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Assessing the performance of the sonAIR aircraft noise model in predicting noise levels at Schiphol Airport

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Aircraft noise is a significant problem for communities surrounding airports. Accurate prediction models are needed to estimate noise levels from aircraft operations. In this research, the accuracy of the sonAIR aircraft noise model in predicting noise levels from departures around Schiphol airport is evaluated by comparison to measurement data from NOMOS and the current best-practice modelling approach Doc29. Results show a significant but consistent underestimation of noise levels by sonAIR, mainly due to a generalisation of emission models. The standard deviation of differences between model results and measurements is lower for sonAIR than for Doc29 by up to 1 dB. Differences between measurement and model results were found in the relation between N1 and noise levels, and for maximum noise levels. The results demonstrate that sonAIR provides more reliable predictions of noise levels on the single flight event level than Doc29. Additionally, this study shows agreement with results from a previous validation study in Zürich, thereby demonstrating the applicability of sonAIR to another airport. This research contributes to better aircraft noise predictions, which will have implications that ultimately lead to a better quality of life for communities affected by aircraft noise.

Nomenclature

L_{AE}	=	A-weighted sound exposure level
$L_{A,max}$	=	Maximum A-weighted noise level
μ	=	Mean value
σ	=	Standard deviation
B737NG	=	Boeing 737 Next Generation series
B738	=	Boeing 737-800
FDR	=	Flight Data Recorder
NMT	=	Noise Monitoring Tower
NOMOS	=	NOise MOnitoring System
NPD	=	Noise-Power-Distance
PBL	=	Pressure Band Level
PCC	=	Pearson Correlation Coefficient

I. Introduction

Aircraft noise is a significant concern for communities located near airports, as it can affect the quality of life of residents and contribute to hearing loss and other health problems [1]. In order to mitigate the impact of aircraft noise on communities, it is important to accurately predict and measure the level of noise that will be generated by aircraft operations. There are various models that have been developed for this purpose, each with their own strengths and limitations. In general, two types of noise models are differentiated: physics-based and (semi-)empirical models [2]. Physics-based models, or theoretical models, are based on physics describing the noise emission and propagation. (Semi-)empirical noise prediction models are based on noise measurements.

In Europe, the European Civil Aviation Conference (ECAC) Doc29 modelling approach is the current best-practice modelling approach which has been previously compared with measurements [3, 4]. This is a semi-empirical method which makes use of Noise-Power-Distance (NPD) tables, which provide a noise value for an aircraft at a certain distance given its thrust setting.

Alternatively, the sonAIR aircraft noise model was created by the Swiss Federal Laboratories for Materials Science and Technology (Empa). Their goal was to fill the gap between best practice approaches for long-term averages on one side, and highly detailed, computationally expensive models on the other side. The model is based on

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backpropagation of flyover measurements from an extensive measurement campaign around Zürich airport. The model is able to simulate single noise events with a high level of detail, but also can perform noise mapping for airports [5]. However, no independent validation study for sonAIR has been conducted, and it has not been applied to airports outside Switzerland yet.

The aim of this study is to apply and validate the sonAIR noise model using noise data from Schiphol airport, by comparing its performance to measurements (NOMOS) and current best-practice modelling approach (Doc29) around the Netherlands' largest airport. These methods are explained in section II. The model input data is elaborated upon in section III. Validation results are given in section IV and are discussed in section V. Finally, conclusions are drawn and an outlook is given in section VI.

II. Methods

A. NOMOS measurements

The NOise MOnitoring System (NOMOS) entails 41 noise monitoring towers (NMTs) around Schiphol Airport. An NMT consists of a six to ten-meter-high tower with a calibrated microphone on top of it. Each microphone is an ISO class 1 microphone, which constantly measures all sounds in its environment with a measurement uncertainty of 0.7 to 0.9 dBA [6]. An overview of the NMT locations can be seen in Figure 1 or in more detail on the NOMOS website*.

It is important to distinguish an aircraft-related noise event from other sounds. Therefore, noise events are defined by fixed thresholds. Each NMT has its own threshold in dBA, selected based on the background noise. The noise event starts when the measured sound exceeds the threshold. Further requirements on the noise events are as follows [7]:

- The duration of the event should be at least 10 seconds and at most 120 seconds;
- The maximum noise level ($L_{A,max}$) of the noise event must be at least 12 dBA higher than the background noise level;
- This $L_{A,max}$ must be the local maximum for 30 seconds before and after the event;
- The sound exposure level (L_{AE}) of the event must be between 7 and 13 dBA above the $L_{A,max}$.

*https://noiselab.casper.aero/ams/

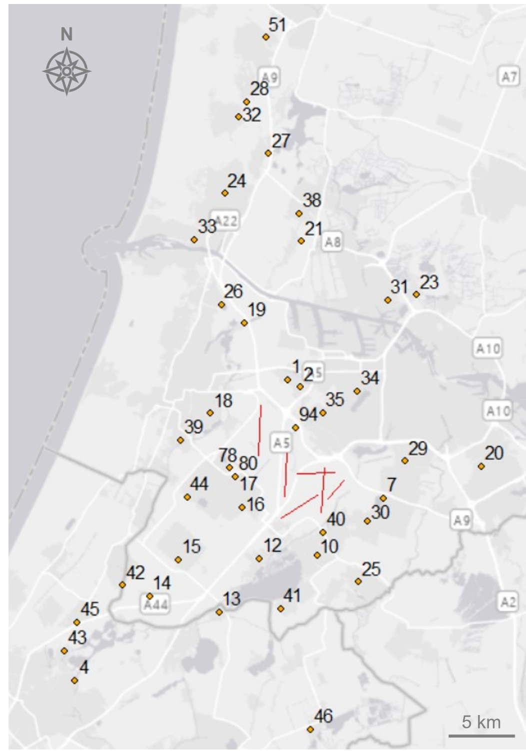


Fig. 1 NOMOS NMT locations

The NOMOS information is processed and stored in the Airport Noise and Operations Management System (ANOMS) application managed by Envirosuite [8]. A noise event is automatically stored if it meets the requirements, and, if possible, it is linked to a flight using radar data.

B. sonAIR aircraft noise model

The sonAIR aircraft noise model consists of two parts: an emission model and a propagation model. Each model is formulated for 24 1/3-octave bands, with a frequency range from 25 Hz to 5 kHz. The emission model is specific per aircraft type.

The emission models were established based on an extensive measurement campaign at Zurich Airport. The noise measurements at numerous microphone positions, along with data from the Flight Data Recorder (FDR) and meteorological data, provided the input data for the backpropagation of the recorded noise to the source. Based on these inputs, linear regression models were established for each 1/3-octave band. The emission models are split into an airframe and engine noise model, whereas the total emitted noise is a sum of both. For most aircraft types, a so-called reduced model was generated, which, compared to the most detailed sonAIR models, does not account for configuration.

Depending on the sound path from source to receiver, the propagation is calculated in two modes. The first calculates direct sound assuming a homogeneous atmosphere. In the second mode, for more complex propagation situations, usually at shallow sound incidence angles, the noise propagation model sonX is used [9]. It accounts for atmospheric absorption, ground effect, foliage attenuation, reflections and the influence of vertical gradients of wind, temperature, and relative humidity.

1. Model inputs

An elaborate explanation of the sonAIR input parameters is given in Zellmann et al. [10]. A brief description is presented in this section. An overview of all input parameters can be seen in Figure 2.

N1 is the rotational speed of the engine's low-pressure fan in %. This parameter strongly correlates with the engine noise and can be derived from noise recordings when FDR data are not available, like e.g. the thrust setting [9]. To determine the relation between N1 and the sound pressure level (SPL), an engine run-up test was performed on an Airbus A330-300 with the TRENT772B engine [10]. The SPL was measured at a distance of 170 meters from the aircraft, at four locations: 15°, 50°, 90° and 120° respectively, with 0° corresponding to the nose of the aircraft. The results provided a second-order polynomial for each 1/3-octave band.

The **Mach number** is chosen to account for speed-dependent sound sources. It influences both the engine noise and airframe noise level. For engine noise, a linear relation is used. i.e. $L_{em,eng} \propto Ma$. A logarithmic relation is derived for airframe noise: $L_{em,afm} \propto \log_{10}(Ma)$, which represents the physics of airframe noise better than a linear relation.

The **air density** ρ is chosen as the atmospheric parameter. The air pressure p and temperature T were omitted because of the close relation between the three, which might lead to multicollinearity.

The directivity of aircraft sound emission is described in spherical coordinates. The engine noise differs along the **polar angle** θ and the **azimuth angle** ϕ, whereas the airframe noise model is independent of the latter.

A binary variable is used to indicate the procedure of the aircraft. The **procedure input** $Proc$ is either departure or landing.

For advanced emission models, the aircraft configuration is described by three variables: **landing gear** (LG, 0: retracted, 1: deployed), **flap handle position** ($Flaps$, depending on aircraft type) and **speed brakes** (SB, 0: not deployed, 1: deployed).

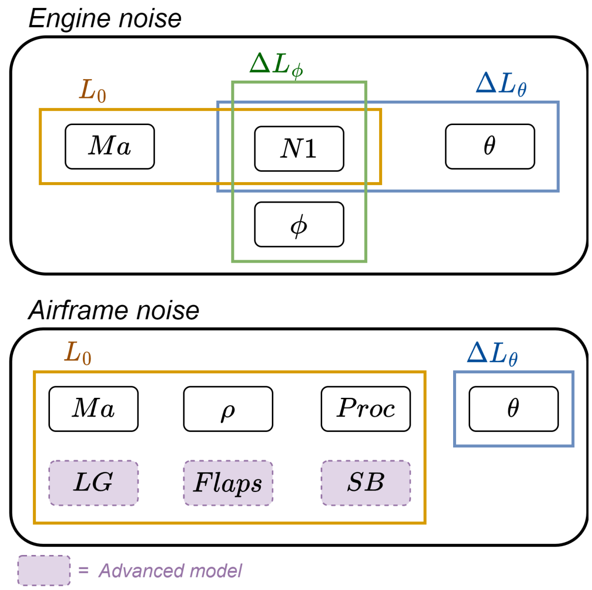


Fig. 2 sonAIR input parameters

2. Regression model

Before regression models are created, the dataset is split into two subsets. The first subset contains data for idle engines ($N1 \leq 40\%$) and the second subset all data for engines on-load ($N1 > 40\%$). The former includes only approaches, the latter both approaches and departures. This separation of the dataset allows for the creation of two different regression models: one for airframe noise and one for engine noise.

The airframe noise model consists of a source term (L_0) and a radiation term (ΔL_θ):

$$L_{em,afm}(f) = L_{0,afm}(lMa, l\rho, Flaps, LG, SB, Proc) + \Delta L_{\theta,afm}(\theta), \quad (1)$$

with $lMa = \log_{10}(Ma)$ and $l\rho = \log_{10}(\rho/\rho_0)$. This transformation of input variables is done to ensure a linear relation with L_{em}.

The engine noise model consists of a source term (L_0) and two radiation terms (ΔL_θ and ΔL_ϕ):

$$L_{em,eng}(f) = L_{0,eng}(Ma, N1) + \Delta L_{\theta,eng}(\theta, N1) + \Delta L_{\phi,eng}(\phi, N1). \quad (2)$$

For the reduced models, the aircraft configuration variables can no longer be used. This changes the airframe model, the engine model remains the same.

3. Model verification

In Zellmann et al. [10], the performance of the model is evaluated using the coefficient of determination R^2 and the root mean square error $\hat{\sigma}_E$. Two aircraft were selected for a detailed evaluation, the Airbus A320 and the Embraer E170. In general, a good correlation was found for the regression models, with R^2_{total} between 0.7 and 0.8 approximately. The engine model performs best, with R^2_{eng} above 0.8 for almost all frequency bands. The airframe model performs worse, with R^2_{afm} values between 0.2 and 0.6; however, it peaks in frequency ranges in which airframe noise is significant. The root mean square error $\hat{\sigma}_E$ shows similar behaviour for both aircraft, with values between 4.5 dB (low frequencies) to 3 dB (mid to high frequencies).

These results lead to the belief that sonAIR is a suitable model for predicting and assessing aircraft noise. The relevance of the model will increase if it is tested and validated for more aircraft types and airports.

4. Model validation

In a validation study by Jäger et al. [5], over 20,000 noise events around Zurich and Geneva airports were simulated and compared to measurements. The reduced and advanced models were evaluated separately. Overall, the advanced models perform well, with almost all aircraft types having a mean difference and standard deviation below values of ±1 dB and 2 dB respectively. The reduced models show an average increase in standard deviation of about 0.7 dB when compared to the advanced models. This difference may be due to the models using less information (no FDR data), both during creation and simulation.

The land cover data was identified as the most influential input parameter. Especially in urban areas, a coarse grid may not differentiate between e.g. a park and (highly reflective) buildings, which can lead to deviations.

An interesting discovery is the seasonal effect of the model accuracy. It is found that the model is quite accurate during the summer months but underestimates the noise levels in winter. Jäger et al. suspect that this may be (partially) due to the fact that all measurements used to set up the model were conducted during spring and summer.

In a comparison study by Meister et al. [11], sonAIR is compared to two other aircraft noise prediction models, FLULA2 and AEDT. It is concluded that sonAIR outperforms these two models when FDR data is available. For simulations without FDR data, all three models gave similar results. Additionally, sonAIR performs better for detailed single flight simulations.

In another validation performed by Jäger et al. [12], sonAIR was compared to measurements around Schiphol airport in collaboration with Delft University of Technology. A total of 74 overflights were measured, using a microphone array consisting of 32 microphones. The results show a mean difference of -0.4 dB, with a standard deviation of 1.1 dB. These results are a first step in demonstrating the applicability of sonAIR to different airports.

C. Doc29 noise model

The Doc29 noise model is the current best-practice method and was developed by ECAC. This approach is the result of the need for a harmonised European approach to noise modelling. The method is described in Volume 1 [13], implementation and verification are presented in Volumes 2 [14] and 3 [15], respectively. It is a modelling technique rather than a ready-to-use model. Doc29 makes use of NPD tables. These tables provide information on the relationship between the noise produced by an aircraft, its power setting and the distance to the observer.

One of the advantages of using NPD tables is that they provide a consistent and standardised method which allows for fast evaluation of the noise impact of aircraft operations. On the other hand, standardisation is also one of the disadvantages, as it may lead to more inaccuracies.

III. Data

In this research, two main sources of data are consulted. First, KLM Royal Dutch Airlines (KLM) provided FDR data for a selection of flights. This is information from on-board the aircraft, which updates every second. Second, the ANOMS software provides radar track data and measurement data. The radar track data is updated every four seconds. Measurement data is available for both flights with FDR tracks and flights with radar tracks.

A. Aircraft selection

To limit the scope of the research, the focus is put on one aircraft type. A table containing all considered aircraft can be found in Appendix A. The aircraft type that was identified as most interesting and relevant is the Boeing 737 Next Generation series (B737NG). This series entails the 737-700, 737-800 and 737-900. This aircraft is used frequently at Schiphol airport and by KLM, thus input data is widely available.

B. Position data

Data on the position of the aircraft can be described in latitude, longitude and altitude. This data is included in the FDR tracks and the radar tracks.

C. N1 determination

For the flights with FDR tracks, N1 data was included in the dataset and could thus directly be used as input. For the flights with radar tracks, N1 was determined following the method as described in Van der Grift [7]. In this method, N1 is estimated by finding the fan tone in the spectrogram of an acoustic measurement. A similar method has been used by Merino-Martínez et al. [4] and Schlüter et al. [16] [17].

D. Measurement data

The acoustic measurement data was retrieved from the ANOMS software. The main metrics used in this research are the sound exposure level (L_{AE}) and the maximum noise level ($L_{A,max}$), as both are commonly used to compare measurements with noise predictions. The measurement data also entails noise level time histories and frequency spectra for 1/3-octave bands from 16 Hz to 16 kHz.

E. Meteorological conditions

To check the validity of measurement data, meteorological conditions were obtained from the Royal Netherlands Meteorological Institute [18]. If during the hour of departure, it is raining and/or the average wind speed is too high, the measurement is discarded for this research. The upper limit for the wind speed was set at 8 m/s, since above that variability of noise levels increases [19].

Noise propagation calculations for sonAIR were carried out in *BASIC* mode, which does not account for meteorological conditions. To correct for this, the methodology as described in Appendix D of Doc29 Volume 2 [14] was used. This entails a correction for meteorological conditions that are different from ISA conditions (i.e. $T = 293.15K$, $p = 101,325Pa$ and $h_{rel} = 70\%$). This methodology makes use of the calculation corrections for atmospheric absorption as described in SAE-ARP-5534 [20].

F. Additional inputs

Two more inputs are required: a height map and a landcover map, which are used to calculate sound reflections. The height map of the Netherlands is available via the Netherlands' Cadastre, Land Registry and Mapping Agency [21]. The landcover file was downloaded through Statistics Netherlands [22].

IV. Results

The simulated results give the noise levels for each desired source-receiver combination. An example noise level time history can be seen in Figure 4, where both models are compared to NOMOS data. The 10 dBA down time line indicates the section of the curve which is used to calculate the L_{AE}. For this example, it can be seen that the sonAIR curve is approximately the same shape as the NOMOS curve. The NOMOS curve is less smooth than the model curves. Doc29 exhibits a wider curve, with longer rise and fall times of L_A. This is typical for the found measurements.

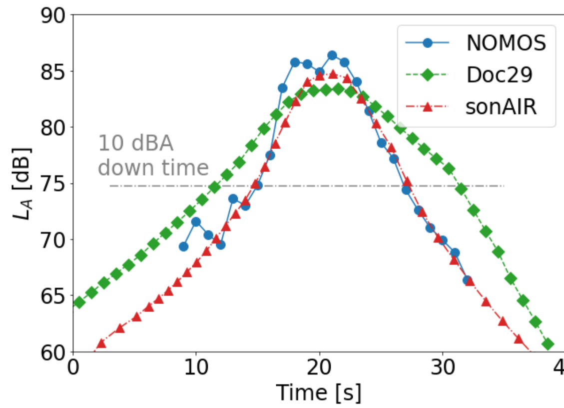


Fig. 4 Example noise level time history for B737NG departure

In this research, noise events are compared on an individual basis, mainly on their L_{AE} and $L_{A,max}$. Results are shown in the form of mean differences, which are calculated by subtracting the measurement result from the model result. The mean differences are expressed by mean values (μ) and the corresponding standard deviation (σ).

A. Noise calculations

A distinction is made between flights with FDR data and flights with radar data. All flights were departing flights.

1. Calculations with FDR data

For the flights where FDR data was available, a total of 112 events could be analysed, consisting of a mixture of 737-700 (15 events, or 13%), 737-800 (89, 80%) and 737-900 (8, 7%). The NOMOS measurement data for these events originates from eighteen different NMTs.

Figure 3 shows the comparison between L_{AE} results from sonAIR, NOMOS and Doc29 for both FDR and radar data. Looking at the FDR data, from the left plot, it can be seen that sonAIR shows fairly good agreement with measurements, with $\Delta L_{AE} = -0.28 \pm 1.57$ dBA. Doc29 results, in the middle plot, deviate more and are more scattered, resulting in $\Delta L_{AE} = 2.12 \pm 2.26$ dBA. The boxplots display the same data. The notches represent the 95% confidence interval of the median. The boxes extend from the first quartile to the third quartile. The whiskers are drawn to the data point closest to and within the 1.5 interquartile range.

The plots comparing the $L_{A,max}$ can be found in Appendix B. The maximum levels show larger underestimations for sonAIR, i.e. $\Delta L_{A,max} = -2.29 \pm 1.93$ dBA. For Doc29 there is an overestimation, with $\Delta L_{A,max} = 1.87 \pm 2.08$ dBA.

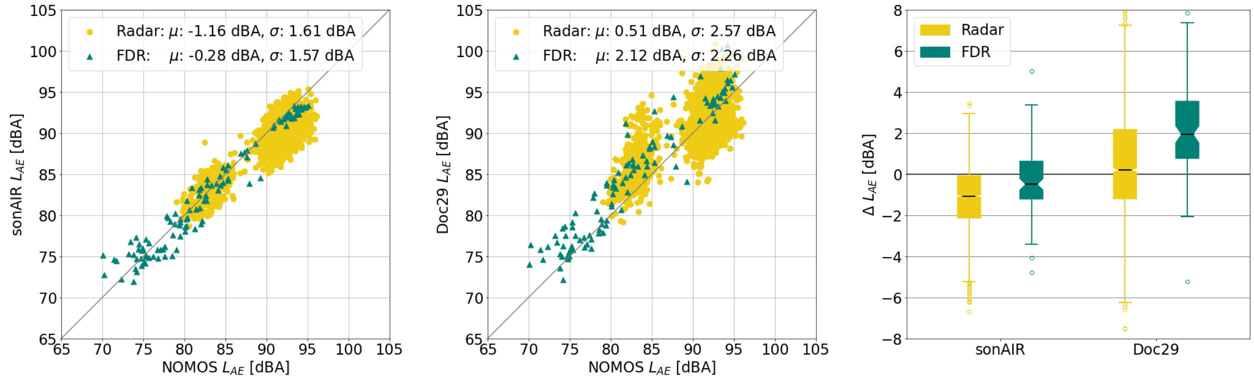


Fig. 3 Comparison of L_{AE} for B737NG departures (FDR: 112 events, radar: 2,761 events)

2. Calculations with radar data

For the flights with radar data, a total of 2,761 events were analysed, all of which were Boeing 737-800 (B738). The NOMOS measurement data was measured by NMTs 34, 40 and 94.

The L_{AE} results can be seen in Figure 3. The left plot shows for sonAIR $\Delta L_{AE} = -1.16 \pm 1.61$ dBA. The Doc29 results show a mean closer to the 1:1 line, but with a larger spread, i.e. $\Delta L_{AE} = 0.51 \pm 2.57$ dBA. The maximum levels, again presented in Appendix B, show similar results. For sonAIR this is $\Delta L_{A,max} = -2.31 \pm 2.25$ dBA and for Doc29 $\Delta L_{A,max} = 0.60 \pm 2.76$ dBA.

B. Calculation sensitivity on input parameters

The B738 radar data results were used to analyse the relation between input parameters and noise levels. The plots comparing the average N1 during the event to the L_{AE} for each event can be seen in Figure 5. For all events, the minimum distance between the aircraft and the NMT is taken and put into bins of 300 meters. A relation is found between the estimated N1 and the modelled L_{AE} for the two models and the measured L_{AE}. The p-value of all relations is smaller than 0.05 except for the 0-300 m distance bin which is 0.1 due to a limited amount of measurements.

The main observation is the big difference in slope between the Doc.29 model predictions and the measurements. The average slope is 0.37 dBA per N1 for Doc.29 in comparison to 0.12 for the NOMOS measurements. This is over three times larger. The mean slope of the sonAIR model is 0.18 dBA per N1 thus lying closer to the measurements.

V. Discussion

A. Model performance

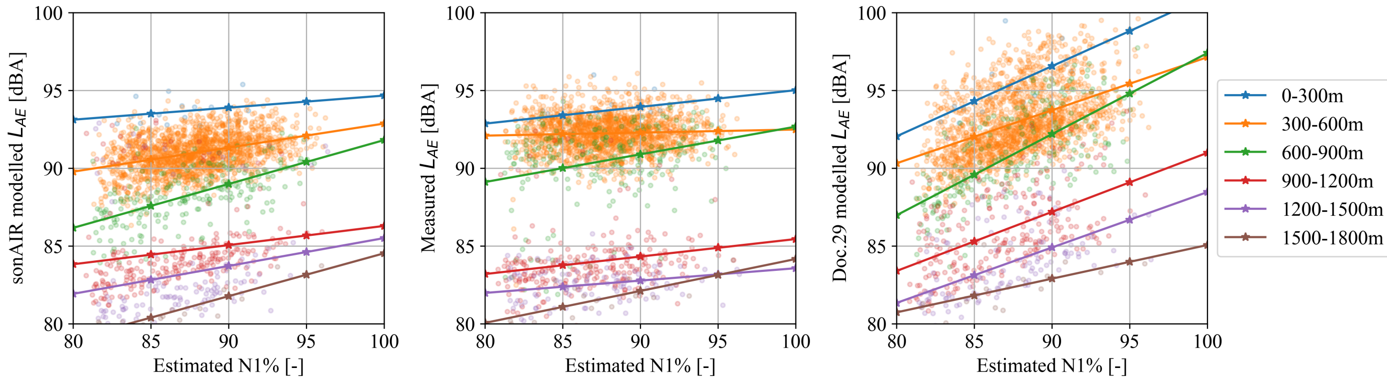
1. sonAIR

The sonAIR model results show a fairly good agreement with measurement results, although there is an underestimation of L_{AE} and $L_{A,max}$. For L_{AE}, this underestimation is around -1.1 dB, which is in accordance with previous results by Jäger et al. [5]. The explanation given in their research is that the emission model is grouped for the B737 series, rather than having a model for each subtype. This leads to inaccuracies: with an increase in size and mass also comes an increasing underestimation of noise levels. Since the radar dataset contains only B738, an underestimation of model results was to be expected.

Values for $L_{A,max}$ are underestimated more, with a mean value of -2.31 dB. In addition to the mean deviation of -1.1 dB, which is found in the L_{AE}, the effects of atmospheric turbulences, which sonAIR does not take into account, are affecting the $L_{A,max}$. According to Jäger et al. [5], this leads to an additional underestimation of the levels by about one decibel, which ultimately results in an expected deviation of approximately -2.1 dB for $L_{A,max}$.

Differences between sonAIR results and measurements show relatively low standard deviation.This indicates that the model has good precision and demonstrates the capability to accurately predict noise levels for single flight events.

Furthermore, there is better agreement for NMT 34 compared to NMTs 40 and 94. This NMT is located further from the runway than the other two, leading to lower noise levels. Looking at Figure 3, the lower left point cloud of the radar data shows results from NMT 34. NMTs 40 and 94 form the upper right point cloud. The data from NMT 34 is close to the 1:1 line, with $\Delta L_{AE} = 0.05 \pm 1.33$ dB.



(a) sonAIR results. **(b) NOMOS results.** **(c) Doc.29 results.**

Fig. 5 Relations between the estimated N1 and the modelled and measured L_{AE} for different distance bins.

2. Doc29

In general, Doc29 model results are similar to findings in previous research, with a mean difference between model results and measurements of less than 1 dB and standard deviations of around 2.5 dB.

However, it is notable that the model results obtained with FDR data deviate greatly from measurements, with a near-consistent overestimation resulting in mean values of around +2 dB for both L_{AE} and $L_{A,max}$. A similar trend is visible for $L_{A,max}$. Radar results show a better overall agreement but with a larger spread.

The standard deviations of Doc29 are relatively high, with values around 2.5 dB. Additionally, in contrast to sonAIR, the Doc29 results for NMT 34 are worse than NMTs 40 and 94.

3. Model comparison

Considering the mean values, Doc29 shows better performance than sonAIR in each case, with an exception for L_{AE} values with FDR data; however, the underestimation of mean values by sonAIR can be attributed to the grouping of emission models. Additionally, while sonAIR tends to underestimate noise levels, Doc29 generally overestimates them, leading to larger differences between the two models. This is particularly visible for the FDR dataset. Remarkably, the mean $L_{A,max}$ value for sonAIR shows a 2.34 dB underestimation, whereas Doc29 overestimates by 1.82 dB.

The standard deviation of sonAIR is consistently lower, by up to 1 dB. Reducing the variability between measurements and model results is of importance, especially for modelling on a single flight event level. This lower standard deviation indicates more reliable noise predictions than Doc29 on the single flight event level.

B. Input data quality

The two main data sources for position data provide inputs of different quality. To determine the effect of this difference, the flights for which FDR data was available were also simulated using radar data. Boxplots showing the ΔL_{AE} results for both simulations are shown in Figure 6.

It can be seen that sonAIR results benefit from the higher quality of FDR inputs. This effect is not apparent in Doc29 results, for which the standard deviation is similar but a larger mean difference is found.

FDR data provide better results for sonAIR, but it is also scarcely available. Radar data on the other hand is more widely available. Since it is important to analyse sufficient events, radar data is a viable alternative when FDR data is not at hand.

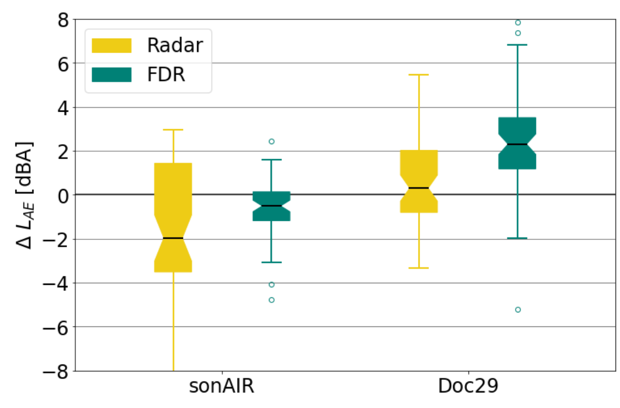


Fig. 6 Boxplots showing ΔL_{AE} for flights simulated with FDR data and radar data

C. N1 relation

In sonAIR, the relation between N1 and engine noise is modelled by a quadratic function, which assumes noise levels to increase with N1. A similar assumption is made in Doc29, albeit a linear increase. This linear increase of noise with N1 is evaluated in Figure 5 and it is found that the current Doc.29 model overestimates this dependency. For the N1 range of 80-100%, an increase of 2.4 dBA is measured, while the model predicts a 7.4 dBA increase. The relation found in the sonAIR model matches the measurements more closely, although still, a small overestimation of 0.06 dBA per N1 (1.2 dBA per 20 N1) is visible.

For the example plot of the larger range of N1 values (20% - 100%) in Figure 7 (adapted from Zellmann et al. [10]), it can be seen why a quadratic relation was assumed for sonAIR. For this N1 range, it seems to be a good and robust fit. Looking at N1 values above 80% only, this fit might lead to the above-mentioned overestimation, as low N1 values are weighted strongly. To better represent the N1-noise relationship in this range, a different regression approach might be more suitable.

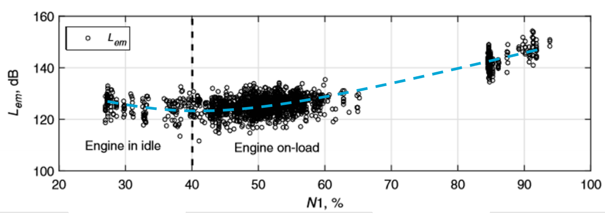


Fig. 7 N1 versus emitted noise for the A320 at 100 Hz. (Adapted from Zellmann et al. [10])

VI. Conclusions and Outlook

In this research, the sonAIR noise model was compared to NOMOS measurements and the current best-practice modelling approach, Doc29, for the Boeing 737 Next Generation series at Schiphol airport. The results demonstrate that sonAIR provides more precise predictions of noise levels on the single flight event level than Doc29. Additionally, this study shows agreement with results from a previous validation study in Zürich, thereby confirming the applicability of sonAIR to another airport.

For further research, more aircraft types can be analysed to examine the versatility of sonAIR. The relation between N1 and noise levels for high N1 values should be explored further. Additionally, the differences in maximum noise levels require further attention.

Although sonAIR provides more precise predictions than Doc29, improvements can still be made. Further measurements to update and refine the emission models are recommended, including separate models for aircraft subtypes, to improve the accuracy of noise predictions.

This research contributes to better aircraft noise prediction. Improvements in this field will have important implications for noise management around Schiphol Airport and other airports worldwide, ultimately leading to a better quality of life for communities affected by aircraft noise.

Appendix

A. Aircraft selection

The table containing all considered aircraft is presented in Table 1.

Table 1 Aircraft selection

Aircraft type	sonAIR	Schiphol	KLM
Airbus A320 family	Adv.*	Yes	No
Airbus A330 family	Adv.*	Yes	Yes†
Airbus A340 family	Adv.*	No	No
Airbus A380 family	Red.	Yes	No
BAe Avro RJ-100	Adv.	No	No
Boeing 737 Series	Red.	Yes	Yes
Boeing 747 Series	-	Yes	Yes
Boeing 767 Series	Red.	No	No
Boeing 777 Series	Adv.*	Yes	Yes
Boeing 787 Series	-	Yes	Yes
Bomb. CRJ-900	Red.	No	No
Falcon 7X	Red.	No	No
Embraer 175	Red.	Yes	Yes‡
Embraer 190	Red.	Yes	Yes‡
Fokker 100	Red.	No	No

**Advanced model available for some types*
†Equipped with different engines than the sonAIR model
‡KLM Cityhopper

B. B737NG maximum levels

The $L_{A,max}$ results for the B737NG can be seen in Figure 8.

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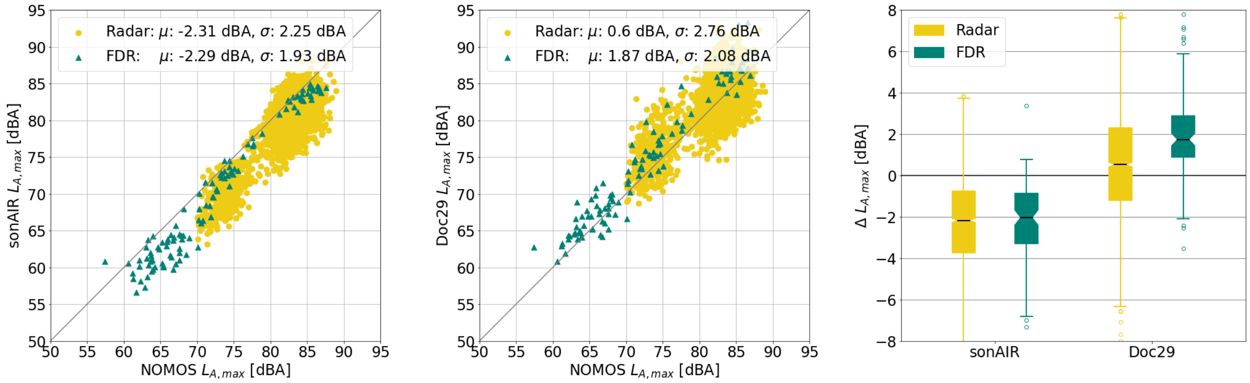

Fig. 8 $L_{A,max}$ **comparison for B737 series departures (FDR: 112 events, radar: 2,761 events)**

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