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A COMPARISON OF MEASURED AND MODELLED AIRCRAFT NOISE LEVELS FOR RTHA

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To reduce the growing distrust in aircraft noise models felt by communities around the airport, it is imperative to ensure accurate modelling methodologies validated by appropriately measured noise metrics. This is especially crucial in regions farther from the airport where L_{den} = 45 - 55 dBA because the amount of affected residents in these areas is large. Currently, there is a lack of measured noise levels at such distances and uncertainty about the assumed procedures, such as the aircraft thrust settings. Regarding the latter, before comparing the model and measured noise levels, it's thus crucial to first create a robust workflow for obtaining accurate input data for the noise predictions. In this contribution, as a first step, audio files from the noise monitoring stations around Rotterdam The Hague airport (RTHA), combined with dedicated array and single microphone measurements, are considered for extracting fan rotational speed, N1. The 64-microphone array and the single microphone system were co-located with one of the monitoring stations at a distance of 1.14 km away from the RTHA runway. The engine settings are retrieved from the intensity-averaged spectrograms obtained from the microphone array. Using the derived thrust settings, the noise levels measured by the monitoring stations are compared with the single-event noise level prediction made by the European Noise model, Doc.29. The aircraft position, i.e., input for the model, is obtained from ADS-B data, which contains the position vector and velocity of the aircraft at 1-second intervals. In the framework of this study, noise predictions for both arrival and take-off procedures for three aircraft types are presented. Finally, this case study aims to investigate the applicability of the data from monitoring stations for the aim of model-data predictions at the mentioned regions.
Keywords: environmental noise, aircraft noise, noise model validation, munisense microphone system

1. Introduction

The aviation industry is rapidly developing to accommodate passengers of all socioeconomic conditions [1]. However, these benefits also bring many detrimental long-term climate change challenges and short-term environmental challenges related to air quality and noise exposure. Community resistance towards expanding aviation operations due to noise exposure is one of the immediate challenges faced by the industry. The proposed aircraft noise reduction measures are threefold: improving aircraft design and producing new technologies, optimizing aircraft operations, and improving policy-making and management [2].

Changing aircraft design is an expensive long-term solution, while the other two measures are more applicable for resolving the current challenges, requiring precise noise exposure prediction. Hence, accurately measuring and predicting aircraft noise is crucial for facilitating precise noise control limits and evaluating noise exposure from various noise abatement procedures. The noise calculations are made according to the guidelines prescribed in the ECAC Doc.29 [3]. They are described by cumulative noise metrics such as the day-evening-night average level L_{den}, but are only applicable for average long-term exposure. According to the 2018 WHO recommendation, major European airports must adhere to a limit of L_{den} = 45dBA, as aircraft noise above this level may cause adverse health issues among the exposed communities [4]. However, this metric is less suitable for model-data comparisons, since comparing the measured averaged exposure with corresponding model predictions cannot reveal the effects of varying parameters, such as aircraft types and operational procedures, on the model-data agreement. This limits the ability to determine the conditions under which the model predictions are less accurate. Hence, it is necessary to predict single-metric noise levels for individual flyovers.

To improve and extend the prediction capabilities of Doc.29, the assumptions made must be verified, and the input must be validated and updated. This input is typically obtained from the Aircraft Noise and Performance (ANP) database subset, i.e., the Noise-Power-Distance (NPD) tables. These tables are curated and extrapolated for a cluster of similar aircraft types with measurements during the aircraft certification process at various standard operation stages and atmospheric conditions. Choosing the most accurate source of input, i.e., power and distance, is necessary to validate the listed noise levels. Therefore, as shown in Figure 1, this paper aims to establish a robust workflow by obtaining accurate input for predicting single-metric noise levels with an accuracy of less than 2 dBA. The noise level validation step is carried out using two types of measuring equipment: A noise monitoring station (NMT) and a Munisense microphone. The radar and ADS-B data validate the distance, and the thrust settings are retrieved from the processed output of a third measurement system, an acoustic array. Then, the noise levels measured during a measurement campaign around Rotterdam The Hague Airport (RTHA) are compared with the predicted values. Furthermore, the applicability of the noise-measuring setups toward model-data comparisons for the future is determined through qualitative and quantitative comparison.

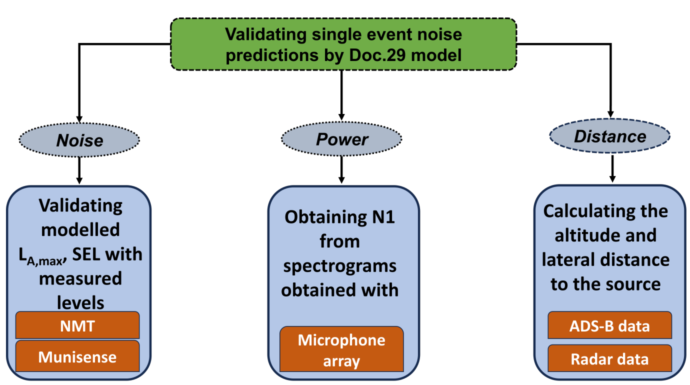


Figure 1: Each key input, i.e., noise, power, distance, is validated with measurements from different sources.

2. Measurement setup

2.1 Noise Monitoring Stations

While being an international airport, Rotterdam The Hague Airport (RTHA) houses only one runway and is located in a densely populated area. Therefore, it is an appropriate case study for validating the noise model at varying observer distances. RTHA is surrounded by six fixed NMTs. The measurements were conducted on 5th Septemeber 2023 near Veldkersweg, Rotterdam, represented by a red circle in Figure 2. The maximum wind speed was 4.63 m/s, and the temperatures ranged from 15°C to 29°C, with relative humidity reaching a maximum of 49%. The total number of flyovers measured with the aircraft type, engine type, and procedure are given in Table 1.

Table 1: List of flyovers measured according to Aircraft type, Engine type, and operating procedures.

Aircraft type	Engine type	Landing	Take-off
EMB190	CF34-10E (82kN)	2	1
B737-700	CFM56-7B22 (101kN)	1	3
B737-800	CFM56-7B27 (121kN)	2	4

2.2 Munisense and microphone array

The measurements obtained from the NMT are of two types: the noise levels and the audio recordings of the flyovers, which are processed into spectrograms. The noise levels are validated with the Munisense microphone. Due to uncertainties in the sensitivities of the array microphones, the measurements of the microphone array will only be used to determine the spectrogram up to higher frequencies than for Munisense and the NMT due to the array's higher sampling frequency; both the array and the Munisense are shown in Figure 2. Since the spectral information obtained from the recorded flyovers by the selected NMT contains interference due to ground reflections, spectrograms obtained from the microphone array are used instead. The specifications of these three setups are described in Table 2.

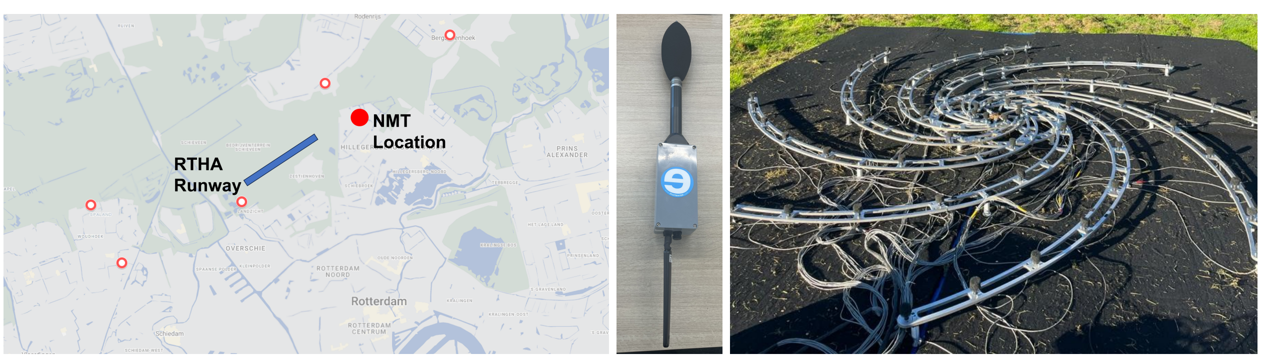


Figure 2: (left to right) RTHA with NMTs where the red dot represents the location of the chosen NMT, and the blue line represents the runway; Portable munisense microphone; 2D array with 64 microphones.

Table 2: Types of measurement equipment and their purpose

Measurement Setup	Specifications	Height [m]	Sample frequency [Hz]
Noise Monitoring Station	Fixed	10	8000
Munisense	Portable & light	5.75	48000
Phased microphone array	Portable & heavy	0.05	50000

3. Doc.29 Model

In ECAC Doc.29 (Volume 2) [3], modelling guidelines for best-practice noise models are stated. This model creates noise contours of day-evening-night averages L_{den} for a year. To calculate L_{den}, the Sound Exposure Level (SEL) is modelled for all flights and data points around the airport grid. The SEL for all flights is logarithmic summed and averaged for the entire year. As mentioned before, best-practice models are based on NPD tables. For different combinations of power settings and distance between the aircraft and the ground, noise values are given in four different metrics. For this research, the two main metrics are the maximum A-weighted sound pressure level $L_{A,max}$ and the SEL of an aircraft noise event. To estimate these metrics for different locations on the ground, a flight path is divided into segments, for example into 1-second intervals. For each interval, a new noise level is determined using the NPD table. At each data point in the grid, the $L_{A,max}$ is calculated by taking the maximum value found during the flight path, and the SEL is calculated by a summation of the noise from each segment. Correction factors, described in chapter 4 of Doc.29 [3], are then applied to retrieve the final values.

The power and distance input needed for the NPD tables is obtained by modelling a flight track. The distance variable is easily obtained by calculating the slant distance d between the aircraft and all the grid points on the ground for each segment. For the power input, thrust procedures are used to estimate the power setting of the specific aircraft type. These procedures consist of several steps based on the aircraft's altitude, speed, and weight. In the creation of L_{den} contours, deriving every single flight and computing a noise grid for it for an entire year can become computationally expensive. Hence, in best-practice modelling, flights of similar aircraft types, routes, and procedures are bundled into a cluster. This cluster is then divided into a main track and subtracks based on historical data. An example of methods to analyze historical tracks and how to create airport-specific profiles can be found in Heblij et al. [5]

For year-round averages, the above-described methods for track modelling have proven to be accurate to 1-2 dB [6]. However, when comparing single-event measurements to these general flight tracks, deviations can become large. Other methods to derive accurate thrust and distance input to the noise model are developed for this research.

4. Obtaining modelling input

4.1 Positional data

Distance is obtained from the flight positional information recorded by ADS-B transponders, which are placed on an aircraft and retrieved by an open-source network known as OpenSky [7]. The correlated information of individual noise events with aircraft time stamps and tail numbers is retrieved from the Trino database in pyopensky library. The relative distance between the noise source and the microphone array is calculated from the aircraft's spatial position, i.e., latitude, longitude, and altitude. ADS-B data has considerable advantages over radar track data because it provides spatial information of the flight at a time interval of 1 s and has better accuracy in the area around the runway.

4.2 Engine settings

The engine setting required for noise prediction is the thrust setting or its related normalized fan rotational speed. Employing Equations 4.1, thrust values are obtained by calculating N1% from the fan's Blade Passing Frequency (BPF). The BPF and its higher harmonics are detected from spectrograms obtained from the noise levels recorded by the microphone array [8].

$$
\begin{aligned}
n &= \frac{60 * BPF}{B} \\
N1\% &= \frac{n}{n_{max}}
\end{aligned}
\tag{4.1}
$$

where B is the number of blades in the specific fan, n (rpm) is the fan rotational speed, and n_{max} (rpm) is the maximum permissible rotational speed of the fan at 100% N1 (values are provided in Table 3).

Table 3: Calculated values of N1% for the given aircraft types defined by the number of blades B.

Aircraft type	B	$n_{max}[rpm]$	Landing N1 [%]	Take-off N1 [%]
EMB190	29	5955	30.42	67.057
B737-700	24	5175	50.65	88.29
B737-800	24	5175	57.62	93.866

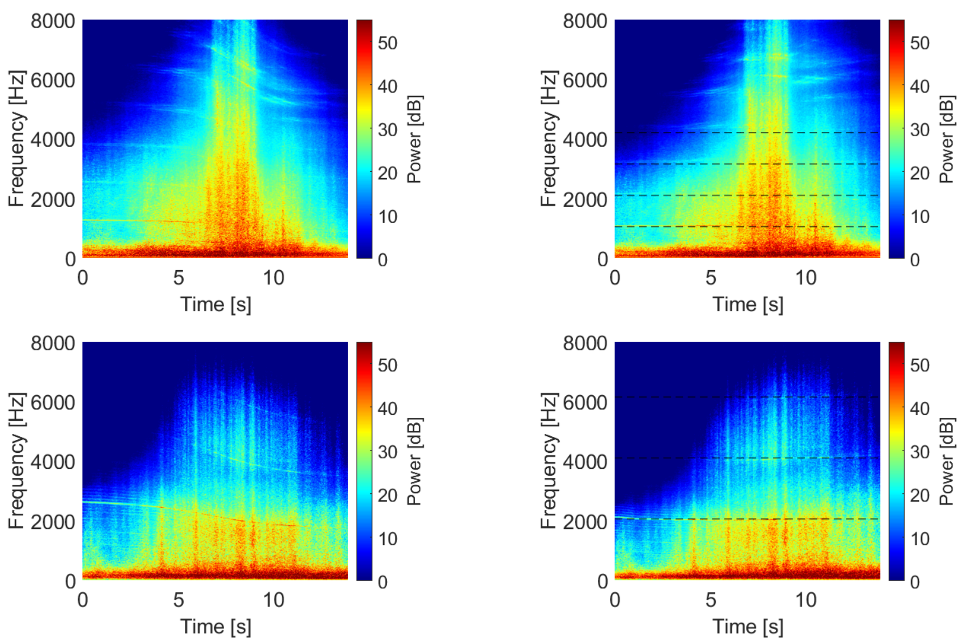


Figure 3: Intensity-averaged spectrograms of the landing of B737-700 (top) and take-off of B737-800 (bottom) without Doppler correction (left) and with Doppler correction (right) where dashed black lines represent the BPF and higher harmonics.

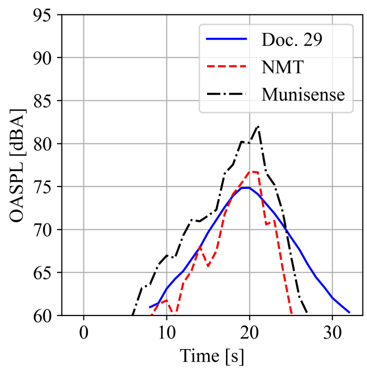
The spectral information is computed by averaging the total intensity calculated for selected microphones. The spectrograms are plotted with the sampling frequency of 50000 Hz, 5000 sampling points/-time block, and Hamming windowing. The spectrograms for all the flyovers are studied, and since no significant spectral information in the range of 8 - 22 kHz is observed, harmonics only up to 8 kHz are considered. The estimated values of N1% engine setting required as the input for Doc.29 predictions are summarized in Table 3. Once the N1% values of the flyovers are retrieved, the thrust of the aircraft can be derived to get the required input for the Doc.29 model. For the conversion of N1% to thrust, this research assumes a quadratic relation between the percentage of maximum rotational speed and the percentage of maximum thrust.

As seen in Figure 3, the measurements of landing and take-off flights exhibit Doppler shifts in frequencies, and the corrected fan tone and harmonics, as described by dashed black lines, are obtained by

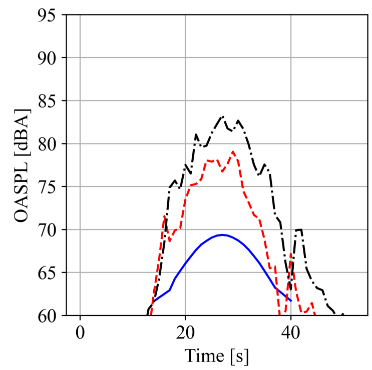
$$\frac{f'}{f} = \frac{1}{1 + \frac{V^2 t_i}{dc}} \qquad t_i = t_e + \frac{d_{min}}{v_c} \tag{4.2}$$

where f' (Hz) and f (Hz) are the observed and emitted frequencies, the speed of sound is $c = 340$ m/s, V (m/s) is the velocity, t_i (s) is the emission time vector, d_{min} (m) is the overhead distance between the aircraft and the array.

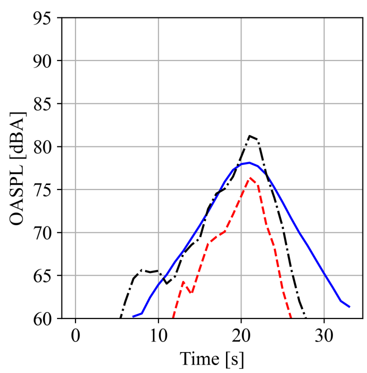
5. Results



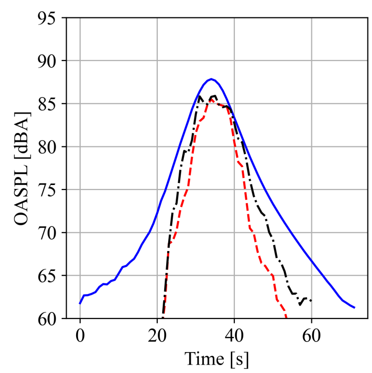
(a) Landing EMB190



(b) Take-off EMB190



(c) Landing B737-700



(d) Take-off B737-800

Figure 4: Overall Sound Pressure level values predicted by Doc.29 compared with the levels measured by NMT and Munisense for arriving and departing flights of types EMB190 and B737-NG.

This section presents the Doc.29. prediction obtained from the given methodology. Along with the predicted noise levels, the curves seen in Figure 4 exhibit the noise levels measured over a single flyover by the NMT and Munisense. These graphs are representative of all the measurements taken, except for the outlier corresponding to] the take-off of EMB190, where an under prediction of more than 10dBA of both $L_{A,max}$ and SEL values is observed. The modelled values for the rest of the cases when compared to the measurements, provide satisfactory agreement. In cases of B737-700, -800 flyovers, $L_{A,max}$ and SEL values are predicted with differences of less than 3 dBA with the levels recorded by both NMT and Munisense. To investigate the agreement of the predictions of SEL values with the noise levels measured by the NMT and Munisense individually, Figure 5 is presented. A good agreement between the modelled and measured SEL by the NMT is exhibited. However, the noise levels measured by Munisense are consistently higher, especially in cases where $OASPL$ is in the range of 60-75 dBA. This could be attributed to the increased effect of interference by the ground. This higher measured noise level at the Munisense microphone is most probably due to its lower setup altitude.

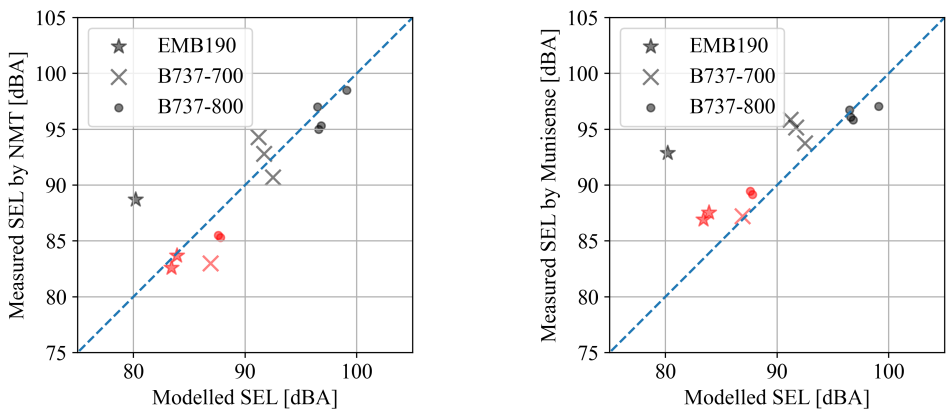


Figure 5: Modelled and measured SEL with NMT (left) and Munisense (right) of arriving (red) and departing (black) flights where the blue dashed line represents correlation = 1.

6. Conclusions

This paper presents a robust methodology for predicting accurate values of $L_{A,max}$ and SEL with Doc.29. The distance input is obtained from the ADS-B data, and engine settings are obtained from the array. Although the data from NMT could be used for validation purposes, the audio they recorded cannot be used to retrieve information concerning the engine settings from the spectrograms due to their sample frequency of 8 kHz and the presence of noise in the background. Hence, this demands that alternate measurement setups, such as Munisense, be made use of. Even though the measurements made by Munisense exhibit higher noise levels than those of the NMT in this paper, this effect can be reduced by setting it at a higher altitude for future measurements, which would reduce the ground effect. Due to the higher sample frequency than the NMT at 48 kHz, the spectrograms from Munisense make it more applicable to retrieve N1%. The thrust settings obtained from the array data in this paper could be used to validate the ones that are obtained from Munisense for the given aircraft types. Additionally, the convenience of transporting Munisense and its ability to record noise levels below $L_A = 60$ dBA makes it an appropriate choice for taking measurements at low-noise regions.

7. Acknowledgement

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