Airport noise insulation programs: The Spanish case

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Noise pollution around airports is one of the most important problems in environmental acoustics. The incessant development of modern societies is continuously increasing the demand for air transport, and airports have to grow to adapt their operational capacity to the new requirements. On the other hand, the economic activity related to airports is closely linked to the expansion of built-up areas around them. Consequently, two completely incompatible land uses are forced to coexist, causing airport capacity to remain limited while the inhabitants do not cease to be annoyed by aircraft noise. Although there are several international initiatives setting the focus on the reduction of noise at the source, people living in residential areas around airports need urgent solutions. Among others, the implementation of sound insulation programs is one of the most widely-adopted solutions worldwide, as it allows a reduction of sound levels in the interior of dwellings, while the operational capacity of the airport remains unaffected. The definition and application of a sound insulation program is a very complex process that needs to manage several opposing factors: health, annoyance, airport capacity, economic costs of insulation measures… In this paper we describe the case of Spanish airport insulation programs. We set the focus on a concise description of the full process, from the creation of noise maps, to the checking of installed soundproofing measures, as carried out by the Spanish administration. As a result of this process, thousands of dwellings and houses have been acoustically insulated to meet indoor noise comfort criteria in Madrid, Mallorca and Malaga airports, among others.

INTRODUCTION

In general terms, noise pollution around airports is one of the major problems with regard to environmental acoustics. The continuous development of modern societies is closely connected to the need for transport, where air transport plays a very important role. On the other hand, noise pollution limits airport capacity[1-3]. Hence, there are several international initiatives aimed at the reduction of aircraft noise emissions and at noise abatement around airports. This is the purpose of the Acare, X3 Noise, Sefa, Cosma, Messiaen, Valiant and Imagine projects, among others.

In 2002[4], the EU adopted the recommendations of the International Civil Aviation Organization's (ICAO): "Balanced Approach to Airport Noise Management"[5]. This Balanced Approach process requires the agreement of a noise target for those airports where a noise problem has been identified. In line with this, all potential measures to manage noise at the airport must be identified, and a cost benefit analysis carried out to determine the most cost-effective package of measures.

The Balanced Approach consists of these main elements: reduction of noise at source, operating procedures, land-use planning and operational restrictions and noise charges. Among the most common noise abatement practices[6] in airports where residential uses are too close, there are only a few real possibilities available: noise abatement operational procedures, operating restrictions and insulation programs, which are the main topic in this paper. The aim of this paper is to describe the outlines of insulation programs as a full process that starts with the identification of a noise problem by

means of noise mapping around an airport, and concludes with the execution of an action plan for the reduction of noise levels in the interior of the rooms of a dwelling. The insulation program implemented in Spanish airports is described in this paper, showing the objectives pursued, and the impartial procedure standardized for achieving them.

NOISE INSULATION PROGRAMS

WHAT IS A NOISE INSULATION PROGRAM?

Insulation programs are action plans implemented to fight noise in the vicinity of airports. They define a process intended to protect the internal environments of buildings by improving the airborne noise insulation of windows, façades and roofs, to meet indoor noise comfort criteria.

THE OBJECTIVES OF NOISE INSULATION PROGRAMS

The goal of noise insulation programs consists in reducing the noise levels caused by airport operations in the internal environment of dwellings, trying to make them compatible with habitability and acoustic comfort. The criteria for acoustic comfort are defined in Spanish regulation (RD 2007a, RD 2007b, NBE 1988) and are summarized in Table 1.

The noise indicator used for the evaluation of indoor noise is the continuous equivalent sound pressure level for each reference interval, calculated according to equation 1:

$$L_{Aeq,T} = 10\log\left[\frac{1}{T}\sum t_i \cdot 10^{0.1 \cdot Li}\right] \quad i \in 1\ldots n \tag{1}$$

where T is the duration of each reference period, and L_i and t_i describe the equivalent level and the duration of each aircraft sound event in the reference time period.

This indicator is used worldwide, as it weights the number of sound events (n), their duration (t_I) and their level (L_i), to compute a single indicator that can be easily compared to limits.

Although there are current research lines setting the focus on new acoustic indicators, the equivalent noise level is an objective indicator that is referenced in most standards and references regarding environmental noise, and noise monitoring[7-10]. Note that the noise indicators used in Table 1, and the established limits, fully agree with the recommendations of the WHO [11] regarding the target noise levels established for the interior of bedrooms during an 8h night period.

Table 1. Acoustic comfort criteria in Spanish regulation

Building usage	**Type of room**	**Noise level targets**		
		Reference time interval: - day period (07:00-19:00, T=12 hours) - evening period (19:00-23:00, T= 4 hours)	**Reference time interval: - Night period (23:00-07:00, T=8 hours)**	
Residential	Bedrooms	40	30	
	Other rooms	45	30	
Hospital	Bedrooms	40	30	
	Other rooms	45	35	
Educational	Classrooms and lecture rooms		40	40
	Reading rooms	35	35	

THE INSULATION PROGRAM FRAMEWORK

The overall scope and outline of the insulation program is supervised and managed by a commission consisting of representatives from the Ministry of the Environment, Rural and Marine Affairs, regional governments and councils whose municipalities are affected by the isophone levels described above, and AENA's (airports administration) environmental department. Throughout the paper we will refer to it as the NIPC (Noise Insulation Program Commission). In close relation to the NIPC, a management office for the acoustic insulation program deals with the execution of the program.

The insulation program begins with the drawing of the airport noise footprint, which establishes the area considered within the insulation program. This footprint is derived from the noise maps of the airport, and includes the area where the predicted noise levels are higher than the target noise limits.

By adding the footprint layer to a GIS (Geographical Information System) tool, a census of the buildings and dwellings included in the insulation program is created. This allows a preliminary estimation of the budget for the action plan, and it is also useful for information to the public concerning the building insulation program. Most of this information can be requested from the local authorities.

The owners of dwellings, buildings or houses included in the program have to apply for their property to be included in the insulation program. There are some administrative criteria that a building or a dwelling must comply with in order to be included in it (legality of the construction, educational, health or residential use…).

If a dwelling meets all the administrative criteria, and it is located inside the acoustic footprint, it will be included in the insulation program. In this case, an architectural description of the building, dwellings and rooms will be carried out as well as an acoustic evaluation of the rooms in order to design a tentative insulation project.

In view of the information gathered in the field by technicians, and the acoustic evaluation carried out by acoustic experts, the NIPC will decide if any action plan must be carried out.

If a dwelling needs to be insulated, the owner has to present a detailed insulation and construction project, which will be economically and technically evaluated by the NIPC. After an agreement on the terms, the insulation project is implemented, and the last stage consists in acoustically checking the performance of the insulation installed.

Table 2 shows the scheme of the sound insulation program, and the responsibilities for every step in it.

INFORMATION FOR THE PUBLIC

AENA reports noise data to the public using the web. A user can download the environmental impact statements, the noise maps and information regarding the geographic delimitation of the insulation program. The procedure that an owner must follow to apply for the insulation is also described on the web.

Besides the official information channels, there are others:

- There are several companies that have detected the installations of insulation measures as a way to make a profit. They inform the owners about their rights, advise them during the process, and act as a consultant in their relation with the NIPC.
- When the insulation program begins and the first buildings are acoustically tested, and then insulated, word of mouth becomes a highly effective communication channel.

Table 2. Scheme of the insulation plan

Schedule	Administration (Ministry, AENA and NIPC…)	Independent acoustic experts (contracted by NIPC/AENA)	Owner (including installer)
Step 1	Noise mapping airports Airport noise footprint delimitation		
Step 2	Survey of buildings and dwellings Information to public		
Step 3			Application for dwellings to be included in the insulation program
Step 4	Administrative criteria evaluation		
Step 5		Architectural description of buildings, dwellings and rooms	
Step 6		Acoustic evaluation of rooms	
Step 7		Tentative insulation project	
Step 8	Decision regarding the inclusion of the dwellings in the insulation program		Appeal
Step 9	Agreement regarding technical and economic issues		Detailed insulation and construction project
Step 10			Installation of insulation measures
Step 11		Checking	Reparation, if required

ACOUSTIC EVALUATION OF INDOOR NOISE LEVELS

The evaluation of indoor noise levels must be done using the long-term equivalent noise level for the day, evening and night period[7,8,12]. But, there are several reasons that advise against direct measurements of these indicators: the cost of long-term monitoring, background noise levels in occupied dwellings, identification of sound events, the large number of dwellings affected … For those reasons, it is necessary to find an alternative procedure to make an objective evaluation of indoor noise levels. This new method is based on simulation tools used to perform noise maps.

A noise map is a graphic representation of the sound level spatial distribution in a region. In the case of airports, noise maps are calculated using simulation tools (INM is the most used noise model for airports). Using INM[13] it is possible to get quite accurate long-term noise evaluations for different scenarios, flight paths, number of operations, types of aircraft, weather conditions, airport configurations… Figure 1 is an example of the flight path setup in an airport.

A conservative virtual scenario is simulated to produce a noise map. This map is added to a GIS (Geographical Information System) to delimit the area included in the insulation program. Every dwelling in the area is assigned its outdoor noise level, which will be used for the calculation of indoor noise levels. Figure 2 shows an example of a noise map calculated for delimiting the area affected by the insulation program, and for the evaluation of outdoor noise levels.

The indoor noise in a room is calculated from the simulation of outdoor noise levels, using the measured airborne sound insulation of the façade. As a first step, the overall outdoor equivalent noise level (L_{1A}, dBA) must be processed using a third octave band (L_{1i}, dB) normalized aircraft noise spectra (NANSi)[14].

$$L_{1,i} = L_{1,A} + NANS_1 \qquad (2)$$

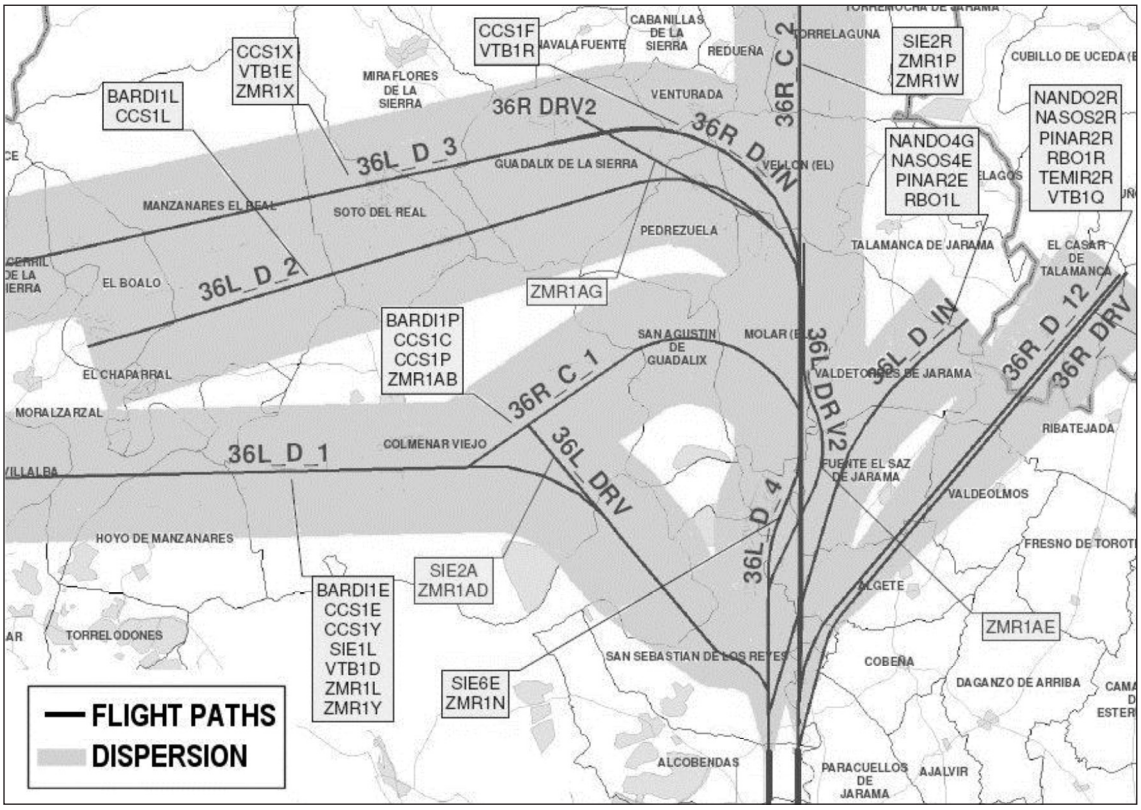

Figure 1. Flight path setup in an airport

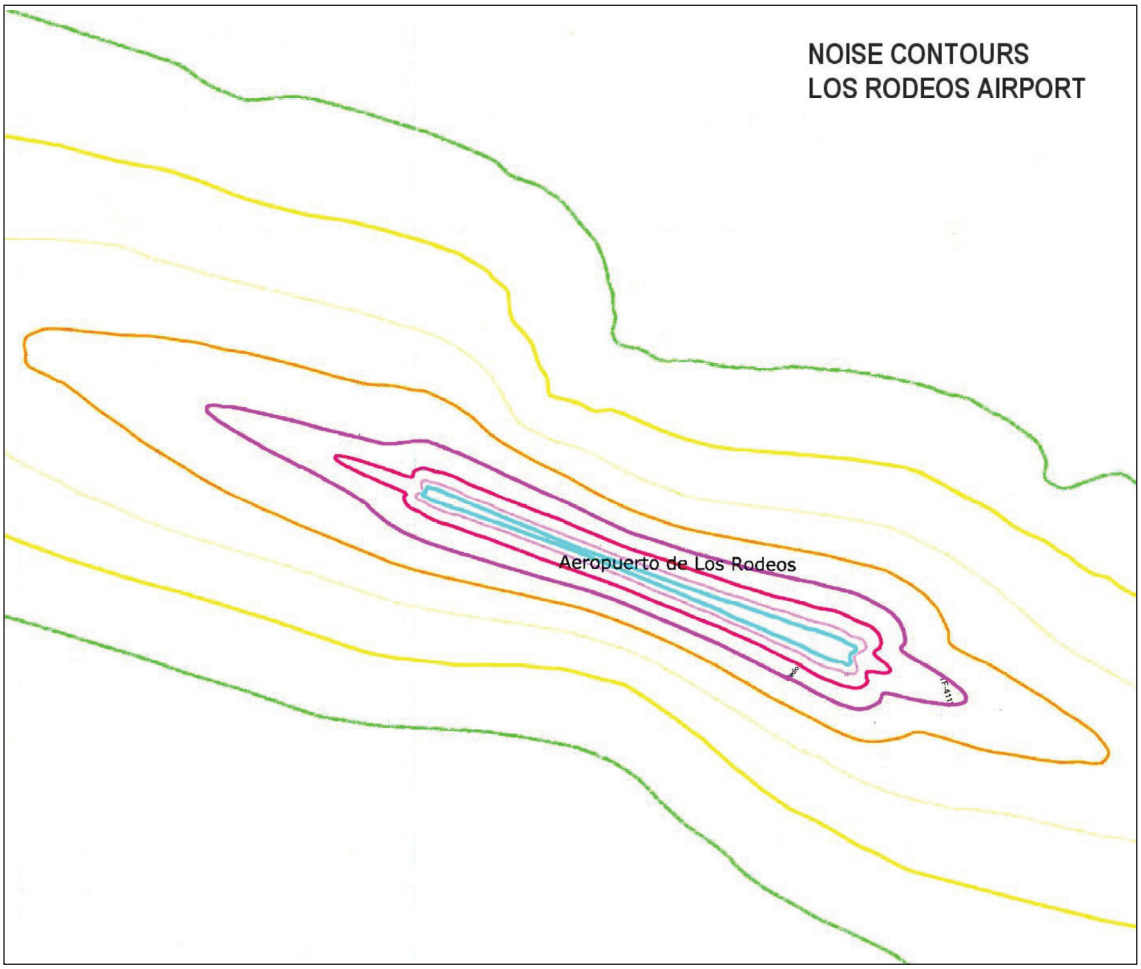

Figure 2. Noise map of an airport

The third octave band standardized level difference ($D_{2m,nT,i}$ measured according to ISO 140-5[15] is used to calculate the indoor values:

$$L_{2,i} = L_{1,A} - D_{2m,nT,i} + 10\log\frac{T}{0.5} \quad (3)$$

These results must be A-weighted (A_i is the third octave band A frequency weighting) to get an overall indoor sound level which is compared to the limits:

$$L_{2A} = 10\log\left[10^{L_{z,i}+A_i}\right] \quad (4)$$

To compare the limits, a conservative protection factor is considered while attempting to avoid any evaluation being underestimated.

Every outer room in the dwelling, and those inner rooms where the insulation of the roof is weak, will be evaluated. The result of the evaluation determines if the insulation needs improving or not.

DWELLING DESCRIPTION (IN-FIELD PRACTICE)

Most of the information needed for the acoustic evaluation must be gathered in the field by visiting the dwellings.

A short description of a dwelling must be made including the following terms:

- Number of rooms
- Volume of the rooms
- Surfaces of the façade and façade elements
- Description of façade elements for every room: walls, windows, doors, openings…
- Use of each room
- Rough plan of the dwelling
- Description of the furniture in the room

In the case of buildings, it is necessary to classify the dwellings in typologies, so that evaluations can be made for each dwelling typology, instead of measuring all the dwellings. This classification makes the evaluation procedure less expensive, and it is also necessary for the program to be properly carried out, by harmonizing the insulation measures for the whole building.

The descriptions allows filtering buildings, dwellings and rooms according to their real use, as only educational, sanitary and residential uses are included in the insulation program. The description and classification of the uses of a room can be problematic in some cases, as it will influence the evaluation.

The state of maintenance of the elements in the façade must also be considered and described, as the maintenance of buildings and dwellings is out of the scope of the action plan.

The composition of the façade and the roof must also be described, as it might be useful for the calculations involved in the insulation projects.

ACOUSTIC MEASUREMENTS (IN-FIELD PRACTICE)

The acoustic measurements regularly consist of airborne noise insulation tests according to ISO 140-5, using the loudspeaker method. In this methodology a wideband random noise is generated from a sound source (loudspeaker) located in front of the façade. The differences between the indoor and the outdoor sound pressure level characterize the insulation of the façade, according to equation 5.

$$D_{2m,nT,i} = L_{1,i} - l_{2,i} + 10\log\frac{T}{0.5} \quad (5)$$

Where, $L_{1,i}$ is the sound pressure level at a reference point in front of the façade for the i-th frequency band, $L_{2,i}$ is the spatial average sound pressure level in the reception room, and T_i is its reverberation time.

Although this is not the preferred method defined in the standard for the evaluation of full façades, it is very accurate and shows high repeatability rates. The measurement of insulation according to aircraft sound events methodology can be quite difficult in almost every room, because of the measurement times needed and the background noise level. This methodology is not used very often, but it can be of application under some circumstances where the loudspeaker method is not suitable (dwellings on raised floors, not enough distance for a loudspeaker…).

In order to calculate the indoor noise levels for every room in a dwelling, the standardized level difference (insulation) must be measured for the façade in every room. Where the circumstances prevent or discourage measurement, the insulation must be estimated using calculation methods.

TENTATIVE INSULATION PROJECTS

Once a room is recommended for its insulation improvement, the best solution needs to be decided.

The owner of the dwelling must present a building project that includes the financial cost, and defines the noise control measures to be implemented to fit the acoustic targets. The NIPC must evaluate this project regarding technical (acoustic and architectural) and economic terms. The acoustic evaluation of the owners' projects is based on a tentative insulation report prepared by independent acoustic experts. This is a very concise and simple document where typical noise control measures are recommended for every room.

This report describes solutions for the façade elements and roofs, and includes the predicted sound value for the room after the implementation of the solution.

The solutions in this project are mainly focused on windows and doors, which are usually the weakest elements for insulation (insulation of full façades is rather unusual). The installation of double glazed windows (or double doors), keeping the existing one, is usually the preferred solution, as it allows higher insulation (even avoiding leakage at the shutter box), thinner glazing, quick and easy installation and the reduction of costs. If required a posteriori, this solution will even allow a substitution of the old window for a new one. Either in the case of substitution or double glazed windows, it is quite important to select sound proof glazing and frames, as due to the spectrum pattern of aircraft noise, the resonator effect in double glazing is one of the main issues to be solved.

Regarding the roofs, sound proof suspended ceilings based on gypsum panels can be a good solution. And, in the case of ventilation openings or air intakes in façades, acoustic louvers can be effective. For the main entrance doors, the acoustic performance must be compatible with other criteria (safety, decorative…)

The solutions described in this report must be adjusted to conform to the acoustic criteria, and they must include a safety margin to assure the protection of the residents.

The sound levels are calculated using the sound insulation index, which is predicted by means of international standards[16] with data from, databases [17-19] or insulation prediction methods[20].

CHECKING TESTS

When the owner's project is accepted, the building work must be carried out. The quality of the elements installed, and their correct installation, will ensure compliance with the acoustic requirements.

The NIPC can request new insulation tests in dwellings to check if the insulation installed conforms to acoustic targets. The procedure in this case is the same as that described in

Table 3. Summary of AENA's acoustic insulation actions (from 2006 to 2008)

Indicator	2006	2007	2008
Acoustic insulation programs approved	9	10	10
List of dwellings entitled to request acoustic insulation	17,276	18,142	18,614
Dwellings where acoustic insulation works have been carried out	12,306	13,353	14,599

previous sections for the acoustic evaluation of the rooms. If the evaluation sound level does not conform to the limits, it will be necessary to find and correct the causes of the insulation leakage. Sound intensity tests can be applied in those cases.

RESULTS

According to AENA's official information[21], its environmental investments carried out within the 2005-2007 period amounted to a total of 167.87 million euros, while the expenses in the same period amounted to 34.2 million euros. The increase in investment during 2007 was mostly due to compliance with the compensatory actions included in the Environmental Impact Statements. Among these are the acquisition of land in the Jarama River Basin and the measures carried out by AENA on the dwellings included in the Acoustic Insulation Programmes. In this latter case, investment amounted to a total of 84,874,677 euros during the 2004-2007 period.

According to [22,23],the environmental investments carried out by AENA within the 2006-2008 period amounted to a total of 199.2 million euros, while environmental expenses reached the figure of 40.2 million euros. Total Environmental investment in 2008 corresponds mainly to the inclusion of the plans for acoustic insulation.

The minimization of acoustic levels and the protection of quality of life in areas surrounding airports have become one of the priorities of AENA. To this end, in accordance with the statements on environmental impact made by the Ministry of the Environment, Rural and Marine Affairs and the recent legislation concerning noise [14,24,25], AENA is proceeding with plans for acoustic insulation in the surroundings of its airports, the objective being, inside the dwellings and buildings of sensitive use within the isophones defined in the areas of execution of the plans, for the acoustic quality to comply with the objectives expressed throughout this paper.

The execution of these acoustic insulation plans has cost AENA more than 190 million euros between the years 2000 and 2008. The execution of the different acoustic insulation plans is managed and supervised by the NIPC.

AENA has carried out actions associated with the acoustic insulation programs for the airports of Alicante, Barcelona-El Prat, Bilbao, Gran Canaria, Ibiza, La Palma, Malaga, Madrid-Barajas, Menorca, Palma de Mallorca, Tenerife Norte and Valencia. Table 3 shows the official data provided by AENA regarding the insulation works and programs.

The noise insulation programs have been applied worldwide, as they have been shown to be effective in reducing the impacts of aircraft noise on homes and public buildings (Schools, Day Care Centres and Hospitals, Churches..) all over the world. But, the specifics vary from one country to another. Most of them take into account window and door changes or reinforcement, but there are some programs considering replacing air conditioning, ventilation systems and roofs.

The amount of money assigned to those noise insulation programs is huge, as an example, $620 million at Schipol aiport, $470 million at Sydney and Adelaide airports or $140 million at Boston airport, $153 million at San Francisco International airport and

$118 million at Detroit metro airport…

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NOISE COMPLAINTS INCREASING IN NORTHAMPTON

The council revealed it received 1,911 requests to deal with noise nuisance in 2010/11. In the last 12 months it has received 1,777 calls. In the last 12 months the council has issued 24 noise abatement notices and carried out one seizure of equipment. Ruth Austen, environmental health manager, said: "Music is the most significant problem, followed by general neighbour noise of moving around a property and then general actions or excessive actions, like banging doors.

HARTLEPOOL CATCHES UP

A dedicated phoneline to tackle nuisance noise in Hartlepool has now been launched. The Hartlepool Council service will allow people to report loud music, parties and other noise-related problems. Calls will be responded to by council officials who will assess the problem before deciding whether further action is needed. The phoneline will be open on Friday and Saturday nights until September.