Article citation info:
Jasiński R, Nowakowski T, Niklas J. Analysis of the variability of daily and monthly exposure to aircraft noise depending on the fleet structure – example of the 737-800 and 737 MAX 8. Combustion Engines. 0000;XXX(X):xx-xx. https://doi.org/10.19206/CE-224386

Remigiusz JASIŃSKI
Tomasz NOWAKOWSKI
Jakub NIKLAS

Combustion Engines
Polish Scientific Society of Combustion Engines

Analysis of the variability of daily and monthly exposure to aircraft noise depending on the fleet structure – example of the 737-800 and 737 MAX 8

ARTICLE INFO

Received: 8 January 2026
Revised: 27 April 2026
Accepted: 10 June 2026
Available online: 13 August 2026

Aircraft noise is one of the most significant environmental concerns around airports, generating both social conflicts and financial consequences. This study examined how the fleet composition influences daily exposure to aircraft noise in the vicinity of Poznań-Ławica Airport, focusing on two widely operated aircraft types: the Boeing 737-800 and the newer 737 MAX 8. Measurements were carried out at six monitoring points during 78 operations, and the analysis was based on the sound exposure level expressed on the physical scale and in decibels. The results show that the 737-800 consistently produces higher noise levels than the MAX 8, with mean L_{ASel} values of 0.89 Pa²·s (94.5 dB) compared to 0.57 Pa²·s (92.6 dB), a difference of 56%. The gap is particularly evident during take-off, where the 737-800 exceeds the MAX 8 by 137% (2.7 dB). Regression analysis confirmed a decreasing trend in SEL with increasing altitude; in the revised analysis, this dependence is modeled using a log-distance function in dB units, with altitude treated as a proxy for source–receiver distance. The simulation of nine fleet composition scenarios for a representative month showed that increasing the share of MAX 8 aircraft substantially reduces the number of days when the daily equivalent sound level (L_{AeqD}) exceeds the legal threshold of 60 dB. Economic analysis using official Polish penalty tariffs for 2025 also showed that monthly environmental fines could be reduced by up to 69% if the fleet were fully modernised to MAX 8. Even partial renewal, with a 60–70% share of MAX 8, reduced costs by 60–70% relative to a fleet dominated by the 737-800. These findings highlight that fleet modernisation is a highly effective strategy for reducing community exposure to aircraft noise and mitigating the financial burden on airports, although the analysis was limited to daytime operations and one seasonal period.

Key words: *aircraft noise, noise levels, noise exposure, fleet, Boeing*

1. Introduction

The increase in air traffic in recent decades has led to a growing problem of noise impacts in the vicinity of airports, alongside the harmful gaseous emissions [20]. One of the most striking examples of this phenomenon in Poland is Poznań-Ławica Airport, which has become the subject of broad public debate, numerous court proceedings, and environmental analyses regarding the exceedances of permissible noise levels in residential areas [7, 38].

The largest international airport in the region is located about 7 km west of the center of Poznań, while still within the city limits. It lies along Bukowska Street, which is also provincial road no. 307. The ICAO code of Poznań Airport is EPPO, while its IATA code is POZ [32, 38]. Both the runway and its apron, along with all airport facilities, are on flat terrain. The passenger terminal building was built at an elevation of 85–88 m above sea level, while the runway lies predominantly between 80 and 90 m above sea level.

The immediate surroundings of the airport consist mainly of residential areas with single-family houses and, to a lesser extent, of commercial and service areas. To the east of the airport, there are allotment garden complexes. To the south and southwest, a large portion of the area near the passenger terminal is occupied by large-capacity car parks for passengers. In addition, the southeast section is home to cargo and general aviation facilities.

In Poznań, in the Ławica district, as in other European airports, continuous, accredited monitoring of aircraft noise is carried out [6]. According to recent years, daily noise levels in protected zones fluctuated between 55 and 60 dB [10], with incidental exceedances of up to 5 dB above the norm. In areas not covered by statutory protection, values can locally reach 65–70 dB, although no legal limits apply there [17]. The issue of aircraft noise has generated significant social consequences, as reflected in thousands of lawsuits filed against the airport operator. In 2022 alone, residents had filed more than 1700 claims, resulting in the award of substantial compensation for loss of property value and the costs of adapting buildings to higher noise levels (e.g., installation of soundproof windows) [1]. The total amount of compensation paid by Poznań-Ławica Airport between 2014 and 2023 exceeded PLN 142 million. This sum is more than three times the amount spent by all other Polish airports combined during the same period. Until mid-2022, the basis for granting compensation was solely the location of a property within the so-called limited use area (OOU) [11]. However, a landmark Supreme Court ruling in June 2022 clarified that location within the OOU alone is not sufficient – it is necessary to demonstrate an actual decrease in property value or the incurrence of real acoustic adaptation costs [32, 38]. This case law significantly narrowed the scope of airport claims and led to a considerable decline in the number of new lawsuits.

Exceedances of permitted noise levels at measurement points also result in the imposition of administrative fines, the amount of which depends on the scale of the exceedance and the number of points [8]. The problem of aircraft noise is the subject of numerous resident complaints, as illustrated by the scale of legal proceedings. Some members of the local community participate in initiatives aimed at developing compromise solutions, such as the introduction of designated approach routes or operating bans. However, noise remains one of the main factors of social conflict surrounding the airport [2, 31].

In recent years, a clear trend has emerged in Europe toward the modernization of short-haul passenger aircraft fleets, driven both by increasingly stringent environmental requirements and by economic pressures associated with high fuel costs. Particular attention has been paid to the introduction of new aircraft variants, such as the Boeing 737 MAX 7, which, through the use of next-generation engines and optimized aerodynamics, offer substantial reductions in fuel consumption and noise emissions [5, 15].

Predictive models suggest that a 10% increase in fuel prices can accelerate fleet renewal by up to a factor of two within a 2–3-year horizon [28]. Market analyses indicate that European carriers such as Lufthansa and Ryanair are already placing significant orders for Boeing 737 MAX aircraft, and the MAX 7 variant is expected to play an important role in regional operations in the coming years. Boeing's strategy to expand the MAX family as a direct response to the Airbus A320neo is reflected in the purchase decisions of key European operators [15].

2. Methodology and research objects

2.1. Research objects

The Boeing 737-800 is a twin-engine, narrow-body, medium-range aircraft (with a range of approximately 5,500 km) belonging to the Next Generation family, the most recent variants of the 737 introduced in the late 1990s. It is capable of operating medium-haul routes, for example, holiday flights or services between European capitals. In an all-economy configuration, the aircraft can accommodate up to 189 passengers. Its cruising speed is 838 km/h, and its maximum take-off weight is 79 tons [1, 16, 22].

The Boeing 737 MAX 8 is also a twin engine, narrow-body, medium-range aircraft, with an extended range of approximately 6,500 km, developed under a program launched in 2011. The first delivery took place in May 2017 to Malindo Air of Malaysia. Compared to the 737-800, the newer model incorporates a few modern features, such as improved cabin soundproofing, larger overhead bins, and more ergonomic seating – depending on customer specifications. In addition, the manufacturer has improved aerodynamic performance, for example, by introducing redesigned winglets [1, 12, 15, 27].

Tables 1a and 1b present a comparison of the key technical and acoustic parameters (from the perspective of certification) of both types of aircraft. It includes numerical data for the Effective Perceived Noise Level (EPNdB), a parameter used to assess the environmental impact of aircraft noise. The comparison considers two selected engines: the CFM56-7B26 (installed on the 737-800) and the LEAP-1B27 (installed on the 737 MAX 8). In addition to the 1B27, the manufacturer also offers the 1B25 and 1B28 variants, which differ in terms of maximum take-off thrust. Since the 1B27 version is the most common among the aircraft studied, its acoustic parameters were chosen for the analysis.

Table 1a. Operating and acoustic parameters of CFM56-7B26 engine in respect of noise levels and noise limits [3, 19]

Aircraft type	B737-800		
Engine	CFM56-7B26		
Maximum take-off thrust [kN]	117.0		
Bypass ratio [-]	5.1:1		
Compression ratio [-]	32.7:1		
Fan diameter [m]	1.55		
Number of fans/low-pressure compressors/ high-pressure compressors/high-pressure turbines/low-pressure turbines [-]	1/3/9/1/4		
Dry engine mass [kg]	2370		
External view of the engine			
Considered maximum take-off mass [kg]	70,985		
Considered maximum landing mass [kg]	65,317		
Measuring points	Lateral [dB]	Fly-over [dB]	Approach [dB]
Noise level (EPNdB)	94.2	84.6	96.4
Noise limit (EPNdB)	96.6	91.3	100.4
Difference (EPNdB)	2.4	6.7	4.0

Table 1b. Operating and acoustic parameters of CFM LEAP-1B27 engine with respect to noise levels and noise limits [18, 19, 33]

Aircraft type	B737-MAX8		
Engine	CFM LEAP-1B27		
Maximum take-off thrust [kN]	124.7		
Bypass ratio [-]	9.0:1		
Compression ratio [-]	40.0:1		
Fan diameter [m]	1.76		
Number of fans/low-pressure compressors/high-pressure compressors/high-pressure turbines/low-pressure turbines [-]	1/3/10/2/5		
Dry engine mass [kg]	2780		
External view of the engine			
Considered maximum take-off mass [kg]	70,306		
Considered maximum landing mass [kg]	65,056		
Measuring points	Lateral [dB]	Fly-over [dB]	Approach [dB]
Noise level (EPNdB)	88.3	79.2	93.9
Noise limit (EPNdB)	96.6	91.2	100.3
Difference (EPNdB)	8.3	12.0	6.4

For comparable airport operations (without acknowledging the mass of analyzed aircraft, what was a limitation of this study), the calculated differences between the measured noise levels and the certification limits at each reference point (lateral, fly-over, and approach) are greater in the case of the Boeing 737 MAX 8: approximately 3.5 times greater at the lateral reference point, 1.8 times greater at the fly-over point, and 1.6 times greater at the approach point. Newer aircraft generations produce lower noise emissions, resulting in lower recorded sound levels and a less disruptive impact on humans and wildlife.

2.2. Methodology

The study was based on experimental data from field measurements conducted at six acoustic monitoring points located around Poznań-Ławica Airport (ICAO: EPPO). The points were placed at locations representative of residential exposure to aircraft noise and of typical operational flight paths. The spatial distribution of the measurement points relative to the airport is shown in Fig. 1.

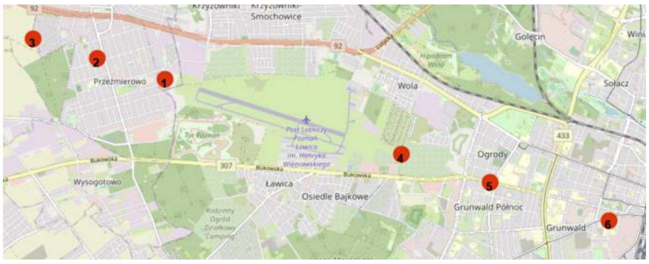

Fig. 1. Location of the measurement points in relation to the airport studied

Measurements were carried out between July and September 2024, covering 78 aircraft operations (n = 468), of which 71% involved the Boeing 737-800 and 29% the Boeing 737 MAX 8. Data were collected using a Brüel & Kjær Type 2250 class 1 sound level meter [21]. The instrument was mounted on the end of a telescopic microphone stand at a minimum height of 3.5 m above ground level, following the requirements specified in the Polish Regulation of Minister of the Environment [29], with the microphone oriented vertically upwards. All monitoring points were located at an elevation of 86.7 m (±2.3 m) and at a distance of approximately 40 m from nearby buildings or obstacles, although the exact distance varied considerably depending on the local land use (see point 4 located directly next to a residential building as an example). The tested aircraft flew over the sound level meter at a distance of up to several meters (horizontally), which depended on the adopted descent path (and which was independent of the authors). The combined uncertainty of L_{ASel} values at the measurement points ranged from 0.7 to 1.6 dB, with the dominant contribution coming from statistical variability, supplemented by wind-related uncertainty (0.1–0.5 dB for wind speeds of 1.0–5.1 m/s). Other components – including instrumental (0.5 dB), calibration (0.2 dB), microphone positioning (0.2 dB), climatic (0.2 dB), and background noise [4, 13] (0.3 dB) – were considered in accordance with the PN-ISO 1996-2 and AIR1845A standards [34], recommendations of the Polish Central Office of Measures. The overall uncertainty did not exceed 1.6 dB, allowing the results to be considered reliable.

The study was carried out in accordance with the Regulation of the Minister of the Environment (Journal of Laws, 2007), Directive 2002/49/EC, and the PN-ISO 1996-2:2019-01 standard [9, 14]. To compare the impact of the two aircraft types, only L_{ASel} levels were analyzed. This energy-based indicator enables comparisons of operations regardless of their duration or number and is also required for models used to evaluate environmental exposure. To determine both the energy and the statistical exposure levels, the L_{ASel} values were converted into physical units ($Pa^2 \cdot s$) [24].

The analysis was supplemented with selected acoustic indicators (L_{Aeq}, L50, L_{AFmax}, L_{Cpeak}, L_{AFsd}, L_{Ae}) [30, 35], as well as with an examination of mutual correlations between these indicators in physical units (Spearman rank correlation coefficient). The significance of the differences was assessed using statistical tests (Shapiro-Wilk, Student's t test and Mann–Whitney U test).

In the environmental simulations, for each monitoring point and each day of August, the equivalent daily sound level L_{AeqD} [36] was calculated using the formula:

$$L_{AeqD} = 10\log_{10}\left(\frac{1}{T_D}\sum_{i=1}^{N} E_i\right) \quad (1)$$

where: L_{AeqD} – daily equivalent A-weighted sound level [dB], T_D – number of seconds in a reference daytime between 6 a.m. and 10 p.m. (16 h, 57,600 s), N – the number of operations executed at that time, E_i – linear exposure contribution defined derived from L_{Asel} (acoustic energy of a single operation) as:

$$E_i = 10^{0.1 A_{Sel_i}} \quad (2)$$

The background energy influence was analyzed and corrected using the following formula:

$$L_{AeqD,corr} = 10\log_{10}\left(10^{0.1 L_{AeqD}} - 10^{0.1 L_{Aeq,bg}}\right) \quad (3)$$

where $L_{AeqD,corr}$ is the daytime equivalent A-weighted sound level after background correction [dB], L_{AeqD} is the uncorrected daytime equivalent A-weighted sound level [dB], and $L_{Aeq,bg}$ is the equivalent background A-weighted sound level [dB] determined for the same reference period. Background correction was therefore performed by energetic subtraction of the equivalent background contribution, rather than by adding an undefined background term inside Eq. (1).

Nine fleet composition scenarios were modeled (ranging from 100% 737-800 to 100% MAX 8, with increments of 10–20%). For each monitoring point and each day when the daily L_{AeqD} exceeded the threshold value of 60 dB, the excess was calculated in decibels, after which the financial penalty was determined according to the tariff thresholds applicable in 2025: EUR 3.92 for each dB above the limit in the 1–5 dB range, EUR 6.86 per dB in the 5–10 dB range, EUR 9.81 per dB in the 10–15 dB range, and EUR 14.71 per dB above 15 dB. This approach enabled an assessment of both the environmental and economic consequences of different fleet configurations.

3. Results

3.1. Comparison of the characteristics of both aircraft types

The general analysis (Fig. 2) showed that the mean value of L_{ASel} for the Boeing 737-800 was 0.89 Pa²·s (94.5 dB), while for the Boeing 737 MAX 8 it was 0.57 Pa²·s (92.6 dB). This difference was statistically significant (Mann–Whitney U test, $p = 0.001$). In practical terms, the 737-800 generated an L_{ASel} level 0.32 Pa²·s higher, corresponding to a 56% increase over the MAX 8, i.e., a difference of 1.9 dB.

The distribution of L_{ASel} by flight phase (takeoff/landing) is presented in Fig. 3. During take-off, the difference between aircraft types amounted to 0.52 Pa²·s (2.7 dB), while during landing it was 0.07 Pa²·s (0.8 dB).

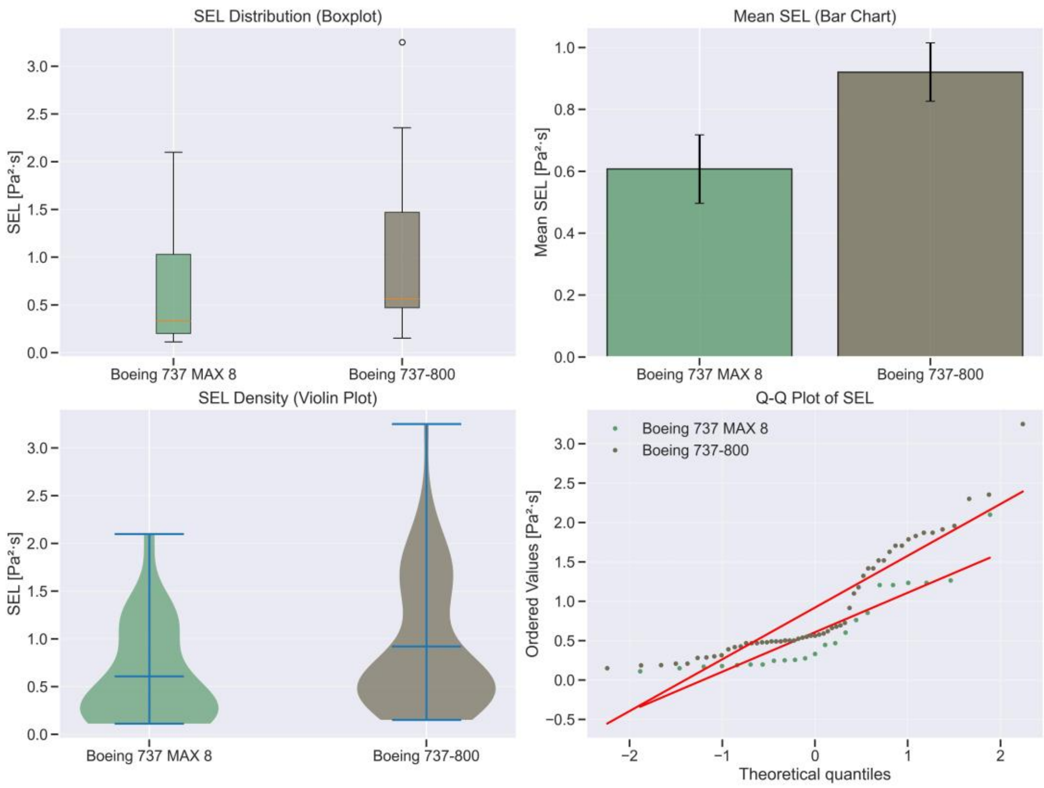

Fig. 2. General analysis of L_{ASel} levels

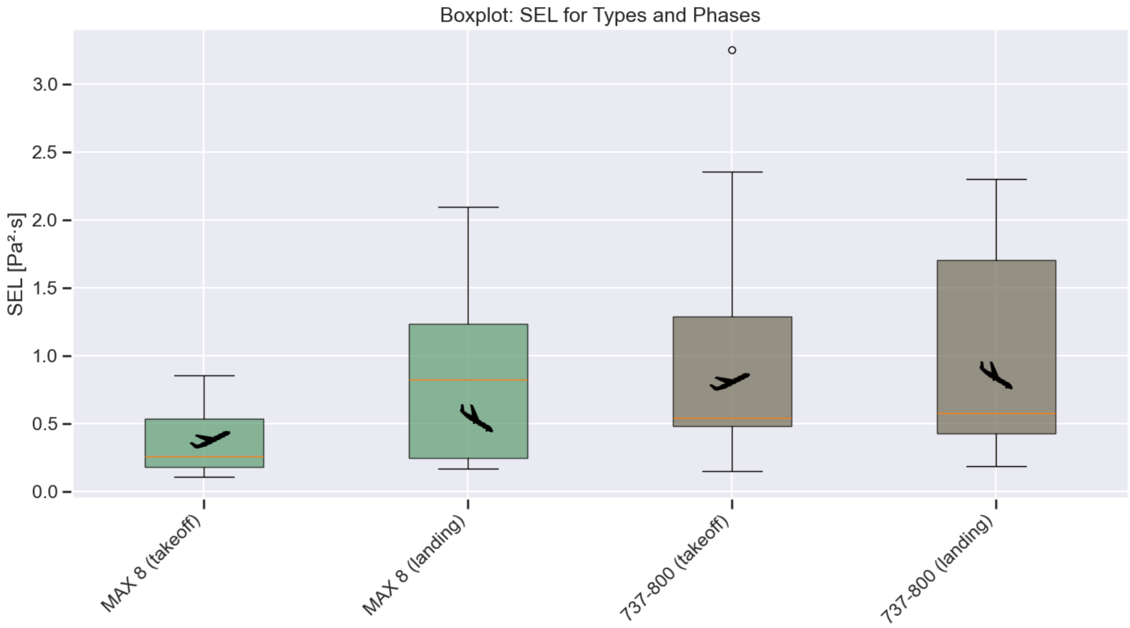

Fig. 3. Distribution of L_{ASel} by take-off and landing phases

The relationship between sound exposure level and flight altitude is shown in Fig. 4 using a log-distance representation in the dB domain. In the revised analysis, L_{ASel} was modeled as a linear function of log10(d)

$$L_{ASel}(d) = \beta_0 + \beta_1 \log_{10} d \qquad (4)$$

where d denotes the source–receiver distance. Because the available dataset did not include the horizontal offset of the aircraft relative to the monitoring point, altitude above the monitoring point was used as a proxy for distance in this analysis. This representation is more consistent with acoustic propagation theory than the previous linear-in-altitude model in meters, because under free-field spreading a level expressed in decibels is expected to vary approximately linearly with log10(d). The larger dispersion visible in the Boeing 737-800 subset likely reflects both greater operational variability and the fact that the aggregated figure includes both landings and departures.

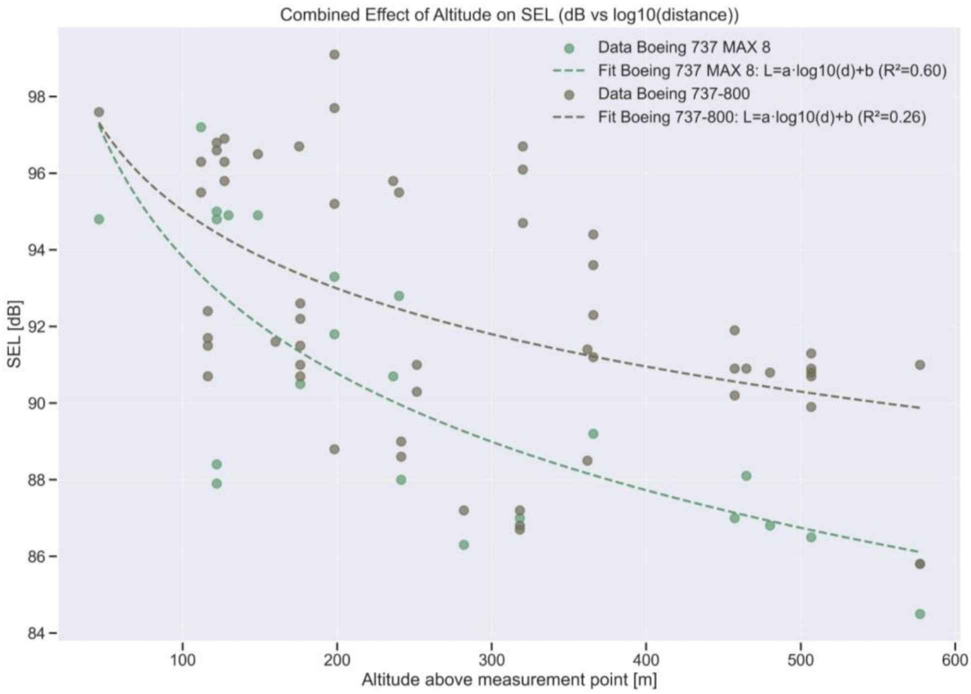

Fig. 4. Relationship between sound exposure level and flight altitude using a log-distance representation in the dB domain for Boeing 737-800 and Boeing 737 MAX 8. Data shown here include both landings and departures

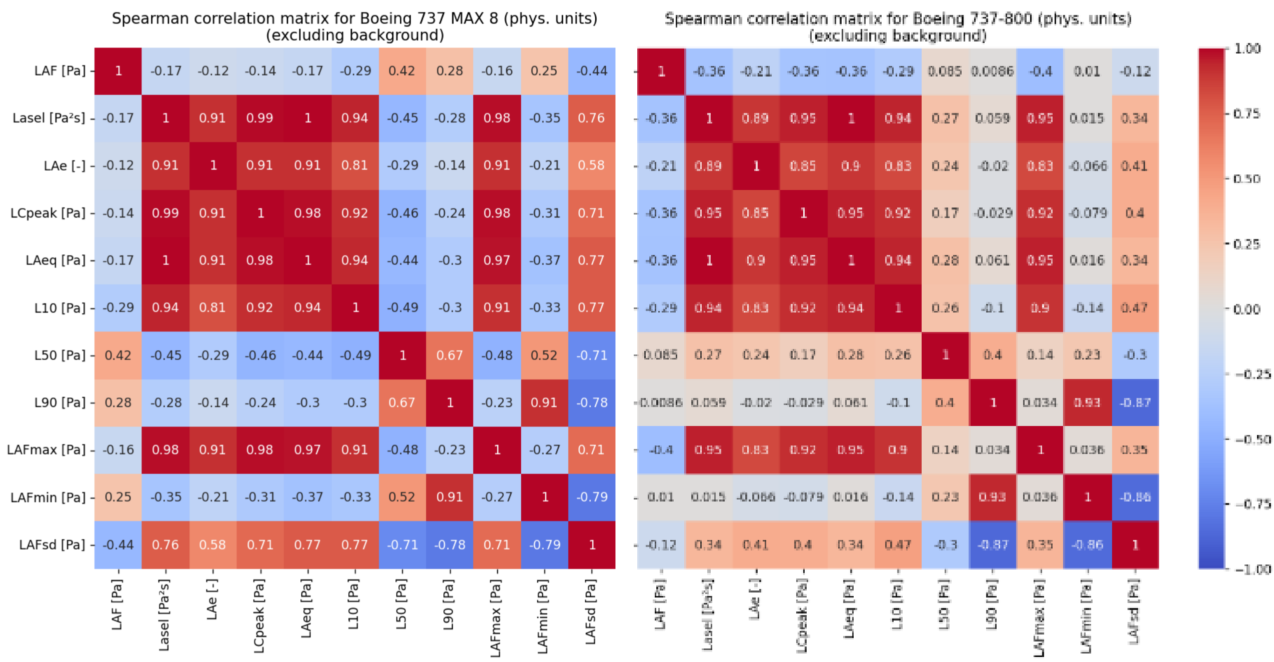

Fig. 5. Statistical summary of correlation values for acoustic indicators

The larger dispersion observed for the Boeing 737-800 subset likely reflects greater operational heterogeneity in that sample and the fact that the aggregated figure combines both landings and departures. As noted above, the Boeing 737-800 generates, on average, 56% higher L_{ASel} values (0.32 Pa²·s, 1.9 dB) than the Boeing 737 MAX 8, with the difference increasing to 137% (0.52 Pa²·s, 2.7 dB) during take-off. The strong dependence of L_{ASel} on both altitude and aircraft type was statistically confirmed. The findings indicate that the 737-800 generates significantly more acoustic energy around the airport than the newer 737 MAX 8. The difference in L_{ASel} is not only statistically significant but also practically relevant for environmental exposure assessment [23].

3.2. Comparison of acoustic characteristics based on indicators and their mutual correlations

The correlation analysis of the acoustic indicators for both aircraft types was carried out using Spearman's rank correlation coefficient, summarized in Table 2. The coefficient was calculated exclusively in physical units (Fig. 5).

Table 2. Basic statistics of Spearman correlations (physical scale)

Aircraft type	Spearman p – mean	Spearman p – median	Std. dev.
737 MAX 8	0.61	0.67	0.31
737-800	0.49	0.36	0.38

For the Boeing 737 MAX 8, the mean Spearman correlation was 0.61 (median 0.67, standard deviation 0.31), while for the 737-800 the corresponding values were 0.49 (median 0.36, standard deviation 0.38). The difference in mean correlation between the two types was 0.12, representing a 24% increase in favor of MAX 8.

To account for the differences between aircraft types, a matrix of absolute differences (corr) was calculated according to Eq. 4:

$$\Delta_{corr} = r_{Spearman_{800}} - r_{Spearman_{MAX8}} \quad (4)$$

The mean value of Δ_{corr} was 0.12 (median 0.086), with extreme values ranging from –0.25 to 0.43 (Table 3). This indicates that, in most cases, correlations are higher for the 737-800, although approximately 25% of the metric pairs show higher values for the MAX 8. A detailed breakdown of these differences is presented in Tables 4 and 5.

Table 3. Statistics of Spearman correlation differences (Δ_{corr})

Statistics	Mean	Median	Std. Dev.	Min.	Max.
Δ_{corr}	0.12	0.086	0.167	–0.25	0.43

The highest positive Δ_{corr} values (0.33–0.43, Table 5) were observed for pairs of indicators related to energetic exposure (L_{Aeq}, L_{ASel}) and variability measures (L_{AFsd}, L_{AFmax}, L_{AFmin}, L50). For example, the correlation between L_{Aeq} and L_{AFsd} was higher by 0.43 for the 737-800, and the correlation between L_{ASel} and L_{AFsd} was higher by 0.42. In relative terms, this means that the 737-800 exhibits up to 50–100% stronger dependencies between these indicators compared with the MAX 8. This reflects greater predictability of variability increases alongside rising energy levels in the case of the 737-800. In contrast, for certain pairs of metrics (Table 5), MAX 8 demonstrated stronger correlations (the largest difference was 0.25, for example, between L_{AF} and L_{AFmax}), although these relationships are less critical from an environmental protection perspective.

Table 4. Indicator pairs with the largest correlation differences ($\Delta_{corr} > 0.3$)

Pair of measures	Difference Δ_{corr} (800 – MAX8)
L_{Aeq} [Pa] – L_{AFsd} [Pa]	0.43
L_{ASel} [Pa²s] – L_{AFsd} [Pa]	0.42
L50 [Pa] – L_{AFsd} [Pa]	0.41
L_{AFmax} [Pa] – L_{AFsd} [Pa]	0.36
L_{Aeq} [Pa] – L_{AFmin} [Pa]	0.36
L50 [Pa] – L_{AFmax} [Pa]	0.34
L_{ASel} [Pa²s] – L_{AFmin} [Pa]	0.34
L_{AF} [Pa] – L50 [Pa]	0.33

Table 5. Pairs of indicators with higher correlations for MAX 8 (corr < 0.3)

Pair of measures	Difference Δ_{corr} (800 – MAX8)
L_{AF} [Pa] – L_{AFmax} [Pa]	–0.25
L_{AF} [Pa] – L_{Cpeak} [Pa]	–0.22
L_{AF} [Pa] – L_{Aeq} [Pa]	–0.19
L_{AF} [Pa] – L_{ASel} [Pa²s]	–0.19
L_{AF} [Pa] – L_{Ae} [–]	–0.10

In this respect, the MAX 8 surpasses the 737-800 in the strength of correlations between these pairs; however, such relationships are of limited relevance for environmental exposure assessment.

In summary, the Boeing 737 MAX 8 shows higher mean and median associations among most acoustic indicators than the 737-800. The relationships between energetic and peak measures (L_{Aeq}, L_{ASel}, L_{Cpeak}, L_{AFmax}) are particularly consistent and predictable. On the contrary, the 737-800 shows greater variability and heterogeneity in correlations, especially for indicators of noise distribution variability. In practice, this implies that for a fleet dominated by MAX 8 aircraft, environmental exposure can be predicted with high precision based on energetic indicators, whereas for the 737-800, it is also necessary to consider statistical distribution parameters of noise.

4. Impact of fleet composition and number of operations on environmental exposure

For the simulations, the number of flight operations was assumed as follows: 115 on weekdays (±10) and 95 on weekends (±10). This approach reflects the actual traffic load and ensures the month's representativeness for the analysis (August). It was assumed that the total number of operations in each variant remained constant, with only the percentage share of individual aircraft types varying between fleet configurations. Nine variants of the fleet structure were analyzed, ranging from extreme cases consisting exclusively of one aircraft type (100% Boeing 737-800 or 100% Boeing 737 MAX 8), through mixed configurations covering successive percentage intervals (10% to 90% for each type, in steps of 10% or 20%), to evenly distributed variants (e.g. 50% 737-800 and 50% MAX 8). Such a broad spectrum of variants enables a comprehensive assessment of the impact of gradually introducing a more modern fleet on the acoustic environment surrounding the airport. These variants reflect both operational scenarios observed during transitional periods of fleet modernization and analytical extremes that allow identification of boundary cases [7, 31]. Consequently, it was possible not only to assess current exposure, but also to predict the environmental effects of progressively increasing the share of Boeing 737 MAX 8 aircraft in total operations. The configurations adopted and the distribution of aircraft types in each structure analyzed structure are shown in Fig. 6.

The results of the L_{AeqD} simulation for different variants of the fleet structure are presented as heat maps (Fig. 7), allowing for a detailed assessment of the noise exposure depending on the measurement point and the proportion of specific aircraft types in flight operations. The analysis is based on a direct comparison of days when the daily L_{AeqD} level exceeded the 60 dB threshold [26].

The color of each block in the heatmap represents the mean daily L_{AeqD} level obtained at a given measurement point and the fleet configuration variant: the more intense the color, the higher the simulated noise level in the analyzed case. Blocks with light neutral colors correspond to measurement points and fleet variants where the L_{AeqD} level did not significantly exceed the acoustic background level, meaning that the impact of aircraft noise was negligible compared to local background noise. At more distant points (5, 6), no exceedances occurred, which is represented by empty blocks. The cells outlined with a purple border indicate cases in which the corrected daily L_{AeqD} level exceeded the 60 dB threshold adopted as a criterion for environmental noise.

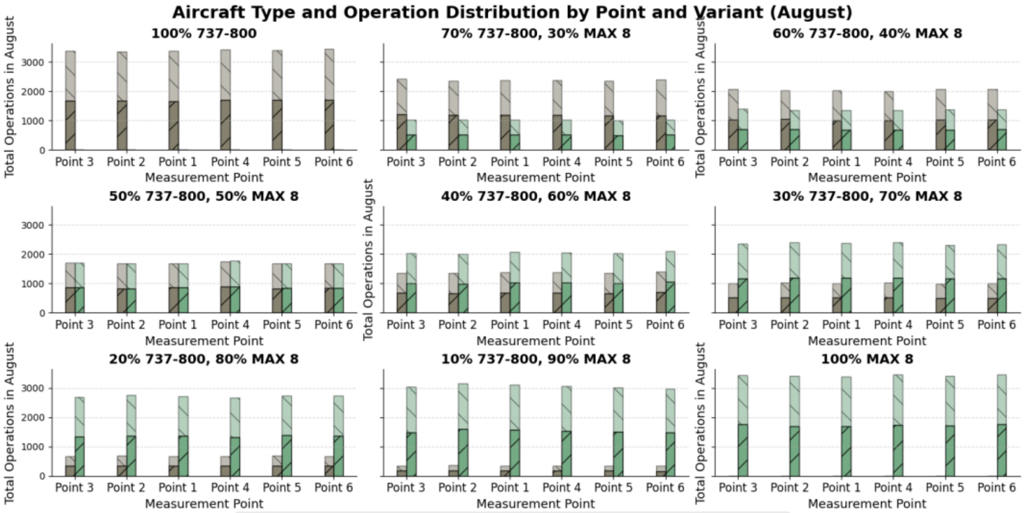

Fig. 6. Percentage structure of aircraft types (Boeing 737-800 and Boeing 737 MAX 8) in each fleet configuration variant used in the simulation analysis (lighter colors are landings, darker colors are take-offs)

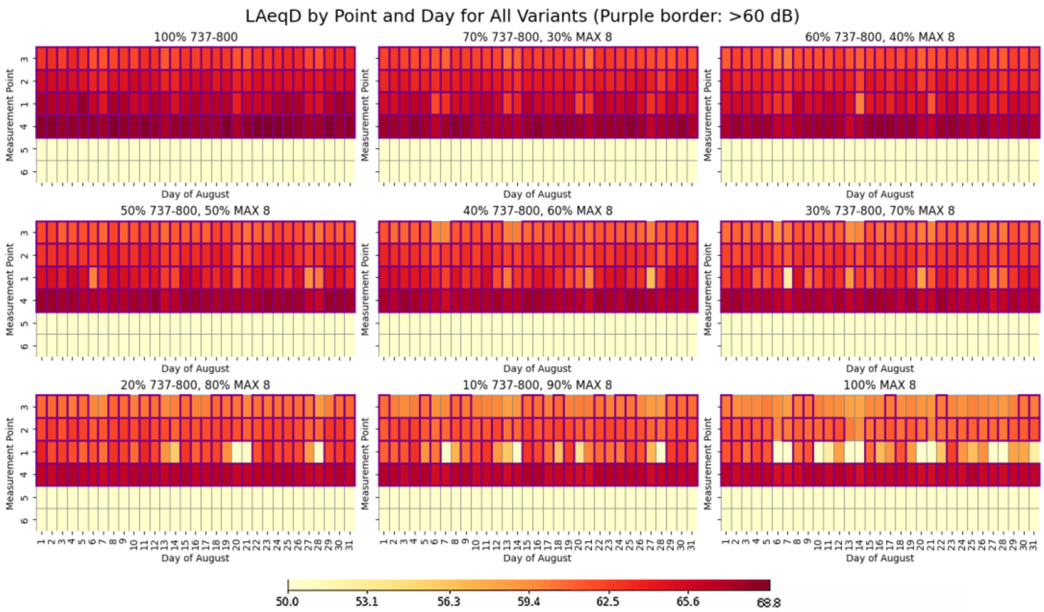

Fig. 7. Heatmap of L_{AeqD} values for different scenarios of fleet composition in flight operations

Regardless of the fleet scenario, measurement point 4, located closest to the airport, always exceeded the established 60 dB threshold. However, from a share of 80% MAX 8, the exceedances became noticeably smaller. For all configurations at points 5 and 6, the L_{AeqD} level did not exceed the background noise level. A strong spatial gradient of exposure is evident: the closer the airport, the greater the frequency and intensity of threshold exceedances. This effect is clearly moderated by the proportion of MAX 8 aircraft, which demonstrate more favorable acoustic and energetic parameters.

The transition from a fleet dominated by 737-800 to one with a higher share of MAX 8 results in a substantial reduction in noise exposure and a marked decrease in the number of days exceeding the environmental threshold. A particularly beneficial effect is observed even with a share of 60–70% MAX 8 [7, 31, 36].

Variants dominated by 737-800 (100%, 70%, 60%) and 50% share lead to threshold exceedances (60 dB) on all days of the month at points 1–4 (the locations closest to the airport). As the proportion of 737 MAX 8 increases, the number of exceedance days decreases, especially at points 1–3 (Fig. 8). With a 100% share of days of MAX 8, the number of exceedances at point 1 is incidental (7 days).

To gather the number of exceedances during the analyzed month (August), a simple Table 6 was created. The greatest benefits of using the MAX 8 aircraft for operations at Poznań Airport can be seen in points 1 and 3, especially with the 100% share in the fleet configuration.

To evaluate the economic consequences of noise exceedances, a study adopted the approach consistent with the penalty rates for exceeding the permitted levels of environmental noise currently in force in Poland [25], as described in the research methodology. The total monthly environmental penalty was calculated as the sum of the values accrued across all days in August at each measurement point and for each fleet composition scenario. Figure 9 presents a comparison of these results for points 1–4, that is, the locations most exposed to aircraft noise.

Table 6. Number of daily 60 dB threshold exceedances in August

Each variant share	Point no. 1	Point no. 2	Point no. 3	Point no. 4
100% 737-800 0% MAX 8	31	31	31	31
70% 737-800 30% MAX 8	31	31	31	31
60% 737-800 40% MAX 8	31	31	30	31
50% 737-800 50% MAX 8	31	31	28	31
40% 737-800 60% MAX 8	26	31	28	31
30% 737-800 70% MAX 8	27	31	26	31
20% 737-800 80% MAX 8	21	31	24	31
10% 737-800 90% MAX 8	13	31	20	31
0% 737-800 100% MAX 8	7	27	10	31

For the baseline variant (100% 737-800), the total monthly environmental penalty (for all points 1–6) amounts to 6069 EUR. In the extreme case of 100% MAX 8, this sum decreases to 1902 EUR, representing a reduction of 4167 EUR (≈69%). Mixed variants confirm a gradual decline in costs. With a 70% share of the 737-800, the penalty amounts to 4979 EUR (a reduction of 18% relative to the baseline); with a 50% share, 4136 EUR (a reduction of 32%); with a 30% share, 3225 EUR (a reduction of 47%); and already at 10% share, the penalty falls to 2353 EUR, corresponding to a reduction of 61% compared to a fleet composed entirely of 737-800 aircraft.

The highest penalty values occur systematically at points 1 and 4, located closest to the airport – for example, in the 100% 737-800 variant, the monthly penalty amounts to 1248 EUR at point 4 and 901 EUR at point 1. At more distant points (5 and 6), the total penalty is zero in every variant, indicating that there are no exceedances of the 60 dB threshold at these locations.

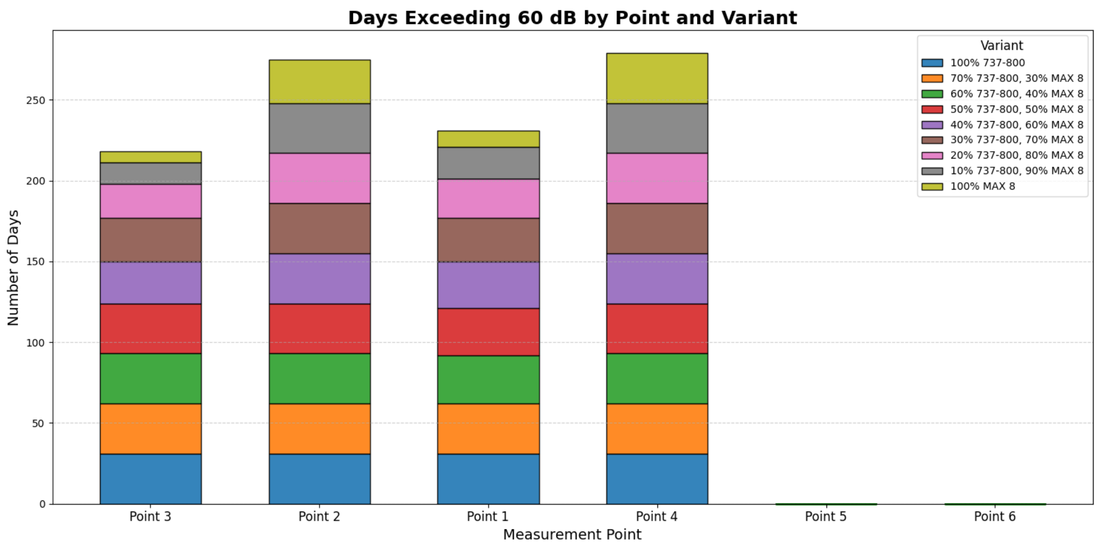

Fig. 8. Number of days that exceeded the environmental threshold by aircraft type and measurement point

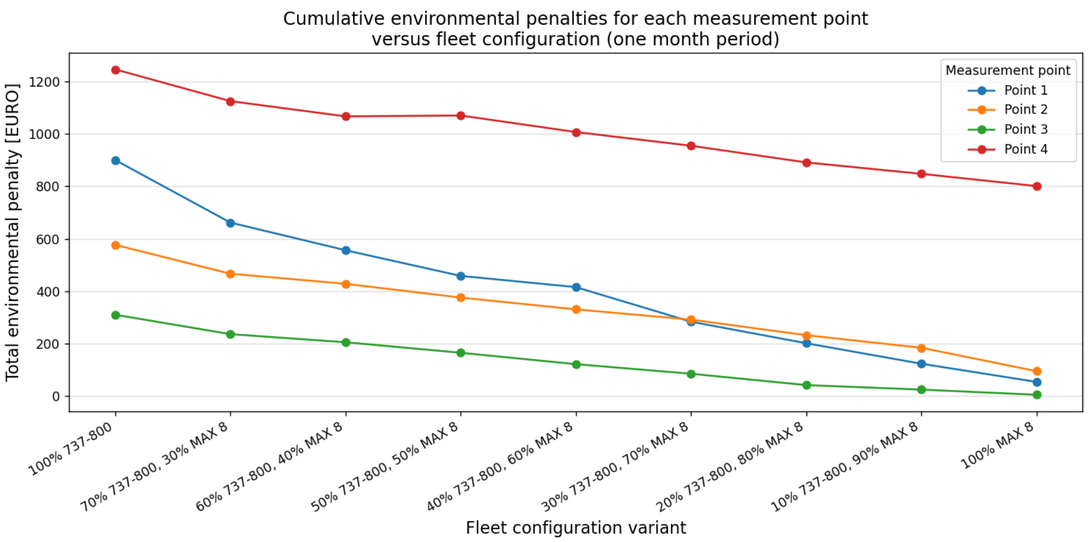

Fig. 9. Total monthly environmental penalty (in EURO) for each measurement point as a function of the fleet configuration variant. Each line corresponds to a different measurement point; values calculated for the sum of all days in August, with daily L_{AeqD} exceeding 60 dB

5. Discussion

When interpreting the results, several important limitations of the study must be acknowledged. First, the simulations were conducted for a single month (August), which allows assessment of seasonal effects but does not account for the variability of acoustic characteristics or the distribution of operations throughout the year. Incorporating annual data could yield different, more nuanced conclusions, particularly regarding air traffic variability and meteorological conditions. The assumed fleet shares in the simulation variants reflect both the actual proportions observed during the measurement campaign and the potential modernization scenarios. In practice, the actual distribution of aircraft types depends on the decisions of airline operators, over which the airport has limited influence, although it is the airport that bears responsibility for meeting environmental obligations. Therefore, the configurations were designed to be representative of both current and potential future fleet composition. Another limitation concerns the acquisition of L_{ASel} and background noise data. The analysis was based on the results of a selected period, and particularly at points 5 and 6, the background noise level was elevated due to strong urban noise, which may have limited the detection of exceedances attributable to aircraft. A different measurement campaign or a different season could produce different results at these points. The environmental cost model used in the analysis considered only exceedances of the daily L_{AeqD} 60 dB and did not encompass all possible consequences of airport operations, such as resident claims, compensations, or investments in noise protection. Therefore, the actual economic balance may be even more favorable under effective fleet modernization. It should also be noted that the study focused on daytime hours, which represent the main phase of air traffic at Poznań Airport. Assessing the impact on the acoustic climate during nights or weekends would require separate analyses, accounting for regulatory specifics and the distribution of operations. In addition, the dataset did not include the full slant distance between the aircraft and the receiver, nor operational metadata such as aircraft mass, payload, destination, or flight phase; therefore, altitude was used only as a proxy for distance, and weight- or phase-related effects could not be quantified explicitly in the present model. Despite these limitations, the findings highlight a strong dependence of noise impact on the type of aircraft operated and confirm that fleet modernization may be one of the most effective tools for managing environmental risk around airports.

6. Conclusions

The results showed that the Boeing 737-800 aircraft generates significantly higher energetic noise levels than the newer 737 MAX 8. The mean L_{ASel} value for the 737-800 was 0.89 $Pa^2 \cdot s$ (94.5 dB), while for the MAX 8 it was lower at 0.57 $Pa^2 \cdot s$ (92.6 dB), representing a difference of 56% (1.9 dB). These differences are particularly pronounced during the take-off phase, where the L_{ASel} level for the 737-800 exceeded that of the MAX 8 by up to 137% (2.7 dB). A statistically significant decrease in L_{ASel} with increasing altitude was observed; however, in the revised interpretation, altitude is treated as a proxy for source–receiver distance, and the fitted relationship is presented in a physically motivated log-distance form in dB.

The correlation analysis of the acoustic indicators revealed that the Boeing 737 MAX 8 is characterized by greater consistency and predictability in the relationships between energetic and peak measures (mean Spearman correlation of 0.61, compared to 0.49 for the 737-800), indicating a more stable acoustic profile for these operations. In contrast, the 737-800 exhibited greater variability and higher correlations in distribution-related noise metrics, suggesting a more heterogeneous acoustic emission pattern for this aircraft type.

Environmental simulations conducted for nine fleet composition scenarios (ranging from 100% 737-800 to 100% MAX 8) demonstrated a marked reduction in the number of days exceeding the L_{AeqD} threshold of 60 dB, as well as a significant decrease in monthly environmental penalties imposed for such exceedances. The findings clearly indicate that increasing the share of Boeing 737 MAX 8 aircraft in the fleet results in a substantial reduction in environmental impacts associated with aircraft noise. For measurement points located closest to the airport, transitioning from a fleet entirely composed of Boeing 737-800s to one fully dominated by 737 MAX 8 results in a reduction in threshold (L_{AeqD}) exceedance days by 80–90% and lowers total monthly penalties from approximately 5000–7000 EUR to 600–900 EUR. Even partial modernization – at a share of 60–70% MAX 8 – reduces costs by 60–70% compared to the baseline scenario. Across the entire study area, the fleet results in a 69% reduction in total penalties, confirming tangible economic benefits from the introduction of aircraft with improved acoustic characteristics. In particular, even with about 50% MAX 8 in the fleet, total costs fall by one-third, while at a share of 70–80% the reduction exceeds 50%.

The findings indicate that fleet modernization toward a greater share of Boeing 737 MAX 8 aircraft with superior acoustic performance is a highly effective tool for reducing community exposure to aircraft noise and minimizing environmental costs incurred by the airport. The analysis accounted for not only acoustic impacts but also for economic and legal dimensions, drawing on national and European environmental protection regulations and normative guidelines.

In summary, the applied methodology and the proposed analytical tools (including L_{ASel} analysis, correlation metrics, and fleet scenario modelling) may serve as effective support for environmental management at airports and the optimization of operational decisions in the context of protecting residents from the adverse effects of transportation noise.

Acknowledgement

The presented results have been co-financed from the subsidies appropriated by the Polish Ministry of Science and Higher Education – 0416/SBAD/0006, and 0415/SBAD/0363.

Nomenclature

L_{Ae}	A-weighted sound exposure level
L_{Aeq}	A-weighted equivalent continuous sound level
L_{AeqD}	Daytime A-weighted equivalent continuous sound level
L_{AFmax}	Maximum A-weighted sound level with fast time weighting
L_{AFsd}	standard deviation of A-weighted sound level with fast time weighting
L_{ASel}	A-weighted sound exposure level (SEL)
L_{Cpeak}	Maximum A-weighted sound level with fast time weighting
L50	A-weighted sound level exceeded for 50% of the measurement time

Bibliography

[1] Batóg J, Foryś I, Konowalczuk J. Airport noise compensation: real estate perspective. J Eur Real Estate Res. 2019; 12(2):250-266. https://doi.org/10.1108/JERER-02-2019-0002

[2] Baudin C, Lefevre M, Babisch W, Cadum E, Champelovier P, Dimakopoulou K et al. The role of aircraft noise annoyance and noise sensitivity in the association between aircraft noise levels and medication use: results of a pooled analysis from seven European countries. BMC Public Health. 2021; 2021(21):15. https://doi.org/10.1186/s12889-021-10280-3

[3] CFM56-7B series specifications. 2008. www.aircraft-commerce.com

[4] Czarnecki ML, Lech A. GTM-120 micro gas turbine engine noise identification. Combustion Engines. 2024;199(4):52-59. https://doi.org/10.19206/CE-189743

[5] Çil MA, Tarhan C. Investigation of emissions from passenger flights Denizli Çardak Airport, Türkiye. Air Qual Atmos Health. 2024;17(10):2395-2403. https://doi.org/10.1007/s11869-024-01579-2

[6] Dekoninck L. Detecting and correlating aircraft noise events below ambient noise levels using OpenSky tracking data. Proceedings. 2020;59:13. https://doi.org/10.3390/proceedings2020059013

[7] Einicke K, Kennedy J. Predicting airport noise impact to 2040: traffic growth and technology uptake. Appl Acoust. 2025;227:110229. https://doi.org/10.1016/j.apacoust.2024.110229

[8] Environmental Protection Law – The upper unit fine for exceeding the permissible noise level. Article 311. Poland: Journal of Laws; Apr 27, 2001.

[9] Felcyn J, Ptak P. Road, tram and aircraft traffic noise annoyance related to the number of noise events and the equivalent sound level. Arch Acoust. 2022;47(4):457-467. https://doi.org/10.24425/aoa.2022.142892

[10] Felcyn J. How the COVID-19 pandemic influenced noise annoyance perception? A case study of Poznan. Poland. 2022.

[11] Forys I, Habdas M, Konowalczuk J. Fair and effective compensation of loss in restricted use areas surrounding airports in Poland. Ekon Srod. 2019;70:87-113.

[12] Gailagista A, Rahma Z, An C, Suparman A, Irenita N. Is it worth replacing B 737-800 NG with B 737 Max 8? Advances in Transportation and Logistics Research. 2018;1:97-104. https://doi.org/10.25292/atlr.v1i1.16

[13] Genescà M, Romeu J, Arcos R, Martín S. Measurement of aircraft noise in a high background noise environment using a microphone array. Transp Res D Transp Environ. 2013; 18(1):70-77. https://doi.org/10.1016/j.trd.2012.09.002

[14] Giladi R. Real-time identification of aircraft sound events. Transp Res D Transp Environ. 2020;87:102527. https://doi.org/10.1016/j.trd.2020.102527

[15] Gonela S, Laeequddin M, Dikkatwar R, NS S. Cascading effect of Boeing's 737 Max technology development. International Journal of Recent Technology and Engineering (IJRTE). 2020;8(5):5208-5215. https://doi.org/10.35940/ijrte.E4863.018520

[16] Jayawardana R, Boeing 737-800 and MAX 8 critical factor simulation. International Journal of Research Publication (IJRPORG). 2020;59(1):1-18. https://doi.org/10.47119/10.47119/IJRP100591820201380

[17] Karczewska A. Noise analysis of Poznań-Ławica Airport. Despite the increase in connections, it's quieter. 2018.
[18] LEAP -1A/-1B. 2026. Available from: https://www.mtu.de/engines/commercial-aircraft-engines/narrowbody-and-regional-jets/leap-1a/-1b/
[19] Lu Y. Civil aircraft engine development: past innovations and future technologies. HSET. 2025;147:294-300. https://doi.org/10.54097/xa5fxp29
[20] Ludwiczak A, Kozakiewicz A, Chachurski R, Karczewski M. Measurements of exhaust emissions from the GTM-120 UAV engine using atmosFIR measuring equipment. Combustion Engines. 2025;203(4):164-169. https://doi.org/10.19206/ce-208515
[21] Ławniczak P, Orczyk M. Assessment of annoyance of traffic noise based on residents' subjective evaluations and actual noise measurements in environment. Geomat Environ Eng. 2024;18(6):5-22. https://doi.org/10.7494/geom.2024.18.6.5
[22] Maciejewska M, Galant M, Fuć P. Comparison of exhaust emission from the most commonly used aircrafts with implementation LTO cycle to operating conditions. Combustion Engines. 2019;179(4):198-203. https://doi.org/10.19206/CE-2019-433
[23] Mahashabde A, Wolfe P, Ashok A, Dorbian C, He Q, Fan A et al. Assessing the environmental impacts of aircraft noise and emissions. Prog Aerosp Sci. 2011;47(1):15-52. https://doi.org/10.1016/j.paerosci.2010.04.003
[24] Makarewicz R, Gołębiewski R. Aircraft noise propagation – the simplest case. Arch. Acoust. 2002;27(2). https://acoustics.ippt.pan.pl/index.php/aa/article/view/420
[25] Notice of the Minister of Climate and Environment of 13 August 2024 on the amount of penalty rates for exceeding the permissible noise level for the year 2025. Poland: Official Gazette of the Republic of Poland. 2024 Aug 20.
[26] Notice of the Minister of the Environment of 15 October 2013 on the publication of the consolidated text of the Regulation of the Minister of the Environment on permissible noise levels in the environment. Poland: Journal of Laws. 2013 Oct 13.
[27] Nowacki M, Olejniczak D. Analysis of Boeing 737 MAX 8 flight, in terms of the exhaust emission for the selected flight. Transp Res Procedia. 201835;158-165. https://doi.org/10.1016/j.trpro.2018.12.033
[28] Oliveira AVM, Caliari T, Narcizo RR. An empirical model of fleet modernization: on the relationship between market concentration and innovation adoption in the Brazilian airline industry. Res Transp Bus Manag. 2022;43:100704. https://doi.org/10.1016/j.rtbm.2021.100704
[29] Regulation of the Minister of the Environment of 16 June 2011 on the requirements concerning the measurement of levels of substances or energy in the environment by the administrator of a road, railway line, tram line, airport, or port. Poland: Journal of Laws. 2011 Jun 16.
[30] Rudno-Rudziński K. Required attenuation of aircraft noise in buildings in the light of data from the Chopin Airport monitoring. Vib Phys Syst. 2019;30:2019117. https://vibsys.put.poznan.pl/_journal/2019-30-1/articles/vibsys_2019117.pdf
[31] Simons DG, Amiri-Simkooei A, Melkert JA, Snellen M. Contribution of aircraft types to noise levels across the NOMOS network of Amsterdam Airport Schiphol. J Air Transp Manag. 2026;131:102910. https://doi.org/10.1016/j.jairtraman.2025.102910
[32] Trojanek R, Tanas J, Raslanas S, Banaitis A. The impact of aircraft noise on housing prices in Poznan. Sustainability. 2017;9(11):2088. https://doi.org/10.3390/su9112088
[33] Type Certificate Data Sheet No. E.115 for LEAP-1B series engines. European Union Aviation Safety Agency. 2026. https://www.easa.europa.eu/en/document-library/type-certificates/engine-cs-e/easae115-leap-1b-series-engines
[34] van der Grift R, Snellen M, Amiri-Simkooei A. Aircraft noise model improvement by calibration of noise–power–distance values using acoustic measurements. CEAS Aeronaut J. 2025. https://doi.org/10.1007/s13272-025-00902-6
[35] Will F. A novel approach for modelling future airport noise exposure. Doctoral Thesis. TU Munich 2019. https://mediatum.ub.tum.de/doc/1483148/1483148.pdf
[36] Wothge J, Belke C, Möhler U, Guski R, Schreckenberg D. The combined effects of aircraft and road traffic noise and aircraft and railway noise on noise annoyance – an analysis in the context of the joint research initiative NORAH. Int J Environ Res Public Health. 2017;14(8):871. https://doi.org/10.3390/ijerph14080871
[37] Zijadić N, Ganić E, Bračić M, Štimac I. Impact of aircraft delays on population noise exposure in airport's surroundings. Int J Environ Res Public Health. 2022;19(15):8921. https://doi.org/10.3390/ijerph19158921
[38] Zydroń A, Chwiałkowski C. The influence of aircraft noise on the prices of residential properties on the example of Poznań. Rocz Ochr Sr. 2021;23:263-278. https://doi.org/10.54740/ros.2021.017

Remigiusz Jasiński, DSc., DEng. – Faculty of Civil and Transport Engineering, Poznan University of Technology, Poland.
e-mail: *remigiusz.jasinski@put.poznan.pl*

Tomasz Nowakowski, DEng. – Faculty of Civil and Transport Engineering, Poznan University of Technology, Poland.
e-mail: *tomasz.nowakowski@put.poznan.pl*

Jakub Niklas, Eng. – Faculty of Civil and Transport Engineering, Poznan University of Technology, Poland.
e-mail: *jakub.niklas@student.put.poznan.pl*