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Modeling and synthesis of aircraft flyover noise

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ABSTRACT

Traditionally aircraft flyover noise is assessed by displaying contours of noise metrics. These models can be used to study noise mitigation measures but they lack the possibility to play-back the audible sound as predicted by their calculations. To that end, noise synthesis is an option that allows to experience differences due to noise abatement procedures or new aircraft designs. A noise synthesis technique for aircraft noise is demonstrated by predicting the noise at a noise monitoring location near an airport. By comparing the synthesized results to a recorded measurement, an indication on the capability of this technique has been acquired. Differences between the synthesized and measured sound remain. A large part of that difference is believed to be caused by the inherent uncertainty when using predictive empirical source noise models. It is shown that differences between departure routes can be captured, thereby illustrating the potential of this method to listen to different take-off procedures. Future improvements in source noise prediction and the inclusion of the effects of turbulence on propagation will further aid to the realism of synthesized aircraft noise.

1. Introduction

The amount of worldwide air traffic has been increasing over the last decades. This has an adverse effect on the noise impact of communities near airports. As such, airports face expansion limitations based on the aircraft noise received in communities. These regulations are usually imposed by legislators who are concerned to protect the communities from adverse effects. In the Netherlands restrictions are inflicted based on computed aircraft noise, in specific noise control points, which are not allowed to exceed a specific yearly dose.

Difficulties remain in the process to predict the amount of noise and the response to that noise, which are two vital operations to estimate the effect on communities. Noise prediction models can basically be categorized in long-term (multi-event) average models or short-term (single-event) models. The difference is that single-event models are specifically tailored to predict the system noise of the aircraft on the ground for a single flyover [1,2]. Multi-event models, like INM [3] and other implementations of ECAC Doc.29 [4], offer predictions for a combination of multiple aircraft and trajectories flying over a community. As such they make a concession, compared to single-event models, in the amount of detail accounting for directivity, noise spectrum and propagation effects. Multi-event models are thus suited to incorporate the annual traffic around an airport and provide results upon which regulations are usually based.

Multi-event models are often used to estimate the effects of noise mitigation measures. These studies are usually executed for procedures like a location based thrust-cutback or continuous descent approach. But given the underlying modeling assumptions, the reliability of the results of such a study become questionable. Single-event models could offer this fidelity but need a lot more aircraft specific input than a multi-event model. Even if such a model is used, its results are commonly expressed as contour plots. Such results are usable to experts who can judge such a result and the underlying models. Non-experts have more difficulty examining the implications from such plots. For instance, differences inside a contour remain, i.e. two locations enclosed in a 58 L_{DEN} contour can exhibit different sound levels and characteristics for the same flyover. The actual sound of such a flyover would provide more insight and allow for a more careful balance judging the potential of noise mitigation measures. Experiencing and comparing audible results from a noise abatement procedure could act as a translation tool to indicate the effects of the effort. This could potentially aid the communication between the operators, airports and communities that are affected to display the potential of noise mitigation measures.

Models that can synthesize calculations (convert a calculation into an audible result) are rare but gaining ground in different places in the scientific community. Differences between the methods exist, for instance [5] is focussed on the re-synthesis of measured aircraft sound whereas [6–8] focuses on the synthesis from

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system noise predictions. A lucid examples of this new technology is the synthesis of sound from a Hybrid Wing Body by NASA [9]. Using such predictive models has the benefit of experiencing aircraft flyovers that are still in the conceptual or preliminary design stage.

At the NLR, work to this end started in 2007 by the creation of a Virtual Community Noise Simulator (VCNS) in a collaborative effort with NASA. The simulator is a sister of the NASA Community Noise Test Environment (CNoTE [6]). The simulator immerses a test person in a virtual environment where an aircraft flyover can be experienced both visually and audibly.

Following [8], where first attempts in the noise synthesis were made by the NLR, a comparison of the synthesis method to typical real life data is desired. Other authors have compared to measurements as well, especially the aircraft noise synthesis team at NASA looked at synthesis including temporal variations [10–13], although comparisons to full flyover synthesized results remain rare. The only one that is known to the authors is by [14] where a small comparison effort to measurements was made. However, their noise prediction is of a proprietary source and therefore it is not clear what the ability of a synthesis technique based on an empirical predictive method is. As such it is necessary to see how the predictions hold up compared to measurements. To that end, the current study will synthesize measured flyovers at a noise monitoring location and quantify the merits and quality of the current method. From that, further indications on future research and on the limitations of the method will follow.

2. Flight mechanics and source noise

The current study researches the abilities of the synthesis technique by comparing it to measurements. To that end four flyover recordings from departures at Schiphol airport are used from a nearby noise monitoring terminal together with the trajectories of the aircraft. Analysis of the flight mechanics and the source prediction models is necessary to obtain a sound source prediction from the aircraft which is the basis of any predictive synthesis technique.

2.1. Flight mechanics

The four departing aircraft studied here are Boeing 747-400's equipped with CF6-80C2 engines. The method explained in this article is generic and could be expanded to different aircraft or trajectories as well. The ground track of the flights used in this study is qualitatively shown by Fig. 1.

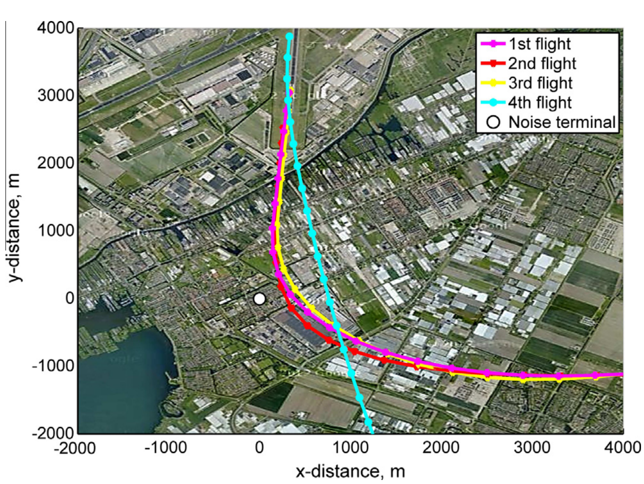

Fig. 1. The ground track of the flight trajectories and the noise monitoring terminal in a nearby community.

Fig. 1 shows three departures that fly more or less the same trajectory whereas one flight deviates. This is the difference between the two departure routes used for this runway. The minimum distance between the noise monitoring location and the fourth flight is larger than the others, which will be shown to have a clear effect on the sound levels.

The radar supplies a reading every 4 s on which the aircraft is assumed to be in equilibrium. Consequently, the effects of aircraft accelerations are excluded from the analysis. Furthermore, the ground speed is assumed to equal the airspeed corrected for a 3 m/s headwind component that was the average for the measurement day. Solving for equilibrium conditions, and using a B747-400 lift–drag polar whilst assuming maximum take-off weight conditions, allows us to calculate the required thrust, drag and lift. The required thrust was a full power condition for that part of the trajectory under study here, which is in line with the take-off condition. With the thrust setting the calculation of the engine state was initiated. The engine state is necessary to provide engine flow conditions to the source noise prediction modules. To calculate the engine state the same method as reported in [8] was used. The engine data used was constructed from publicly available data and data available within the NLR GSP model [15].

2.2. Source noise

Aircraft noise is generally subdivided in two categories: engine noise and airframe noise. The engine is the primary source of interest during take-off, during landings the noise of the airframe has become equally important. Empirical models have been used to calculate the source noise levels because they need a limited amount of input and offer a reasonable accuracy for a low computational time. They also provide generic capabilities that potentially allows to evaluate different aircraft.

Engine noise has been split into three sub-sources, jet mixing noise, fan noise and core noise. Jet broadband noise has been modeled using the model developed by Stone [16]. The model estimates the mixing noise as a function of the exit velocity, pressure and temperature of the engine outflow. Three distinctive areas have been modeled due to different outflow regions where mixing occurs. Although jet noise is a distributed source, it is assumed that it can be represented as a point source since the distance to the observer is large for flyover conditions.

Fan noise comprises both broadband and tonal components. The tonal components are caused by fan rotor–stator interaction and, dependent on the power setting, shocks emmanating on the fan rotor. The latter noise is popularly known as Buzz-Saw noise. Heidmann developed a model [17] to predict fan noise which was updated [18] to yield better results. In the analysis of the update, it was noted that the Buzz-Saw noise was severely overpredicted. Therefore, changes were made to counteract these overpredictions by using measurements from a CFM56 engine. Differences were however still observed when a CF6-80C2 engine was modeled. Consequently, the fan tonal noise predictions, as made by the updated Heidmann model, have been corrected by inspecting the published measurements [18].

Engine nacelles are usually treated with acoustic lining material to suppress noise in the inlet as well as the (bypass) exhaust. In the previously mentioned update of the Heidmann model, this deficiency in the prediction capability was noticed as well. Consequently, an empirical method to estimate liner effects was constructed based on measurements [19]. This method has been used to calculate the effects of liners.

Core noise consists of compressor noise, combustion noise and turbine noise. Compressor noise was included as well based on cal-