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A statistical evaluation on flight operational characteristics affecting aircraft noise during take-off

Paolo Gagliardi[a], Luca Teti[b], Gaetano Licitra[c,d,*]

[a] Department of Physics, University of Siena/CNR-INSEAN, Via di Vallerano 139, 00128 Roma, Italy
[b] IPOOL Srl, Via Cocchi 7, 56121 Pisa, Italy
[c] ARPAT – Environmental Protection Agency of Tuscany Region, Area Vasta Costa, Via Marradi 114, Livorno, Italy
[d] CNR-IPCF, Via Moruzzi 1, 56124 Pisa, Italy

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ABSTRACT

Aircraft noise immission level during the initial phase of take-off is influenced by several parameters, which often produce a significant fluctuation on measured noise levels at the noise monitoring terminal. This fluctuation is not only due to the different aircraft involved in the process, but it is also strongly dependent on the operational settings and characteristics of each take-off, even when the same aircraft type is analysed. The goal of this study is to investigate the relationships between the operational characteristics of flight departure and aircraft noise by means of a statistical approach in order to identify the parameters on which pilots could take action for noise-reduction purposes. The operational settings considered in the present work include actual take-off weight and ground run distance, lift-off aircraft ground speed and ground speed during the initial climb phase. Other variables, for instance source-receiver distance and weather conditions, such as air temperature, air density and headwind were also included in the analysis. The above mentioned parameters of B737-800 flight-departures were collected respectively during 15 days of July 2015 and September 2016. The data collected during the first session is the training set, while the second sample is the test set. Each sample of both datasets was joined with the corresponding noise level provided by the noise monitoring network. Principal Component Analysis and Multiple Linear Regression were performed in order to derive a simplified predictive noise model at a specific point on the ground. This method produced a good Sound Exposure Level estimation. The findings may also be useful to point out the operational characteristics causing the noisiest aircraft flyovers. Consequently, scheduled flight departures could be re-organized by introducing departure-direction and/or departure performance restrictions in order to minimize noise impact on the urban areas.

1. Introduction

Reduction of noise pollution is currently considered one of the most important challenges to be faced in order to ensure a high standard of living for the population in an urban context. The rising influence of globalisation has brought to an increasing need for mobility causing a sharp increase in the usage of air transport. Therefore, noise from airport operations plays a central role in noise concerns of the community. Several studies have indicated that a prolonged exposure to aircraft noise can be directly related with health issues such as cardiovascular diseases [1–5], children impairment [6–8], general annoyance [9,10] and sleep disturbance [11–13]. Flight events generally produce high levels of noise that are also associated with hearing loss [14].

Although significant progress has been made in terms of aircraft noise mitigation, the need to develop and apply new measures to limit its adverse effects persist. The efforts of researches focused on the reduction of aircraft noise at the source have seen considerable progress in the last 60 years with the introduction of quieter propulsion systems accordingly with the ICAO-aircraft-certification classification [15]; moreover, new noise control devices and aerodynamic improvements have been gradually introduced. These developments have led to a noise-emission decrease of about 20 EPNdB [16]. NAMs (Noise Abatement Measures) include specific restrictions for aircraft that are certified in accordance with Chapter 2 and 3 of ICAO Annex 16, Volume I. In the last years many airports have introduced several NAMs which consist, among other things, in Noise Abatement Procedures (NAPs), ground operating restrictions, sound insulation and noise charges as specified in [17,18] and [19]. In particular, NAPs refer to the aircraft noise reduction along the propagation path while sound insulation is normally performed at the receiver. All these measures follow the well-

* Corresponding author at: ARPAT – Environmental Protection Agency of Tuscany Region, Area Vasta Costa, Via Marradi 114, Livorno, Italy.
E-mail address: g.licitra@arpat.toscana.it (G. Licitra).

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known "Balanced Approach" scheme developed by ICAO and re-proposed in the Regulation 598/2014 [20]. Furthermore, noise mapping can be indirectly included in this scheme due to its primary role in the noise action plan development [21]. Noise mapping is a fundamental tool to monitor and predict environmental noise impact generated by airport operations. Noise maps can be produced by means of aircraft noise models [22,23]. These models are normally based on empirical and/or semi-empirical equations [24,25]. Sound emission of the source and sound propagation from the source to the receiver are considered in order to predict noise at a predetermined reference point. With the aid of good-quality input data and for a large sample of aircraft movements corresponding to a typical day based on a yearly average, such models are able to produce accurate representations of the sound level distribution in a given space, even though they can lose prediction accuracy when single flight events are considered as observed in [26]. In fact, aviation noise is a complex subject due to the variability of a large amount of parameters which affect sound generation and propagation. In order to increase the prediction accuracy of the models, above all track radars data are not available, ADS-B (Automatic Dependant Surveillance-Broadcasted) data can be helpful as shown in [27,28]. The information contained in these data are essentially related with aircraft position, velocity and identification.

The purpose of the present work is to provide a simple model for predicting aircraft noise single event in a given reference point by considering ADS-B data as input and taking into account some specific flight-operational characteristics that have prominent effect on noise impact on the ground. The main task of this model is providing to the stakeholders an easy tool based on easy to find flight parameters for a quickly and preventive selection of the noisiest aircraft.

Principal Component Analysis (PCA) [29] has been applied on the independent variables (ADS-B data, aircraft weight and weather parameters) in order to give a qualitative interpretation of their mutual correlations, to reduce the dimensionality of the problem as suggested in [30] and, above all, to avoid multicollinearity. Subsequently, a Multiple Linear Regression (MLR) on the selected principal components has been performed in order to estimate the aircraft noise generated by take-off events.

General information about noise data and ADS-B data collection is presented in detail in Section 2 together with the statistical method discussed above. Section 3 provides the results achieved by performing this classical linear-estimation and includes the results of the validation of the model using a second dataset as test set; the practical utility of this model and noise issue derivations are also highlighted (Section 4). Conclusions and suggestions for future developments based on this work are emphasized in Section 5.

2. Methodology

2.1. Background information

The analysis is based on aircraft noise and track data collected at the Pisa "Galileo Galilei" International Airport. This airport is located along the coast at about 2 km from the city centre of Pisa. Even though the airport consists of two runways, flight departures and approaches occur in the totality of cases from the main runway named 04R-22L. Information about track data and flight performances is provided by an ADS-B system compensating the non-availability of the most common radar tracks [28]. The noise monitoring network consists of 5 stations all equipped with type-1 sound level meters, which are periodically calibrated: 3 of them (P1, P2 and P4) are located almost exactly along the projection of the typical route of take-off from 04R runway (i.e. towards the city, NNE direction), although station P1 is currently out of order.

Due to the small distances occurring between the main runway and the region of interest taking into account in the present work, the initial flight path can be considered straight and the lateral dispersion of the backbone track negligible (see Fig. 1). More details of Pisa airport can be found in [27,28].

2.2. Dataset description

2.2.1. Noise data

Noise data corresponding to the Sound Exposure Levels (SELs) generated by the B737-800 aircraft flyovers and recorded by the P2 fixed-noise-monitoring terminal (installed near the airport area along the ground projection of the typical take-off path) were considered. Two different dataset of flight departures, which occurred from 04R runway, were analysed. The first set of noise data, consisting of $m = 143$ samples, was composed by a subset of the dataset already used in [28], and it was used as the training set. The second one was composed by 115 samples of noise events recorded from the 15th to the 30th of September 2016 and it was used as test set in the validation process. Each dataset included only take-off events during a period of 15 days of two different years as resumed in Table 1. The SEL of each measured event, i.e. the constant sound level that has the same amount of energy in one second as the original noise event [31], was calculated following the threshold method.[1] The obtained values were considered to be affected by a total uncertainty of $\pm$ 1.2 dB(A) as suggested in [32] and investigated in [33], by considering only the uncertainties due to the instrumentation and SEL calculation. In order to minimize variability due to difference in noise emission among aircraft type it was chosen to consider only the B737-800 aircraft model in the analysis, because its use is prevalent at Pisa airport.

2.2.2. ADS-B data, flight performance estimation and weather parameters

In order to build up the matrix X of the independent variables (or predictors) an ADS-B data elaboration was necessary. For each take-off event the variables directly derived from ADS-B data were considered together with the event-associated weather conditions. Moreover, the Take-Off Ground Run Distance (TGRD) was calculated by using the geo-coordinates provided by the ADS-B system every 0.5 second [28] and the Actual Take-Off Weight (ATOW) corresponding to the gross weight of the aircraft during the departure procedure was also collected. A total of $n = 9$ variables were used in order to describe each flight event and they are resumed as follows:

- X_1: Actual Take-Off Weight (ATOW): the aircraft gross weight at the moment of releasing its brakes;
- X_2: Take-off Ground Run Distance (TGRD): the distance covered by aircraft from the brake-release to the rotation phase;
- X_3: Headwind (HW): the component of wind velocity vector in the direction of the aircraft motion. Conventionally, headwind has positive values when its direction is opposite to the direction of the aircraft motion;
- X_4: Aircraft ground speed (V_{TO}) when the aircraft reaches the rotation point (or take-off point);
- X_5: Altitude reached by the aircraft at the end of the runway during take-off (H_{22L});
- X_6: Aircraft altitude (H_{P2}) above the ground when its flight path projection on the ground reached the minimum distance from the P2 reference point;
- X_7: Aircraft ground speed of the aircraft when its flight path projection on the ground reached the minimum distance from the P2 reference point (V_{P2});
- X_8: Air density (ρ);
- X_9: Air temperature (T).

[1] When the aircraft sound level exceeds a given threshold for a minimum of time. SEL is usually calculated by considering the time interval in which the sound level exceeds the threshold level. In this case the value of threshold consists in subtracting 10 dB(A) from the maximum value recorded with the $L_{AS,max}$ metric (the so-called "10 dB(A) down" rule).