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AN ASSESSMENT OF AIRCRAFT NOISE MEASUREMENTS AROUND SCHIPHOL AIRPORT FOR THE PERIOD 2006 - 2022

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The growth shown by the aviation industry has given significant economic benefits, but also causes disturbance to communities living near airports, including annoyance and potential health problems due to the high aviation-induced noise levels. Therefore, regulations are implemented by imposing limits on the yearly cumulative noise levels at specific locations around airports. This requires understanding and prediction of the varying aircraft noise levels. This is traditionally achieved by using so-called best-practice or regulatory models, such as the Dutch aircraft noise model, which require low computational costs and limited model inputs. This way of noise monitoring comes with significant model approximations and hence potential deviations of the model predictions from the actual noise levels. The limitations of this current approach has given rise to distrust in communities near airports. Hence, the models need to be validated against real measurements, for which use is made of the stations from the Noise Monitoring System (NOMOS) around Schiphol Airport. In this contribution, we analyzed the time series of the yearly averaged L_{den} measured at 35 NOMOS stations for the period from 2006 to 2022. A distinction is made between noise from aircraft and that due to other noise sources. We observe a decreasing trend of 0.52 ± 0.04 dB(A)/year in L_{den} for the investigated time period. One of the objectives is to determine how the measured L_{den} can be assigned to the various aircraft types in the fleet at Schiphol. This is performed by an L_{den} time series analysis of the averaged time series over all stations, combined with changes in the fleet composition. The results from the unconstrained least squares (LS) and non-negative least squares (NNLS) methods are presented and compared. Based on the obtained model for 2006-2020, predictions are performed for 2021 and 2022.

Keywords: Airport noise monitoring, Day–evening–night average level (Lden), NOMOS measurement system, Time series analysis, Fleet composition Schiphol, Non-negative least squares (NNLS) modeling

1. Introduction

Since its start, the impressive growth of the aviation industry has resulted in significant economic benefits. This advantage comes at the price of high and increasing aviation-induced noise levels, resulting in annoyance and health problems [1, 2, 3]. Together with air pollution and adverse climate effects, these increased environmental noise levels are considered an important threat to the health of the population. Consequently, communities near airports demand reductions in aviation activities. The concerns are widely recognized and measures to counteract the aviation-induced noise are taken by aircraft manufacturers, airliners and airports. There are continuous efforts to make aircraft quieter, e.g. by increasing the bypass-ratio of the turbofan engines and applying acoustic lining [4]. In addition, flight procedures and operations producing less noise in populated areas have been established. The implementation of these measures is enforced through charges and regulations (see [5, 6]).

These regulations are such that hard limits are imposed on the yearly cumulative noise levels at various locations around airports. These noise levels are traditionally calculated using best-practice models or regulatory models. Such models are based on legal compliance requirements, such as described in Document 29 of the European Civil Aviation Conference (ECAC) ([7]), and are capable of calculating noise contours around airports with low computational cost and limited model inputs. The resulting contours, representing the noise impact of aircraft operations over large areas and e.g. for a full year, are typically employed to check compliance with noise limits and to estimate future aircraft impacts.

Various noise metrics can be used to measure annoyance [8]. For current regulatory purposes aircraft noise contours using the L_{den} metric are mainly considered. L_{den} stands for the (yearly-averaged) day-evening-night average values and will be described in section 2. Noise monitoring using best-practice models, which inherently employ significant approximations, can result in deviations of the model predictions from the actual noise levels, which, in turn, has given rise to distrust in communities near airports [9]. Validation of these models against real measurements can potentially reduce this distrust [10].

We present a fully empirical analysis of the noise levels measured around Schiphol airport for the period 2006-2022. Use is made of the L_{den} noise metric as obtained from the NOMOS measurement system. The results presented in this paper are part of a bigger research program where, among other things, the experimental data analyzed here is used for validation of the best-practice models. Such model-data comparisons are not presented here. However, in this contribution we describe the development of an empirical model that relates the measured L_{den} trend with the changing fleet composition at Schiphol Airport.

The paper is organized as follows. Section 2 briefly describes the NOMOS measurement system, noise data and fleet composition. We also explain the L_{den} metric. In section 3 the least squares and outlier removal methods are briefly reviewed. Section 4 presents the results. The section starts with a time series analysis of the measured yearly-averaged L_{den} data, making a distinction between noise due to aircraft and the total noise measured. We then present the results of the empirical model, correlating the measured L_{den} trend with the various aircraft types in the fleet at Schiphol over time. The model is trained for the period 2006-2020 and is used to predict the situation for 2021 and 2022. Section 5 summarizes the results.

2. NOMOS system, noise data and fleet composition

This study uses data available at the website (European Aircraft Noise Services, [11]), which provides yearly-averaged L_{den} values obtained from the Noise Monitoring System (NOMOS) installed around Schiphol Airport. The NOMOS system consists of more than 40 measurement stations positioned in the Schiphol area, see Figure 1.

Basically, each station is a calibrated microphone mounted on a 6-10 m high mast, which is either

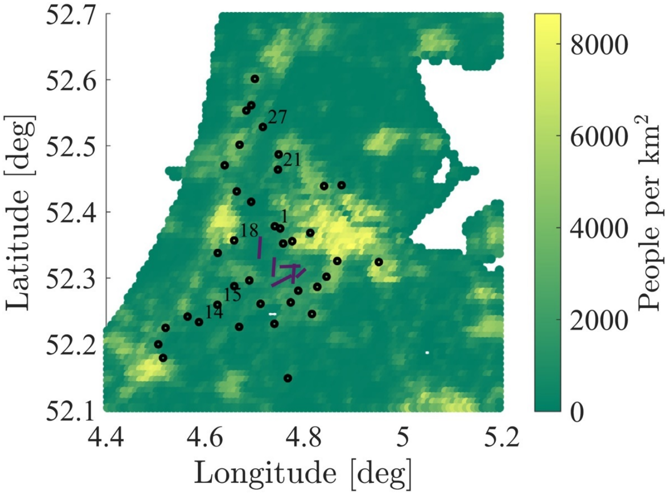

Figure 1: Distribution of NOMOS measuring stations around Schiphol Airport for noise analysis [10].

connected on a roof of a building or just on the ground. The microphones continuously measure the noise in the environment. We consider the yearly-averaged L_{den} data from the above mentioned website for the period 2006-2023. The L_{den} noise metric is defined as [12]

$$L_{den} = 10\log_{10}\left(\sum_{i=1}^{N_d} 10^{\frac{\mathrm{SEL}_i}{10}} + \sum_{j=1}^{N_e} 10^{\frac{\mathrm{SEL}_j+5}{10}} + \sum_{k=1}^{N_n} 10^{\frac{\mathrm{SEL}_k+10}{10}}\right) - 75 \tag{1}$$

with N_d, N_e and N_n the number of detected aircraft noise event during day-time (07:00-19:00), evening-time (19:00-23:00) and night-time (23:00-07:00), respectively. SEL_i, SEL_j and SEL_k are the corresponding Sound Exposure Levels of the day-time, evening-time and night-time events, respectively. The normalization term -75 dB(A) originates from the number of seconds in one year. The L_{den} metric has units dB(A). The Sound Exposure Level of a noise event, e.g. from an aircraft, is given as

$$SEL = 10\log_{10}\left(\int_0^T 10^{\frac{L_A(t)}{10}}\mathrm{dt}\right) \tag{2}$$

with $L_A(t)$ the measured instantaneous A-weighted sound pressure level during the event. The integration time T is chosen such that it covers the time interval during which $L_A(t)$ is not more than 10 dB(A) below the maximum value $L_{A,max}$. T is then known as the 10 dBA down-time. As mentioned in the introduction, contours of L_{den} (and L_{night}) are calculated using best-practice models for the area around an airport. Typically, L_{den} values lie in the range 40 – 70 dB(A).

To link the above L_{den} data to aircraft types, we need details on the number of aircraft types over the years. There are in total $p = 13$ classes of aircraft types over $m = 17$ years from 2006 to 2022 (with no aircraft composition data available for 2023). These classes are derived from larger fleet categories, namely Boeing 737 (2 classes), Airbus narrow body (3 classes), Embraer and Fokker (4 classes), and Boeing wide body (4 classes). As indicated in Fig. 2, we will exclude two aircraft classes, 320neo and E295, due to insufficient data as they are recent additions to the aviation transport sector, considering in total $p = 11$ classes.

3. Least squares method

The time series measurements are the yearly-averaged L_{den} in dB(A) of the NOMOS stations. Two linear models of observation equations, as represented by Eq. 6, will be used to conduct the L_{den} time

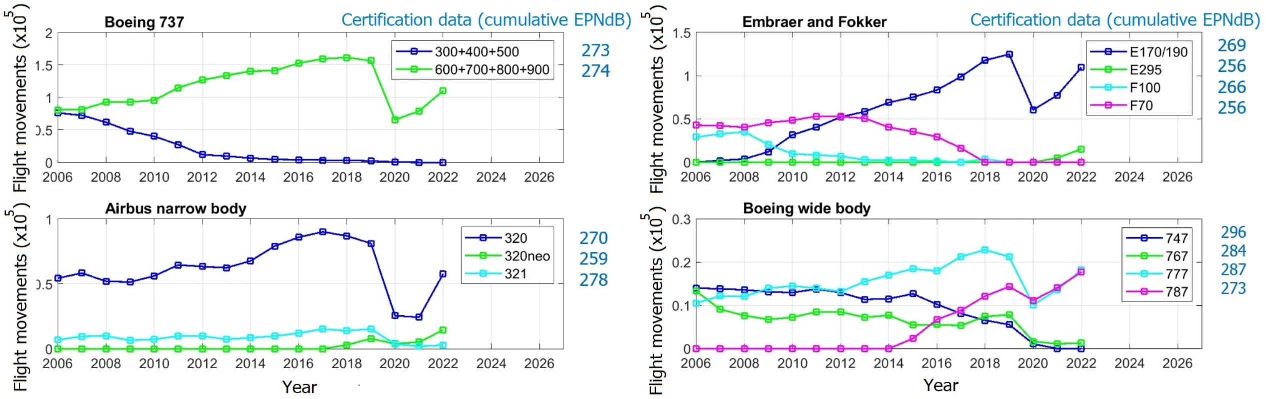

Figure 2: Number of aircraft, classification and certification data around Schiphol Airport for the period of 2006-2022. We use 11 essential classes, omitting recent additions 320neo and E295 due to insufficient data.

series analysis. The first model is just the linear regression model as

$$L_{den}(t) = L_0 + r\,t \tag{3}$$

where L_0 is the intercept and r is the rate. This leads to the i^{th} row of the design matrix as $A_i = [1 \;\; t_i]$, where $i = 1, ..., m = 17$. The results presented in section 4.1 are based on the above linear model.

The results of section 4.1 will indicate a decreasing trend in the observed L_{den} data. We therefore aim to investigate a possible correlation between the observed trend in the measured L_{den} over the years with changes in fleet composition at the airport. A question arises regarding the extent to which the observed noise reduction can be attributed to the quantity and quality (indicated by certification data) of the most commonly used aircraft types taking off and landing at Schiphol. To establish a linear model of observation equations, for L_{den}, we may write

$$L_{den}(t) = \alpha_0 + \alpha_1 N_1(t) + ... + \alpha_p N_p(t) \tag{4}$$

where $N_i(t)$ is the number of aircraft type i, $i = 1, \ldots, p = 11$ for the given period from $t = 2006$ to $t = 2022$ (see Fig. 2). The above equation leads to the i^{th} row of the design matrix as

$$A_i = [1, \;\; N_1(t_i), \;\; ..., \;\; N_p(t_i)] \tag{5}$$

where i runs from 1 to $m = 17$.

The above linear relationships (Eqs. 4 and 3) can be rewritten in a compact matrix form using the following linear model of observation equations:

$$y = Ax + e, \;\; D(y) = Q_y \tag{6}$$

where y is a vector of m observations (L_{den} values), e is a vector of m residuals, x is a vector of n unknowns (coefficients α_i, $i = 0, 1, ..., p$), and A is an $m \times n$ design matrix ($n = p + 1$), and Q_y is the given $m \times m$ covariance matrix of observations y. The parameters x are assumed to be unknown and will be estimated using the least squares method [13]. In this paper, we provide the results of two least-squares-based methods tailored for our application, which include the unconstrained Least Squares (LS) and Non-Negative Least Squares (NNLS), see [14].

The least squares estimate of the unknown parameters x is

$$\hat{x} = \left(A^T Q_y^{-1} A\right)^{-1} A^T Q_y^{-1} y \tag{7}$$

with the covariance matrices

$$Q_{\hat{x}} = \left(A^T Q_y^{-1} A\right)^{-1} \tag{8}$$

which describes the precision of the estimates $\hat{x}$.

We use the w-test statistic to identify possible outliers in the time series [15]. A null hypothesis H_0, expressing that the data is not an outlier, is usually formulated against m alternative hypotheses corresponding to m observations, expressing that they are outliers. If the covariance matrix of observables is diagonal ($Q_y = \sigma^2 I_m$), with σ^2 the known variance of the data, the w-test statistic becomes

$$w_i = \frac{\hat{e}_i}{\sigma_{\hat{e}_i}} \tag{9}$$

with $\hat{e}_i$ the least-squares residual i and $\sigma_{\hat{e}_i}$ its standard deviation, for $i = 1, \ldots, m = 17$. This test statistic can be tested within a given confidence level $1 - \alpha$. The above test statistic follows a standard normal distribution under the null hypothesis H_0, expressing that the data is not an outlier.

4. Results and discussion

4.1 Observed trends in measured L_{den}

In this section we present results for the individual NOMOS stations and for their average over all stations. The yearly-averaged L_{den} for aircraft noise only, for the period 2006-2023, is shown in Figure 3 for NOMOS stations 2 and station 21 as two representative examples.

A linear least-squares fit (Eq. 3) applied to the data shows that in these cases a significant decreasing trend (i.e. negative slope) is obtained. As observed from the figures, we suspect that some of the data points might be affected by some (unknown) extraordinary large error. Therefore, we also applied outlier removal using the method described in the previous section. As indicated in the figures, the updated slope (green dashed line) can significantly deviate from the original one (dashed black line).

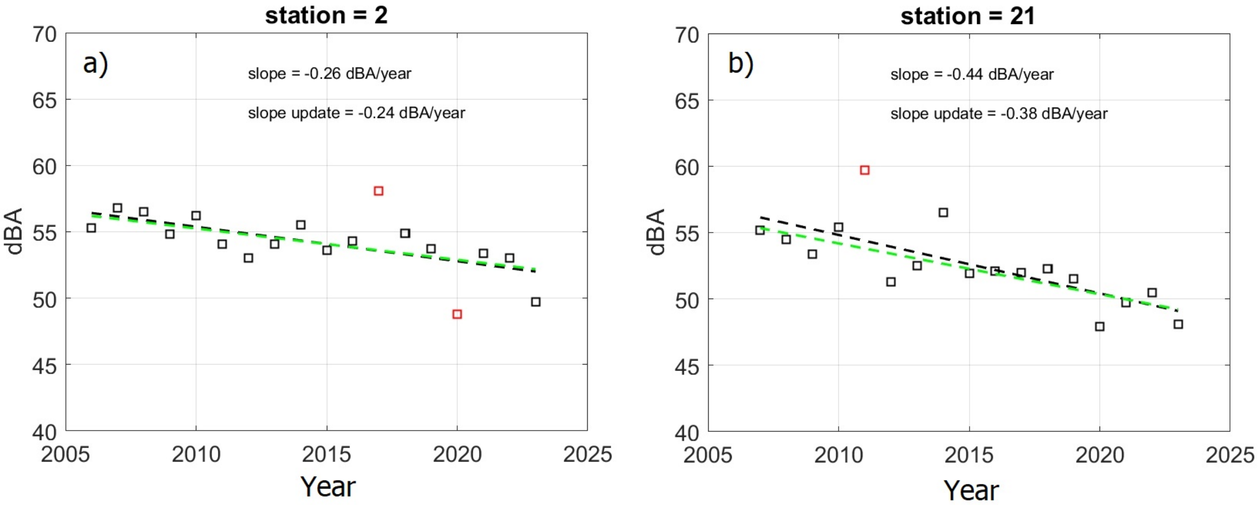

Figure 3: Linear least-squares fit and outlier removal for two typical NOMOS stations (2 and 21).

The (updated) slopes obtained for all NOMOS stations are mapped in Figure 4a. It is observed that for nearly all stations a negative trend is obtained, except for 2 out of 40 stations (yellow circles). For comparison a map of the obtained slopes for the total noise measured is shown in Figure 4b. For the total noise (i.e. background noise plus aircraft noise) a considerably larger number of stations exhibit a

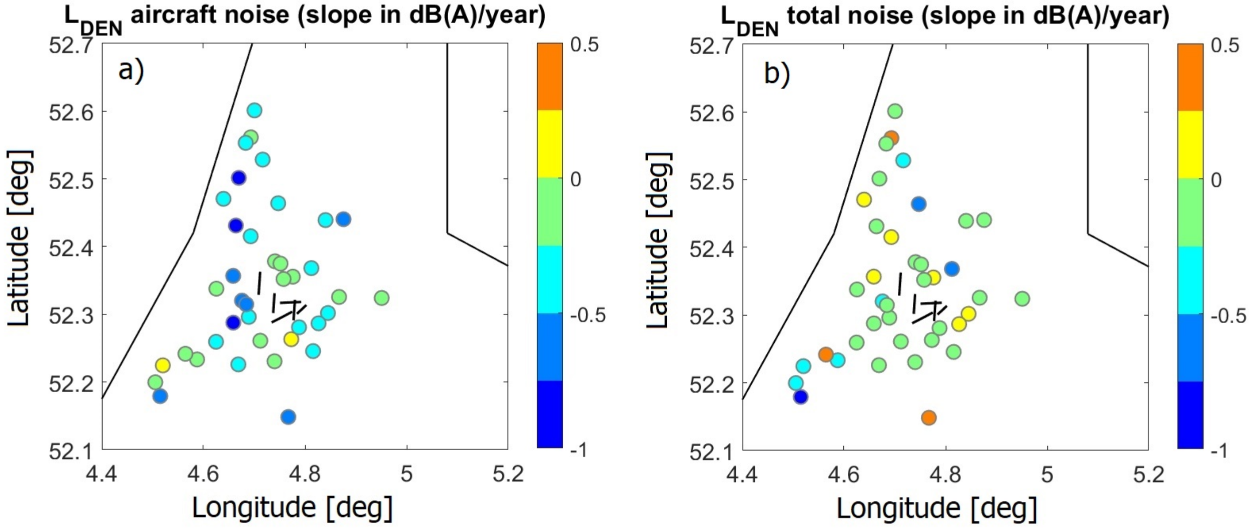

Figure 4: Scatter plot of estimated slopes for all NOMOS stations after least squares fit and outlier removal; aircraft noise (left), total noise (right).

positive trend, with the negative trends being less prominent compared to those observed for the aircraft noise alone (see Figure 4a).

This result is also observed when the data are presented in a different way. In Figure 5 we show all measured yearly-averaged L_{den} data in one graph, together with the L_{den} data per year, averaged over all NOMOS stations. The averaged data are linearly least-squares fitted (Eq. 3). The estimated slope of the averaged data and its precision is $\hat{r} \pm \sigma_{\hat{r}} = -0.52 \pm 0.04$ dB(A)/year, i.e. a decrease in L_{den} of almost 9 dB(A) for the period 2006-2023. The estimated trend is not only statistically significant but also substantial. For example, a 3 dB(A) decrease in L_{den} for aircraft noise corresponds to a reduction of a factor of two in number of flight movements when we assume the aircraft in the fleet are the same, i.e. having the same loudness.

For comparison, similar results for the total noise are also shown in Figure 5. Now the slope and its precision turns out to be $\hat{r} \pm \sigma_{\hat{r}} = -0.17 \pm 0.04$ dB(A)/year, i.e. a decrease in L_{den} of 3 dB(A) for the period 2006-2023. Note that, on average, the L_{den} for total noise is more than 10 dB(A) higher than the L_{den} for aircraft noise alone. This means that the contribution of background noise, i.e. all noise other than that due to aircraft, to the L_{den} for total noise is dominant ([10]). The origin of the observed L_{den} trend for aircraft noise is believed to be due to changes in the fleet composition at Schiphol, at least for a substantial part (see section 4.2). The origin of the observed L_{den} trend for total noise is less obvious and might be due to a decrease in background noise, the decrease in aircraft noise (as it is still present in the total noise) or a combination of both. Also, a decrease in microphone sensitivity due to overdue maintenance can play a role (see e.g. [16]).

4.2 Establishing an empirical predictive model

To attribute the estimated negative trend in the yearly-averaged L_{den} (Fig. 5) aircraft noise to the fleet composition at Schiphol, we establish an empirical model between measured L_{den} trend and fleet composition over time. This indicates that if we know the number and composition of the aircraft types operating around Schiphol airport, we can predict the L_{den} associated with those aircraft.

We establish a linear model $y = Ax + e$ using the model in Eqs. (4) and (5). There are in total $p = 11$ classes of aircraft types (see Fig. 2), and measurements for $m = 17$ years from 2006 till 2022. The design matrix A is of size $m \times n = 17 \times 12$. We aim to train and implement a predictive model. The 17 data points are split into 'estimation' and 'prediction'. The estimation process is the training step (based on

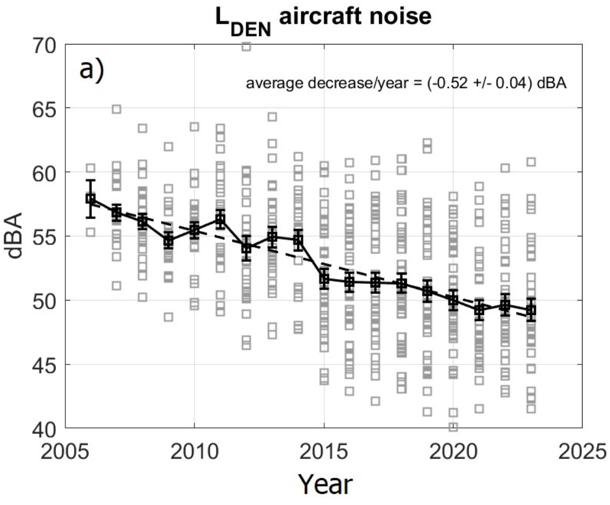

Figure 5: Comparison between trends in aircraft (a) and total (b) noise levels over the time period 2006-2023.

historical data), and the prediction is the testing step (to test the performance of the prediction). We use 15 data points (from 2006 to 2020) for training and use the data of 2021 and 2022 for prediction (testing), so a two-year ahead prediction.

The results are presented in Fig. 6. Although the prediction results for the first year (2021) exhibit consistency between the two methods, disparities arise in the predictions for the subsequent year (2022). Notably, the NNLS prediction outperforms the unconstrained LS method. This offers new opportunities and potential challenges for future studies on L_{den} noise monitoring around airports.

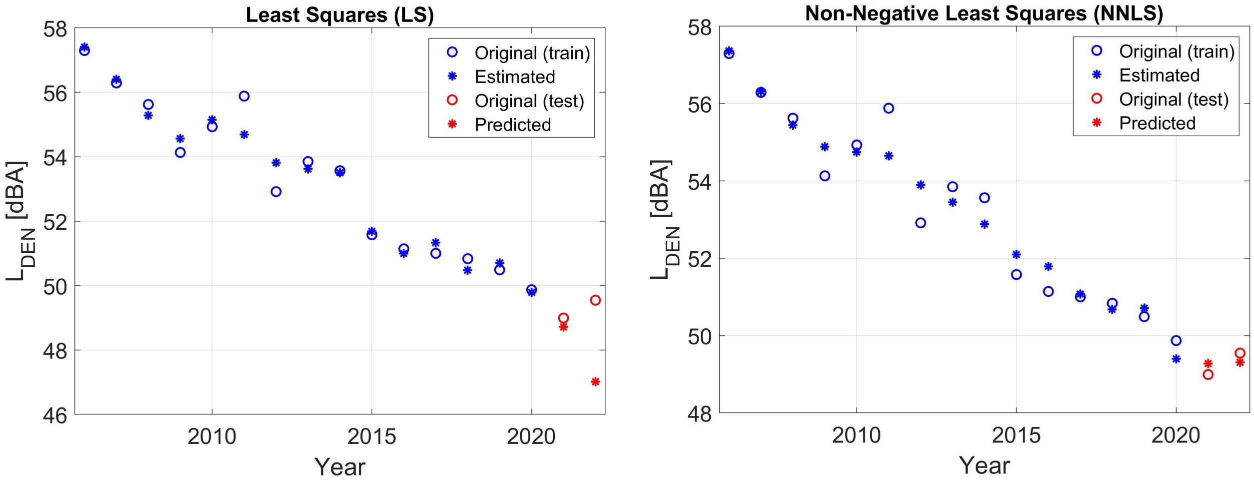

Figure 6: L_{den} data estimation and prediction performance using LS (left) and NNLS (right) methods.

5. Conclusions

The aviation industry's growth yields substantial economic benefits but also poses challenges for communities near airports. To implement noise monitoring, traditionally, noise predictions are based on models like the Dutch aircraft noise model. However, these models, though cost-effective and requiring limited inputs, entail significant approximations, leading to deviations from actual noise levels. This discrepancy has fostered distrust among airport communities, necessitating validation against real measurements from e.g. the Noise Monitoring Systems (NOMOS). We analyzed NOMOS data from 2006 to 2023, observing a decreasing trend in yearly averaged L_{den}. We also assigned measured L_{den} to aircraft types at Schiphol Airport using the least squares methods including the non-negative least squares (NNLS). The prediction results of NNLS were promising, requiring further investigation in future studies.

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