aircraft Noise Annoyance) [7] attempted to perform sound engineering of aircraft with the goal of lowering the community noise annoyance. Although the use of auralization was made here, this was based on recorded aircraft noise data and separating the major components such as broadband noise, fan tones and buzz-saw noise from the recordings via spectral decomposition [8]. This technique differs from the technique described in this paper in that the noise spectra and directivities are not prediction based or obtained from parametric semi-empirical source noise models. Both projects focused on the sound aspect of annoyance and an interactive coupled visualization was not attempted. Both projects were nonetheless very significant in terms of better understanding aircraft noise annoyance experienced by the residents, and SEFA was one of the first projects to approach aircraft noise assessment in an alternate way by focusing on the sound quality rather than level or intensity.

The National Aeronautics and Space Administration (NASA) Langley Research Center of the US was the first organization to perform prediction based aural synthesis of aircraft noise as well as attempt to couple the auralized noise with a 3D visualization [9]. The auralization methodology of NASA is similar to that pursued by RWTH Aachen University currently, and NASA performed a coupled visualization using a Head-Mounted Display (HMD). NASA has been actively using aircraft noise auralizations of fan tonal and jet broadband noise to better understand their subjective perceptions and has attempted to make the synthetic auralizations sound more realistic via incorporation of temporal fluctuations [10,11]. NASA has also auralized synthetic audio of future Hybrid Wing Body and CROR aircraft flyovers for demonstration of their noise reduction and acceptance possibilities [12,13]. The National Aerospace Laboratory (NLR) of the Netherlands further developed the HMD visualization capability – the Virtual Community Noise Simulator (VCNS) and performed auralizations of propagated noise spectra on the ground [14]. The focus of NLR has so far been on incorporating detailed atmospheric effects into the auralizations such as wind and turbulence to better reflect measured audio [15]. NLR has also made use of auralizations combined with visualizations as a demonstration tool to policymakers and residents, to show for instance how a change of flight route would sound to residents in a small town, using the local scenery as the visualization background for their familiarity.

The purpose of applying VR technology to aircraft noise thus far has mainly been twofold – aid in understanding and quantifying the annoyance aspect of aircraft noise, and demonstration to non-experts and residents of new aircraft designs or changes in operations. Both these two goals of using VR technology i.e. annoyance studies and demonstration to non-experts are also currently envisioned at RWTH Aachen University.

3. VR simulation of aircraft noise at RWTH Aachen University

The methodology with which the VR simulation of aircraft noise was achieved is described in this section. The approach of the ILR for aircraft noise modeling is described in Section 3.1, the approach of the ITA for real-time capable aircraft noise auralization in Section 3.2 and the approach of the VRG for interactive 3D visualization is explained in Section 3.3. Section 3.1 also describes the efforts at the ILR of attempting to capture aircraft noise annoyance via metrics that describe the quality of the sound and not just the level. The overall VR simulation technique was developed for an interdisciplinary internal RWTH Aachen University project, VATSS – Virtual Air Traffic System Simulation, which had the goal of making aircraft noise more communicable to non-experts by making the use of Virtual Reality technologies [16]. The motivation behind the interdisciplinary approach was the view that such a complex VR simulation of air-traffic encompassed more than one specialized field and thus could be performed in the most efficient way by utilizing the already existing expertise at the specialized institutes (see Fig. 1).

3.1. Aircraft noise modeling methodology

A detailed parametric noise prediction tool was developed in the previous years at the ILR for multidisciplinary preliminary aircraft design and overall mission noise impact assessment. The ILR Noise Simulation and Assessment module – INSTANT [27], based on NASA's Aircraft Noise Prediction Program (ANOPP), implements

Fig. 1. Aircraft noise simulation in the VR CAVE facility of RWTH Aachen University.