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Study of children's exposure to aircraft noise at school and application of a new method to pilot cases in proximity to the A.Vespucci airport in Florence (Italy)

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'Belief in oneself is one of the most important bricks
in building any successful venture'
Lydia Maria Child

A chi non ha mai smesso di crederci
e a chi, forse, non ci ha mai creduto.

Abstract

Noise due to take–offs and landings at airports affects 0.6 million people at European level, causing average Lden values above 55 dB outside urban areas. This scenario represents a much smaller proportion if compared with the one caused by road and rail traffic noise, although aircraft noise is considered by citizens as more annoying than the other noise sources. Currently, some of the open research topics, which are the most highlighted in the scientific literature concerning aircraft noise, regard the need to test the new CNOSSOS–EU calculation method proposed by the EU Directive 2015/996, to be mandatory adopted by EU Member States within 2022, and the exposition of children to noise together with the development of specific curves of annoyance.

The CNOSSOS–EU calculation method defines new algorithms for creating strategic noise maps for road, railway, aircraft and industrial noise. The new calculation method should be adapted to national legislation before the end of 2018, and applied in the next round of 2021/2022. Concerning this first open issue, technicians and experts are requested at EU level to test in simple pilot cases the new introduced calculation methods and the software in which they are implemented. Consequently, in the current work a simulation of the CNOSSOS–EU calculation method has been carried out by considering as aircraft noise source the A.Vespucci airport in Florence and comparing the outputs with those obtained by applying the well–established INM calculation standard. Moreover, both models have been validated according to a noise measurement campaign carried–out in correspondence of one of the public buildings closest to the airport's runway, specifically a building of the University of Florence located in Sesto Fiorentino.

Concerning the second thematic, contrasting outcomes have been obtained from already carried–out studies, in terms of cognitive tests results and possibilities for children to develop resilience skills together with coping mechanisms. Moreover, until now tests have been mainly carried–out during the normal course of lessons, without the possibility of controlling the time relative to the passage of the individual aircraft. Finally, new and updated curves of annoyance specific for children need to be introduced and evaluated.

In the Manuscript a schematic protocol to support the application of the new developed methodology in further pilot cases contributing to the cited open issues is illustrated, together with the deep description of each phase of the method, according to the experience carried out during the research. Moreover, the application of the method to the two selected pilot schools is described, together with the phases of data acquisition and analysis. Due to the PhD activity's timing and available resources, the application of the developed method to the pilot cases and the consequent collection and analysis of the data have constituted only a first attempt of investigation, certainly they do not have the claim to be a complete and concluded work but a cue to continue the investigation with other samples of students, possibly more congruent between them, and resources. Different skills and subjects such as acoustics, audio signal processing techniques, optimization algorithms, psychology, sociology and statistics skills have been involved in the research and in the method definition.

Finally, possible application scenarios and key aspects to be addressed in a future research work are described in the thesis.

List of Figures

List of Tables

Acronym list

dB decibel

EC European Commission

END Environmental Noise Directive - European Union Directive 2002/49/EC relating to the assessment and management of environmental noise

ERF Exposure–response function

EU European Union

OR Odds Ratio

RR Relative Risk

HA Percentage of ‘highly annoyed’ population

Lden Day-evening-night noise level as defined in the Annex I of the END

SEL Single–event level

LAmax A–weighted maximum sound pressure level

LA90 A–weighted sound pressure level exceeded for the 90% of the measurement time

T60 Reverberation time

ARMOD Aircraft Noise Modelling Task Group

CadnaA Computer Aided Noise Abatement

INM Integrated Noise Model

LEPN Effective tone–corrected perceived noise level

LAmax Maximum A–weighted sound level

LPNTSmax Maximum tone–corrected perceived noise–level

RANCH Road traffic and Aircraft Noise exposure and CHildren’s cognition and health

NORAH Noise-Related Annoyance, Cognition, and Health

SAMBA Studio sugli effetti dell'AMbiente sulla salute dei BAmbini residenti a Ciampino e Marino

OCR Optical Character Recognition

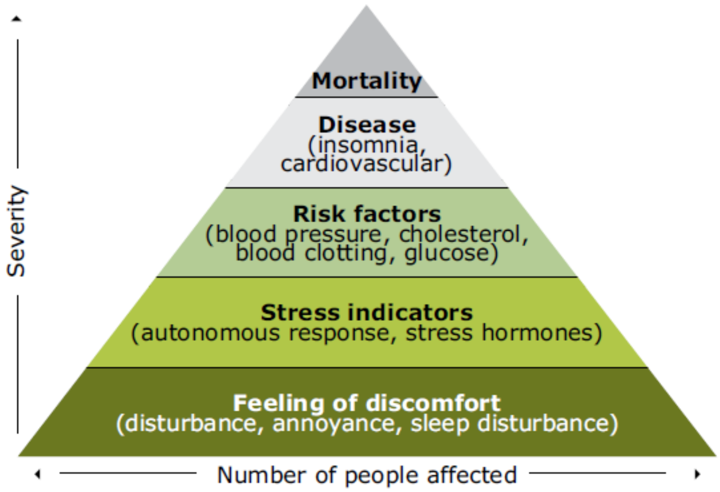
Contents

Chapter 1

Introduction

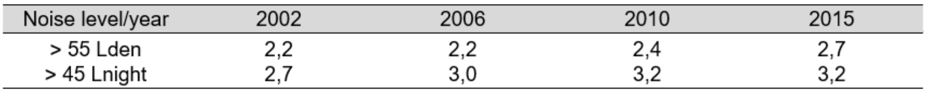
Noise pollution is widely recognised as a growing environmental concern since it is caused by a varied number of sources and it is widely present both in the urban and in the natural environments. Consequently, its effects are reflected in the well–being of exposed human populations, in the health and distribution of wildlife on the land and in the sea, in the abilities of children to learn properly at school and in the high economic price society must pay [1]. Just to provide some quantitative outcomes, environmental noise causes at least 10 thousands cases of premature death in Europe each year, almost 20 million adults are annoyed and a further 8 million suffer sleep disturbance due to environmental noise, over 900 thousands cases of hypertension are caused by environmental noise each year, noise pollution causes 43 thousands hospital admissions in Europe per year. Specifically, road traffic is the most dominant source of environmental noise with an estimated 125 million people affected by noise levels greater than 55 decibels (dB) Lden. According to the most recent EAA Report [1], a number of adverse health impacts, both direct and indirect, have been linked to exposure to persistent or high levels of noise. Figure 1.1 illustrates how exposure to noise affects health and well–being.

Within a part of a population exposed to elevated levels of noise, stress reactions, sleep–stage changes and other biological and biophysical effects may occur. These may in turn lead to a worsening of various health risk factors such as blood pressure. For a relatively small part of the population, the subsequent changes may then develop into clinical symptoms like insomnia and cardiovascular diseases that, as a consequence, can increase rates of premature mortality. Besides the effect due to noise exposure on humans, there is also increasing scientific evidence regarding the harmful effects of noise on wildlife [2]. Whether in the terrestrial or marine environment, many species rely on acoustic communication for important aspects of life, such as finding food or locating a mate. Anthropogenic noise sources can potentially interfere with these functions and thus adversely affect species richness, reproductive success, population size and distribution. Noise pollution is also known to widely affect behaviour in some species. The requirements for identification and protection of quiet areas according to the END ([3]) also presents an ideal synergy with the need to protect species vulnerable to noise pollution and areas of valuable habitat identified by other European assessments, such as Natura 2000 protected sites. Moreover, in the Green Paper on Future Noise Policy in 1996 presented by the European Commission, it estimated the annual economic damage to



Source: Babisch, 2002, based on WHO, 1972.

Figure 1.1: Pyramid of noise effects [1].



Noise level/year	2002	2006	2010	2015
> 55 Lden	2,2	2,2	2,4	2,7
> 45 Lnight	2,7	3,0	3,2	3,2

Figure 1.2: Data from the Commission regarding the number of people affected by noise (in millions) in Europe on base of the 53 airports [8].

the EU due to environmental noise as potentially ranging from EUR 13 million to EUR 30 billion (European Commission, 1996). The Green Paper considered that the key elements contributing to these external costs were a reduction of house prices, reduced possibilities of land use, increased medical costs and the cost of lost productivity in the workplace due to illness caused by the effects of noise pollution. A European Commission working group earlier developed a position paper 'Valuation of noise' [4] based on the willingness–to–pay principle, drawing upon data from [5]. The paper recommends the use of a benefit of EUR 25 per household per decibel per year above noise levels of Lden = 50–55 dB. Even though this threshold has been criticised by some as being too low, it appears that most noise-abatement measures deliver a positive cost/benefit ratio [6].

With specific reference to the aircraft noise problem, in 2002 ANOTEC investigated the noise exposure at 53 airports in Europe [7] accounting for 8.7 million aircraft movements [8] and in the proposal for an updated Directive EC/2002/30 [9] the data and forecasts indicated in Figure 1.2 are presented.

According to Figure 1.2 a significant growth trend in the number of people exposed to airport noise has occurred in the past and is expected in the immediate future. In fact, despite the use of aircraft engines that are increasingly performing also from the point of view of noise emissions is growing, the number of flights and passengers is constantly increasing (Figure 1.3).

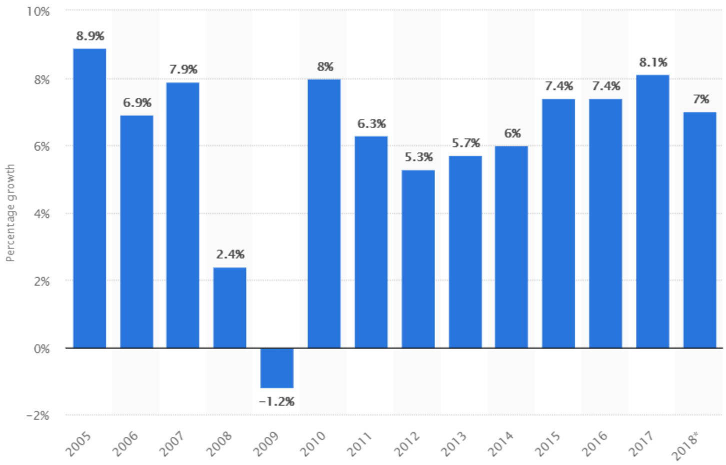


Figure 1.3: Percentages of world aircraft demand from passengers increasing from 2005 to 2018, source:ICAO.

In the context of noise exposure data reported in accordance with the END, aircraft noise affects only the areas immediately surrounding an airport [1]. This is due to the fact that in many cases the reported END data relates only to airports and often considers only flights either landing or taking off at a particular airport. Any other type of overflight is not commonly considered by the END data. Therefore, the different types of environment in which each airport is located could lead to variations in the number of exposed people. This is of special relevance when analysing people exposed to aircraft noise inside agglomerations and the different abatement measures that could be implemented to tackle the situation. On this basis, noise from take–offs and landings at airports affects 0.6 million people at European level above 55 dB Lden outside urban areas (estimations raise this scenario up to 1.25 million people since the data are to be completed). This scenario represents a much smaller proportion if compared with road and rail traffic noise, although air traffic noise is regarded as more annoying than the other noise sources (ISO, 2003). Despite the technological developments occurring in the last 30 years tackling noise at source, the impact of individual events may be very high given the noise levels that could be achieved by each aircraft. Moreover, the growing volume of air traffic is not helping in the reduction of the number of people exposed to aircraft noise, particularly during the night (EU, 2012). Inside urban areas, nearly 2 million people are exposed above 55 dB Lden due to aircraft noise, as reported in August 2013. In general, there is one agglomeration in each Country having, by far, the largest number of exposed people, which in most cases corresponds to the capital city. It is estimated that for all expected airports data, the true value increases to 3.7 million people exposed above 55 dB Lden due to noise from airports. In the majority of Countries, there is only one major airport captured by the END specifications, which is quite frequently located close to the capital city. In bigger countries, such as France, Germany, Spain and the United Kingdom, more than one major airport is identified and therefore reported, so agglomerations other than the capital city have citizens exposed to aircraft noise. Countries with

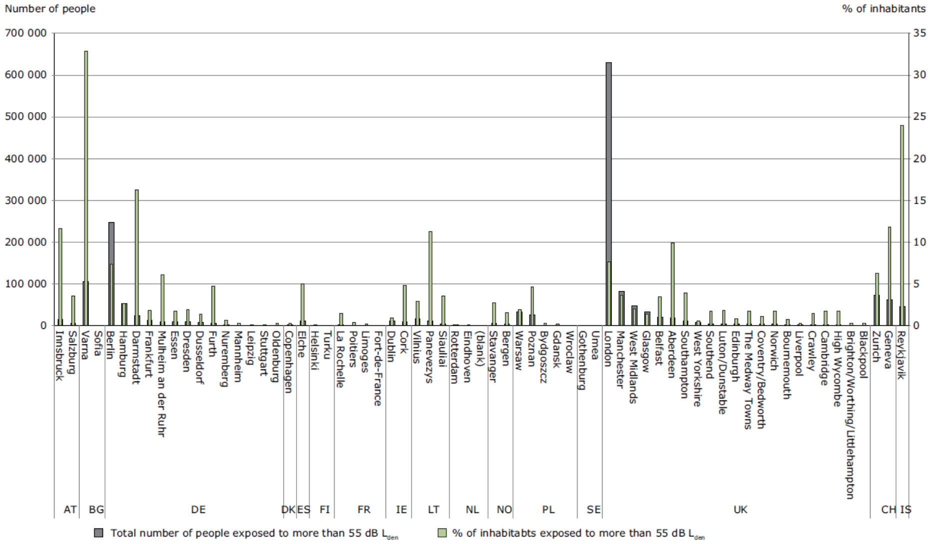


Figure 1.4: Number of people exposed to airport noise Lden > 55 dB per agglomeration total and percentage (2012). Agglomerations sorted by country, then by number of people exposed [1].

larger agglomerations and with higher numbers of inhabitants at country level will have more people exposed to aircraft noise inside urban areas, but this variability will also depend on aircraft traffic volumes, on local factors such as location and surroundings of the airport, and even on population density at country level. This means that urban areas with the highest number of exposed people do not systematically coincide with the agglomerations with the highest percentage of people exposed above 55 dB Lden due to aircraft noise (Figure 1.4).

The main problems regarding the impact of aircraft noise have been summarized in October 2018 in the WHO new guidelines [10] in which strong recommendations are made concerning aircraft noise limits to be respected during the day (45 dB according to the L_{den} parameter) and the night (40 dB according to the L_{night}) periods since these noise levels are respectively associated with adverse health effects and sleep disturbances.

With regard to the various noise sources, and in particular aircraft noise, it is possible to classify the gaps present and the research aspects still open in two main categories: the first related to the objective characterization of noise emission in view of the implementation of noise maps and the need to test the new method of evaluation CNOSSOS–EU to be definitively adopted for the next round of mapping 2021/2022, the second of purely subjective value and related to the perception of aircraft noise and annoyance by children.

The current Thesis tries to give a contribute on both the above–mentioned categories, focusing on the new CNOSSOS–EU calculation algorithm to be adapted by national legislations before the end of 2018 and applied in the next round of 2021/2022 noise mapping and on the study of children exposed to aircraft noise at school and as illustrated in the following paragraphs.

Chapter 2

Thesis goals and structure

The research carried out during the PhD course mainly concerned the necessity stressed by the EC to test the new CNOSSOS–EU calculation methods for noise, including aircraft noise, to be officially adopted by Member States within 2022 and the study of children's exposure to aircraft noise in schools, allowing the development of a new methodology which was then tested in two case studies near the A.Vespucci airport in Florence.

Concerning the first point, a small application has been carried out by testing the new CNOSSOS–EU calculation method in a neighbourhood of the A.Vespucci airport in Florence. Moreover, the simulation's outcomes have been compared with those obtained by applying the INM standard (currently adopted by the majority of Member States) and results have been validated according to an aircraft noise measurement campaign carried out in the proximity of the A.Vespucci airport in Florence.

With regard to the second issue, the analysis of the state of the art highlights the multiplicity of possible effects on children due to chronic exposure to aircraft noise in terms of health, annoyance, cognitive processes and long–term effects. In addition, children are considered more sensitive to noise than adults. In fact, the children need a greater signal/noise ratio to understand a conversation, also taking into account the fact that they have not developed yet a stored knowledge that allows them to reconstruct the meaning of a conversation in case it is disturbed by background noise. More recent studies show, however, that children exposed to aircraft noise may be able to develop resilience mechanisms and get used to this source of noise to the point of developing coping mechanisms that would allow them to obtain results in some cognitive tests even better than children not exposed to noise. The study of the state of the art shows contrasting results in particular regarding cognitive tests and the possibility that children are able or not to develop resilience mechanisms against aircraft noise. Moreover, the tests that were also conducted in the context of European projects such as RANCH, NORAH and SAMBA were carried out during the normal course of school lessons, without the passage of aircraft could be controlled and without the possibility of reproducing the tests in similar conditions in other school environments selected as control–case study, not subject to the disturbance due to aircraft noise. Finally, the scientific literature clearly shows the need to update the existing annoyance curves for aircraft noise specifically for children.

The research activity was therefore mainly directed to the development of a method that could contribute, at least in part, to solve the problems highlighted by the analysis of the state of the art in order to understand if aircraft passages could influence the listening ability of children at school and the development of curves of annoyance specific for children disturbed by aircraft noise. The extensive description of the method is preceded by a protocol in order to facilitate its implementation in further pilot cases. The main innovative elements of the proposed method concern: the design of an electro–acoustic system and an on–site listening laboratory to be considered equivalent to a classroom located near the take–off/landing paths of aircraft and the processing of audio signals capable of reproducing the take–off movement of the aircraft, also representing different environmental configurations or different types of windows, concurrently with the questionnaires submission.

Accordingly, the thesis is organized as follows: Chapter Three presents the state of the art about the main problems related to aircraft noise. The description covers the necessity to test the new CNOSSOS–EU calculation methods and the possible effects of aircraft noise on children. In Chapter Four, firstly the theoretical comparison carried out between the INM and the CNOSSOS–EU standards is described and the design of the proposed test to verify the CNOSSOSS–EU method is illustrated. Subsequently, is presented the novel approach to evaluate the children exposure to aircraft noise and the possibility that exposed children could develop a resilience capacity. After the presentation of the method's protocol, each phase of the method is deeply described: acoustic measurements of aircraft noise levels in classrooms, reverberation time and façade sound insulation; synthesis of the measured signal and calibration of the electro-acoustic system; synthesis of a signal obtained in the presence of virtual conditions of reverberation time and façade sound insulation; tests submitted to children. Moreover, innovative aspects of the methodology with respect to the state of the art analysis are highlighted. Furthermore, the selected pilot cases are introduced: a school located along the landing and take-off routes of airplanes and a control school located in a quiet and residential area far from the airport. In Chapter Five, an application of the CNOSSOS–EU calculation method to the A.Vespucci airport of Florence is described together with obtained results; moreover, the analysis made on the basis of the questionnaires collected in the two pilot schools are illustrated, with particular attention to the comparison between data obtained in the disturbed school and in the control case to understand if a form of resilience capacity could have been developed by the children of the first school. Finally, Chapter Six presents the conclusions of the work and possible improvements that may be addressed in the next future.

Chapter 3

Background

The environmental problems associated with the presence of an airport are never negligible and concern the management of waste, air pollution (gaseous emissions from aircraft operating on the airport and support vehicles), motor vehicle traffic induced by the physical presence in a significant portion of the territory, the exploitation of local water tables and aircraft noise. Among the impacts listed above, aircraft noise pollution on areas near airports is the most evident and frequently reported disturbance element by the population [11]. Noise generated by aircraft depends on a number of factors, including the architecture of the airspace (the entry and exit routes serving a specific airport), the operating procedures adopted to travel the assigned route, aircraft emissions, the engine, as well as the disturbance produced by the means of transport and road traffic induced. In particular, aircraft noise has a greater impact on local communities, especially in areas with a good noise climate, during the initial take–off and landing phases (final descent and braking phase).

In the current dissertation attention is focused on the problem concerning the noise impact on citizens due to airports. Among the several current issues related to this noise source which have been highlighted at European level, it has been decided to concentrate on the study of the new CNOSSOS–EU noise calculation method and on the effects of children exposure to chronic aircraft noise at school.

In the current section a synthesis of the carried–out state of the art analysis is reported mainly focused to these two aspects. It has been deemed useful to divide the presentation of the state of the art into two parts, the first one regarding the new CNOSSOS–EU calculation models and the second one about the effects of children chronic exposition to aircraft noise. Concerning the noise calculation method, an overview about the European processes which have led to their introduction is made (Section 3.1).

Regarding the second aspect, it has been dealt with in Section 3.2. In particular, the first sub–section has been dedicated to the effects of aircraft noise on people's health (Section 3.2.1). Subsequently, a sub–section is also dedicated to the comparison of reactions to noise between children and adults (Sub–section 3.2.2), followed by a sub–section in which the problem of 'annoyance' and of the development of annoyance curves is addressed (Sub–section 3.2.3). Moreover, the longitudinal effects due to the exposure to aircraft noise are analysed (Sub–section 3.2.4) together with the possible consequences in terms of children cognitive processes (Sub–section3.2.5). Finally, the main results achieved by the RANCH, NORAH and SAMBA projects are summarized (Sub–section 3.2.6) and some considerations about the potential resilience capacities and the potentiality of developing coping mechanisms against noise of children are made (Sub–section 3.2.7). The current section helps to provide a starting point for introducing the reasons that led to this PhD research and to clarify the objectives illustrated in Section 2.

3.1 The 2015/996 European Directive and the CNOSSOS-EU project

In July 2015 the EU Directive 2015/996 [12] was published in the Official Journal of the European Union (OJEU), as the result of the Commission of 19/05/2015 which establishes common methods for the determination of noise in accordance with Directive 2002/49/EC [9] of the European Parliament and of the Council.

The establishment of this Directive represents an important conclusion of the path started more than ten years before with the EU Directive 49/2002 which aimed to avoid, prevent or reduce, in accordance with their respective priorities, the harmful effects, including annoyance, of exposure to environmental noise generated (Article 1) by major sources, in particular road and rail vehicles and their infrastructure, aircraft, outdoor and industrial equipment, and mobile machinery. In this regard, Member States have been designated as the responsible for defining noise maps, which should be carried out on the basis of common assessment methods. On the basis of the noise maps, Member States then draw up action plans to avoid and reduce environmental noise where necessary, in particular where exposure levels are likely to have harmful effects on human health, and to maintain environmental noise quality when it is good. Until now, Member States have adopted the noise indicators (Lden and Lnight) set out in Annex I to Directive 2002/49 for the preparation and revision of strategic noise maps. These values are established in accordance with the assessment methods set out in Annex II to Directive 2002/49/EC, which had to be updated to technical progress. As regards Strategic Noise Maps, they are developed using the Common Assessment Methods (Annex II) if these methods have been adopted by Member States, but the latter may also adopt different methods, provided that they refer to priorities identified by the common methods, as well as to assess other national measures to prevent and reduce environmental noise. Finally in 2008, the Commission started the development of the Common Methodological Framework for Noise Assessment under the project ‘Common Methods for Noise Assessment in the EU’ (CNOSSOS–EU) under the leadership of the Joint Research Centre (JRC) which had the objective of standardizing the procedures for quantifying noise exposure in all Member States, so as to have comparable data and to be able to provide policy makers, therefore, with technical tools and scientific evidence for the development of effective policies against the noise problem. The CNOSSOS–EU process in the first part addresses with a technical analysis the link between the noise emission level of the sources (railway noise, road traffic noise, industrial noise, aircraft noise) and the exposed population while in the second part it explains how to carry out an acoustic evaluation by software, specifying the requirements that the latter should have. As far as aircraft noise is concerned, CNOSSOS–EU has adopted as forecast model that one reported in the internationally recognized ECAC DOC 29 [13], a document prior to Directive 996/2015 dealing with standard methods for calculating noise contours around civil airports, from which the predictive model was taken. Once this assessment tool had been consolidated, the associated input database, within its limits of practical application, still needed to be defined. This aspect, together with those ones related to the Directive 2002/49/EC which needed to be further defined and/or have not yet been defined, have been definitely fixed in the European Directive 996/2015 [14]. With the Directive 996/2015 new common assessment and calculation methods have been established or transposed for the main transport infrastructure and they will be officially adapted to the Member States' national legislation by the 31 December 2018 and applied to the 2021/2022 noise mapping round. Until that date Member States can continue to use existing assessment methods that they have previously adopted at national level.

3.1.1 Considerations

According to Section 3.1, the importance and urgency of testing the CNOSSOS–EU calculation method in further pilot cases, also highlighting its limitations, emerges, given that Member States will have to adapt it to their national legislation by the end of 2018 and officially use it starting from the 2021/2022 noise mapping round, also considering what has been expressed at European level [14], [15]. In addition to the need to test the new calculation standards, there is also the urgency to understand how these are implemented within dedicated software. With regard to the latter, it is currently the Aircraft Noise Modelling Task Group (AIRMOD) that is specifically developing case studies. The present PhD research also provides a contribution in this sense, as explained in the Section 5.1.

3.2 Aircraft noise effects on children

3.2.1 How aircraft noise affects health

One of the first scientific report which has analysed the relationship between noise and health was published in Great Britain in 1963 [16]. It stated that: 'for the most part, people's well–being is diminished by noise, so in this sense of the term there is no doubt that noise affects health'. While it concludes that noise affects sleep, it states 'we have not been able to find any evidence that moderate noise (. . .) produces any direct and measurable physiological effect on the average person. The general effect of noise on health must therefore be more psychological than physical (. . .)'.

Between 1996 and 1997 health indicators such as general health status, use of sleep medication and use of medication for cardiovascular diseases have been measured during a cross–sectional survey with 11.812 respondents living in the neighbourhood of the Schiphol airport (Amsterdam) in order to study their relation to aircraft noise exposure [17]. The associations were statistically significant for all the indicators, except for use of prescribed sleep medication or sedatives and frequent use of this medication. None of the health indicators were associated with aircraft noise exposure during the night but use of non–prescribed sleep medication or sedatives was associated with aircraft noise exposure during the late evening. Vitality related health complaints such as tiredness and headache were associated with aircraft noise, whereas most other physical complaints were not. A small fraction of the prevalence of poor self–rated health (0.13), medication for cardiovascular diseases or increased blood pressure (0.08), and sleep medication or sedatives (0.22) could be attributed to aircraft noise. Studies suggest that repeated elevation of blood pressure in relation to noise exposure might have pathological effects on health in the long–term on adults [18]. Obtained results suggest associations between community exposure to aircraft noise and the health indicators of poor general health status, use of sleep medication, and use of medication for cardiovascular diseases.

It is well–known that uninterrupted sleep is known to be a prerequisite for good physiological and mental functioning of healthy persons [19]. Noise can cause difficulty in falling asleep, awakening and alterations to the depth of sleep, especially a reduction in the proportion of healthy rapid eye movement sleep. Other primary physiological effects induced by noise during sleep can include increased blood pressure, increased heart rate, vasoconstriction, changes in respiration and increased body movements [19]. Exposure to night–time noise also may induce secondary effects, or so–called after–effects. These are effects that can be measured the day following exposure, while the individual is awake, and include increased fatigue, depression and reduced performance [20]. Night–time effects can significantly differ from daytime impacts, in this regard the WHO reports an onset of adverse health effects in humans exposed to noise levels at night above 40 dB [21] especially regarding self–reported sleep disturbance, environmental insomnia and increased use of somnifacient drugs and sedatives. In 2003 Miedema et al. published a report on night–time transportation noise and sleep disturbance [22]; a separate report on self–reported sleep disturbance and aircraft noise followed one year later [23]. An exact causal relationship between noise and mental illness remains ill–defined, and it may well be that noise is just one of many factors affecting mental health. The WHO has previously suggested that environmental noise intensifies the development of latent mental disorder. Symptoms cited include anxiety, stress, nervousness, nausea, headaches, instability, argumentativeness, sexual impotency and mood changes. Studies on the use of drugs such as tranquillisers and sleeping pills, on psychiatric symptoms and on mental hospital admission rates do however suggest links between environmental noise and adverse effects on mental health [19]. Concerning the main effects of noise exposure on humans hearing, some studies have shown an increased prevalence of high frequency hearing loss in populations exposed to higher noise levels [24]–[26], while others have not found a significant relation between length of residence in a noisy community and severity of hearing loss [27], [28].

Focusing on children, according to Stansfeld et al. [29], many environmental factors affect their health and development and the knowledge and management of this mechanism is central in order to achieve a sustainable living and the prevention of illness. Noise in particular leads to annoyance, reduces the overall environmental quality and could affect health and cognition [30]. Low birth weight and prematurity have been the outcomes most examined in relation to environmental noise [31], [32]. Moreover, an association between road traffic and aircraft noise exposure and blood pressure in children exists. With specific regard to noise disturbance during the night period and children, they seem to need more time to fully recuperate from nocturnal sleep restriction than adults [33]. Moreover, inadequate sleep results in tiredness, difficulties in focusing attention, low thresholds for negative reactions (irritability and easy frustration), together with difficulties in controlling impulses and emotions [34]. In the study carried-out by Evans [35], psycho–physiological, cognitive, motivational and affective indices of stress were monitored among elementary school children chronically exposed to aircraft noise. It has been demonstrated that chronic noise exposure is associated with elevated neuroendocrine and cardiovascular measures, muted cardiovascular reactivity to a task presented under acute noise, deficits in a standardized reading test administered under quiet conditions, poorer long–term memory and diminished quality of life on a standardized index. Children in high–noise areas also showed evidence of poor persistence on challenging tasks and habituation to auditory distraction on a signal to noise task. The study of Chen et al. [36] investigates the influence of high–frequency aircraft noise on the function of the auditory system of school–age children. The selected sample was characterized by 228 students attending a school located along the flight path of the Kaohsiung airport in Taiwan and 151 students attending a school located far from the airport. The cochlear and retro-cochlear function of students was evaluated with audiometry which indicated that the hearing ability was significantly worse in the children studying in the first school.

In the studies of Evans and Lercher [37], [38], it has been proved that chronic exposure to aircraft noise does not directly affect anxiety and depression, however noise might influence self–reported stress, social functioning, behavioural adjustment and well–being in children. A pattern of physiological and psychological stress responses is associated with chronic exposure to noise in children. In particular, catecholamine secretion is commonly seen as a physiological marker of chronic stress. Chronic high levels of noise exposure have been also associated with higher levels of systolic and diastolic blood pressure [35], [37], [39]–[41] and catecholamine secretion [35], [37].

For young people in general, the risks to hearing are more likely to result from leisure noise from clubs and rock concerts and recently there has been concern over sound levels from personal listening devices. Over the last 20–30 years the number of young people with social noise exposure has tripled to around 19% [42].

In the ENNAH final report [43] the necessity of investigating the long–term health effects of noise exposure especially for children younger than 8 years old is stressed.

3.2.2 Differences with adults in noise perception and effects

Primary school children are particularly vulnerable to extraneous noise sources [44], yet are likely to experience high levels of noise in classrooms [45]. Before teenage years, the younger the child the greater the detrimental effect of noise and reverberation [46]–[49] with children under about 13 years of age being particularly susceptible. Primary school children require more favorable signal–to–noise ratios than adults to achieve comparable levels of accuracy in understanding of speech [50], [51]. Children may be more susceptible to the negative impact of chronic noise than adults, because the understanding of speech in a noisy environment only reaches adult levels in the late teens [52]. Thus, children may have a reduced capacity to anticipate the impact of noise, as well as a lack of well–developed coping repertoires for dealing with noisy environments, relative to adults. Attention, memory, and reading are all involved in cognitive development at primary school age (5–11 years). Children attend to information that is then encoded in memory through processes of rehearsal, organisation, and elaboration [53]. Strategies for retrieval of information from memory develop gradually. Reading depends on perception and memory and, at an early stage, awareness of speech sounds, which could be distorted by ambient noise [54]. In this frame, environmental stressors can have a great effect on the degree to which information is processed, retained and recalled [55]. Furthermore, children are less able than adults to make use of spectro–temporal and spatial cues for separation of signal and noise [56], [57]. These findings demonstrate that children are especially prone to informational masking, i.e., masking that goes beyond energetic masking predicted by filter models of the auditory periphery. Children are also less able than adults to use stored phonological knowledge to reconstruct degraded speech input. In fact, children's phoneme categories are less well specified than adults' ones [58], but also for the lexical level since children's phonological word representations are more holistic and less segmented into phoneme units. Finally, young children are less able than older children and adults to make use of contextual cues to reconstruct noise–masked words presented in sentential context [59] and more distractable [60]. Concerning attention, children's immature auditory selective attention skills contribute to their difficulties with speech–in–noise perception.

3.2.3 Annoyance and exposure–response curves

Annoyance is defined as a feeling of displeasure associated with any agent or condition known or believed by an individual or group to adversely affect them [61]. In addition to annoyance, people may also feel a variety of other negative emotions, for example feelings of anger, depression, helplessness, anxiety and exhaustion.

Comparing the aircraft noise with the other main sources of noise from transports, the effect of aircraft noise on annoyance is roughly 50% higher than road traffic noise and more than 100% higher than rail traffic noise (see figure 3.1). Air traffic is considered second in environmental noise relevance only to road traffic noise. Another reason why air traffic must be considered when investigating environmental noise is that air traffic noise is not evenly spread over the total area of Europe but is concentrated in the vicinity of airports [62].

It is important to underline that the acoustic parameter used to report annoyance curves is traditionally Lden, which may certainly appear suitable to express the noise generated by noise sources such as road and rail traffic but probably less representative of aircraft noise, if analysed in relation to a subjective parameter of noise perception such as annoyance. The aircraft noise, in fact, it is characterized by short–term but high intensity events due to take–offs and landings that can be difficult to assess in terms of annoyance if spread over the whole day.

In areas with day–evening–night aircraft noise levels (Lden) below 70 dB(A), annoyance is among the most important health effects caused by aircraft noise [63]. Several exposure–effect functions for noise annoyance have been established in the past decades, relating traffic noise exposure, including aircraft noise, to the percentage of highly annoyed persons [64]–[66]. Some of them are based on very large data sets, collected from different studies in various countries [65] and for many years defined a sort of de facto standard for noise impact assessment for noise policy issues, e.g., within the scope of noise abatement in the European Union [67].

However, many of the original data sets with studies dating back as far as to the 1960s are by now to be considered outdated and may not any longer correctly reflect the relationship between noise metrics and annoyance measures [68]–[71]. As an effect, in 2010, the European Environment Agency recommended to use

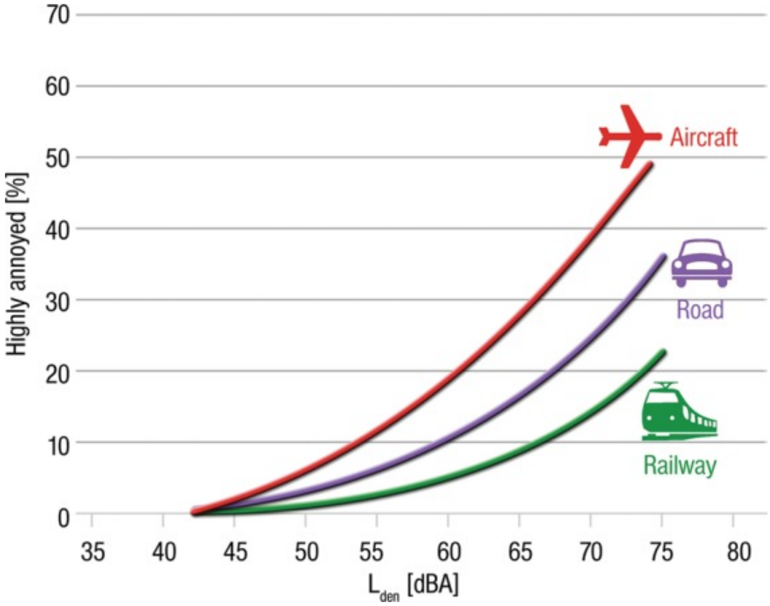


Figure 3.1: Percentage of persons highly annoyed by aircraft, road, and rail traffic noises. The curves were derived for adults on the basis of surveys (26 for aircraft noise, 19 for road noise, and 8 for railways noise) distributed over 11 countries [62].

the updated exposure–response relation with the post–1990 data [6]. Examples of curves of annoyance developed by Miedema et al. and referred to adults are reported in Figure 3.2 in which a distinction is made between annoyed (Graph on the left) and very annoyed people (Graph on the right).

There is evidence that today people are more sensitive toward aircraft noise than they were decades ago. Guski [68] re–analyzed the data from the Miedema and Vos meta–analysis [65] with respect to the year of the study and the respective Lden for 25% highly annoyed (HA) persons and found that the exposure level needed to elicit a particular level of annoyance decreased considerably over the past decades. This trend has also been investigated and confirmed by van Kempen and van Kamp [69] who added more recent studies to the data set. As could impressively be demonstrated in a recent multinational study [73], the annoyance shift seems to be specific to aircraft noise: whereas the so called 'EU curve' [67] for road traffic noise very well matches the exposure-effect relationships that can be found with new survey data, the EU curve for aircraft noise systematically underestimates the percentage of HA persons at any given exposure level. Concerning the reasons of this shift of the exposure-effect curve, several explanations are being currently discussed. On the one hand, in the past two decades, as Bröer argued [74], aviation is no longer considered a sign of modernity and technical progress, and probably steadily lost its technological advancement appeal to its adverse effects such as noise and air pollution. On the other hand, the numbers of air traffic movements have doubled or tripled at many airports in the past decades, whereas the sound energy of single aircraft movements has consistently decreased, thus altering the trade–off between number of movements and total sound energy of all movements which might also lead to a change in the overall perception of aircraft noise and

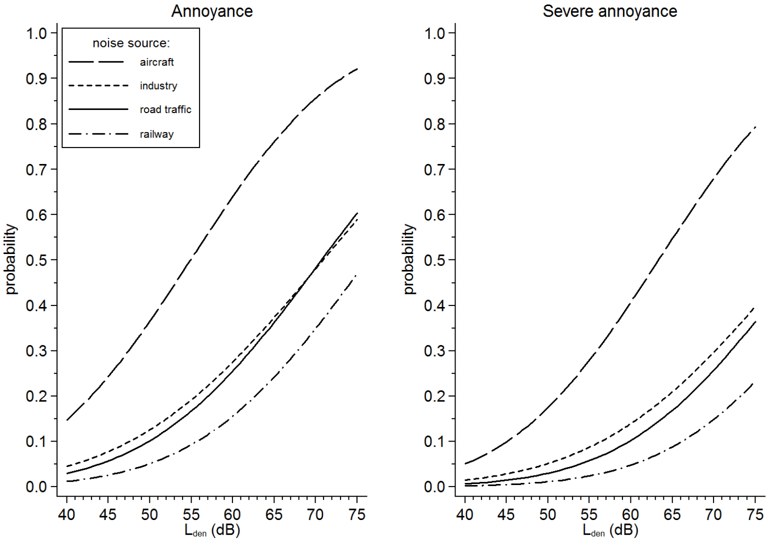


Figure 3.2: Probability of annoyance and severe annoyance from aircraft, industry, road traffic and railway noise as function of Lden (source: Miedema and Oudshoorn, 2001; Miedema and Vos, 2004a; Janssen en Vos, 2009) [72].

ultimately to an increase of annoyance. It has been reported as a result of the recently published ANASE study in the UK [75] that the number of aircraft movements today better explains variance in annoyance than it did 20 years ago [76]. Further possible explanations for this trend, e.g., increasing public debate about the continuous expansion plans of airports, have been discussed in van Kempen and van Kamp [69]. In conclusion, in noise effect research, routinely updating the databases for establishing exposure–effect functions that provide a sound basis for noise impact assessment for current and future scenarios is a permanent necessity. When it comes to forecasting community response to aircraft noise after a (prospective) operational change (e.g., opening of a new runway), an additional source of uncertainty in the estimation of the degree of annoyance potentially comes into play, the so–called over–reaction effect. The study carried out by Brink et al. [77] aims to tackle both these issues. A typical application for exposure-effect functions that are derived from community surveys would be when public authorities must forecast future annoyance in the course of a prospective airport expansion, opening of a new airport, or changes of the flight regime or operating plan. As such parameters change, they usually elicit a step change in exposure. There is evidence that a step change of noise exposure generally goes along with a so called ‘over–reaction’ of the residents: with an increase of the exposure level, people are more annoyed than would be predicted by steady-state exposure-effect curves, whereas with a decrease of the level, they are less annoyed than would be predicted by the same curves [78]–[80]. Although some models and tentative explanations have previously been published [81], the mechanism of how residents judge their level of annoyance in response to the exposure change is not understood in detail. As pointed out by Fidell et al. [79], the lack of information may partly be due to scarce opportunities to carry out field studies on the effect of abrupt and clear changes in noise exposure. It is useful, however, to seek a better understanding of these effects, in order to serve the interest of local governments, airport authorities, and the public in as precise as possible predictions of the effects of (future) changes of noise exposure.

The two surveys carried out around Zurich Airport in 2001 and 2003 [77] provide the most up to date exposure-effect functions for aircraft noise in Switzerland, developed with the application of logistic–regression models and related polynomial approximations. The Lden function curve for the average model runs about parallel with the generalized EU curve published in the EU position paper on noise annoyance [68] but is shifted toward the left by about 5 to 10 dB, indicating that the percentage of highly annoyed persons is actually higher than would be predicted by the EU curve (Figure 3.3). The current data provide additional evidence that annoyance has increased in the past decades and that aircraft noise annoyance of residents in Europe (and probably elsewhere too) nowadays no longer seems to be well reflected in the EU curve, confirming other recent findings from the UK, Germany, The Netherlands, Greece, Spain, and Italy [73], [82]–[84].

As highlighted in Paragraph 3.2.2, in comparison with adults, children may be particularly vulnerable to the effects of noise because they have less capacity to anticipate, understand, and cope with stressors [86]. In the research carried out by Van Kempen et al. [85] almost 3 thousand children aged 9–11 years have been recruited from primary schools located around the Heathrow airport (London, UK), Schiphol airport (Amsterdam, The Netherlands) and Madrid–Barajas airport (Spain). Questionnaires on annoyance at school and at home to students and on potential confounding factors have been submitted to children and parents and data analysis carried out by using the PCA method. The most interesting outcomes were that the only significant confounder was the mother education, that severely annoyed children agreed more often that 'noise makes it hard to work' than children who were less annoyed and a stronger correlation between aircraft noise levels and annoyance rather than road traffic noise and annoyance has been highlighted. From Figure 3.4 it is possible to see that from an average value of 63 dB(A) the percentage of severely annoyed children becomes significant ($\sim 15\%$). According to the RIVM report [72], exposure–response relations for noise annoyance among adults have been widely studied, and large datasets have allowed the construction of 'generalised' relations. At the moment several source–specific exposure-response relations for annoyance are available. Otherwise, for children generalized exposure-response relationships are lacking. According to Lercher [38] this omission is due to a lack of a standard methodology for measuring annoyance in children and insufficient representative data on which to base a generalized exposure–response relationship. Also according to the ENNAH final Report [43] there are some open issues concerning exposure–response curves, with particular regard to the updating of dose–response relationships, particularly noting the trends in levels of increasing aircraft noise annoyance over recent years, the assessment of exposure–response curves specifically for child populations and the further examination of exposure–effect relationships in different contexts, for different samples and vulnerable groups and for different noise metrics, whilst recent evidence of exposure–effect relationships between noise exposure and children's cognition has provided knowledge about thresholds for effects.

3.2.4 Longitudinal effects

Long–term exposure to noise may initially impair performance on cognitive tasks, but the effect may diminish over time as the individual becomes habituated to it

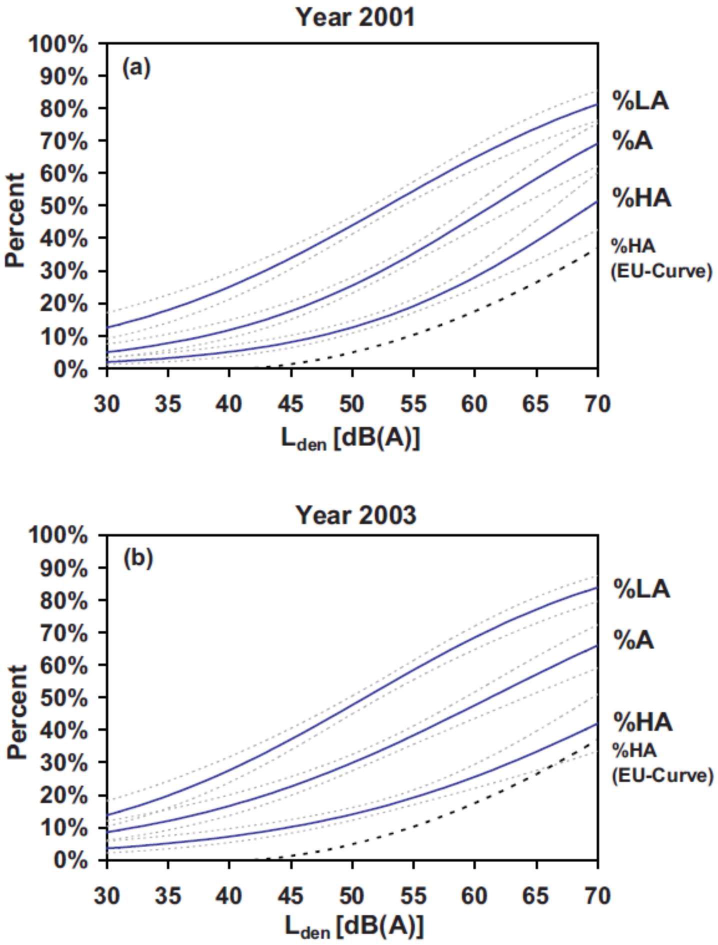


Figure 3.3: Percent little annoyed (%LA), annoyed (%A), and highly annoyed (%HA) as a function of Lden, with 95% confidence limits. (a) Survey 2001, N = 1538. (b) Survey 2003, N = 1452. The EU-curve (European Commission, 2002) for %HA is shown for comparison [85].

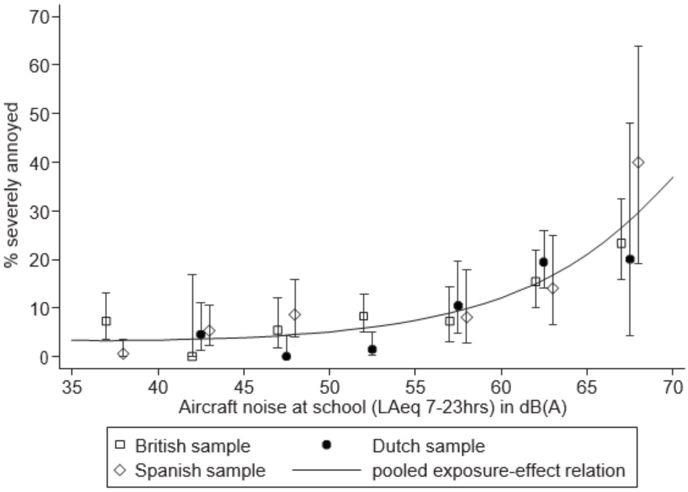


Figure 3.4: The country–specific percentage severely annoyed children by 5 dB bands of aircraft noise (LAeq,7–23 h) at school and the relationship between aircraft noise at school and the percentage of children severely annoyed derived after pooling the data and adjustment for confounders. The vertical lines correspond to the 95% confidence interval [85].

or learns coping mechanisms, such as filtering out distracting auditory stimuli [87]. A significant number of studies have addressed the issue related to the longitudinal effects due to the aircraft noise exposure [88]–[93] with reference to the airports of Munich (Germany), London (United Kingdom) and Durban (South Africa).

The common adopted procedure is to carry out cognitive tests with children living in the proximity of an airport before and after its closure (experimental groups), also by involving control groups.

In Munich the study began in the fall of 1991 [88] before the change–over of airports. The two experimental groups were comprised of the children at the old Munich International Airport that were exposed to high levels of aircraft noise and the children who were to be so exposed at the new airport, all aged 9–12 years when the study started. The two control groups were selected from areas that were not or would not be exposed to much aircraft noise and they were matched with their respective experimental groups on the basis of socio–demographic characteristics. One wave of data collection occurred prior to the change over of airports, the second wave one year later and the third wave two years later. A total of three hundred twenty-seven children took part in all the measurement waves. The main obtained results are that cognitive tasks requiring central language processing (recall and language mastery) are particularly sensitive to noise. For the studied age–span these effects turned out to be reversible, but there is no certainty of how much the reversibility is locked at that age group. The memory span in running memory appeared to be improved when the old airport closed down.

Despite in developed Countries several studies about the existence of negative associations between aircraft or road traffic noise and children's reading comprehension [29], [52], [63], [88], [92], [94]–[99], memory [29], [52], [92], [95], [98]–[100], attention [92], [98], [101], motivation [29], [98], blood pressure [55], [98], annoyance/quality of life [52], [98], [102] and stress [92], [98] have been carried out, little is known about the associations of aircraft noise exposure with children's performances in developing countries, with specific reference to the African contexts. The study carried out by Seabi et al. [89] has been conducted in South Africa on the basis of a three–phases baseline survey before (involving 732 children with a mean age of 11.1 years, range 8–14), immediately after (involving 649 children with a mean age of 12.3 years, range 9–15) and one year after (involving 174 children with a mean age of 13.3 years, range 10–16) the relocation of the Durban International Airport in South Africa to La Mercy. Participants were divided among those strongly exposed to airport noise and those living in a quiet environment.

The study was guided by the following questions:

1. Is there a statistically significant difference between children in the noise and quiet groups on how they cope with noise exposure before and after relocation of the airport?
2. Is there a statistically significant difference between children in the noise and quiet groups in terms of disturbances to activities at school and home before and after relocation of the airport?

Concerning coping mechanisms, one qualitative study explored children's perceptions of noise and how they coped with it [55]. Children reported that their daily activities (homework, school work, playing) were affected by high levels of aircraft noise. Depending on how capable children are of controlling the effects of noise sources, they implemented different coping strategies. Although they felt that they could close the windows or tell their neighbours to be quiet, they were not in control over noise generated outside their homes such as aircrafts and busy roads. In order to cope with the sources of noise, the majority of these children covered their ears, wore headphones or played music, and these methods were followed by thinking about something else and telling the person to be quiet. Children's activities were substantially disturbed at school throughout all the phases of the study within the noise-exposed group than those in relatively quieter zones. Then, children who were exposed to aircraft noise continued to use more coping strategies (e.g. covering of ears, tuning out, and waiting for noise to finish) than their counterparts despite the relocation of the airport. Taken together, these findings provide evidence that aircraft noise exposure adversely affects children's school activities and that these effects have a long-term impact on children's behaviour. Moreover, the same sample of 820 children took part in a second experiment during which measurements were made, by means of standardized tests, of episodic memory, recall and recognition, prospective memory, working memory, attention, non–verbal intelligence and questionnaires about socio-economic status, perceived health, parental level of education, noise perception, sensitivity to noise and annoyance caused by noise were submitted to children's parents, teachers and children. The main obtained results is that background noise has a minor effect on memory then expected. Then, while a negative effect of aircraft noise was found on perspective memory, a little effect was highlighted on episodic memory recall and recognition, working memory and attention. The last finding could be due to a mechanism of habituation. In London cognitive tests have been performed both in schools exposed to high aircraft noise levels in a neighbourhood of the Heathrow airport of London and in low-noise impact areas [103] and the main obtained result was that children exposed to high levels of aircraft noise at school have higher levels of noise annoyance than children studying in low noise exposed schools. One year later the same experiment was repeated [92] and obtained results show that it is still unknown whether prolonged exposure to aircraft noise results in increasing adverse effects, or whether the effects remain constant, or the effects lessen or disappear. This outcome is confirmed also in the ENNAH final report [43] which motivates to understand the burden of disease and disability–adjusted life years in relation to noise exposure and cognitive impairment confirming that, so far, the assumption has been made that there is no lasting effect of noise exposure on cognition after the cessation of noise exposure but this has not been empirically tested yet. Children's development in reading comprehension may be adversely affected by chronic aircraft noise exposure. Moreover, a significant noise effect on reading remained at follow-up indicating that further noise exposure over time was associated with an increase in the size of the difference in reading impairments in the high noise exposed group compared with the control sample. Noise annoyance remained constant over a year with no strong evidence of habituation. Chronic aircraft noise exposure was associated with poorer sustained attention in children. Aircraft noise adversely affects the performance and health of school children and that these effects do not habituate over time. Adaptive behaviours may reduce the immediate stress response in the form of physiological adaptation, but the coping process itself may have adverse health effects that might be measured through self–reported stress [104].

3.2.5 Cognitive processes

It is generally accepted that noise has a detrimental effect upon the cognitive development of primary school children [63], [105]. In the study carried out by Shield and Dockrell [106] the effects of chronic noise exposure upon children's academic attainments have been evaluated by comparing noise levels measured inside and outside classrooms in England and Wales with recognized standardized measures of children's attainments in primary school. From the carried out analysis it turned out that external noise has a significant and negative impact on children performances especially on those of older children. Moreover, children appear to be particularly disturbed by noise generated by individual external events (trains, planes, lorries, motorbikes). During the research of Bridget and Dockerell [107] noise and cognitive surveys were carried out in 16 primary schools in central London in 140 classrooms. The results of the correlation analysis between measured noise levels in schools and the results of standardised assessment tests suggest that internal classroom noise is related to children's performance and the noise parameter most closely associated with questionnaires' scores is the background noise level (LA90) in occupied classrooms.

Two major reviews published in the early 1990s, concluded that chronic noise exposure of young children has an adverse effect, particularly upon their reading ability [102], [108]. Moreover, the effect of chronic aircraft and road traffic noise exposure on reading comprehension in primary school children is definitely established [35], [103], [109]–[112]. 'Reading impairment' is defined as the lowest 10 percentile of the reading scores of the children exposed to noise levels under 50 dB Lden. From the approach it follows that, otherwise than for noise related annoyance and sleep disturbance, there is a certain percentage of reading impairment in the absence of noise. The increased risk in reading impairment due to noise

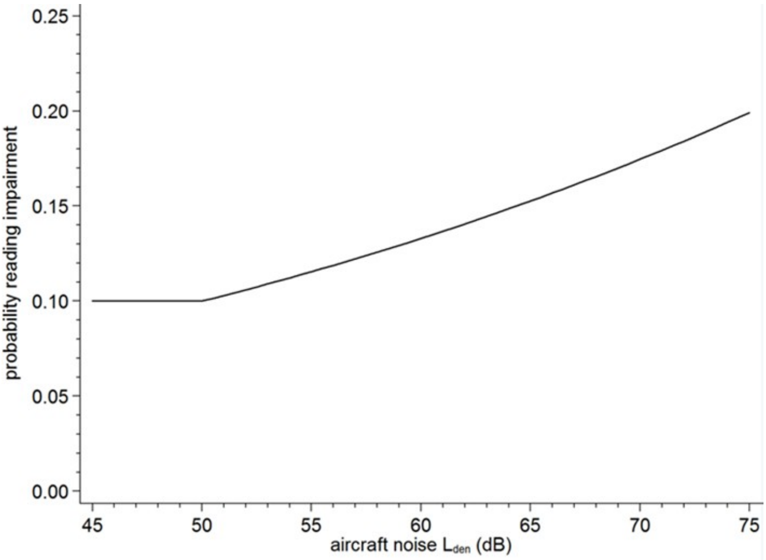


Figure 3.5: Probability of reading impairment among children 7-17 year old as function of Lden (aircraft noise) [95], [113]

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exposure can be described with a logistic model [95], [113] (see Figure 3.5).

Numerous studies have uncovered associations between ambient noise exposure and reading deficits among elementary–aged schoolchildren [102]. Moreover, the negative impacts of school noise levels on reading acquisition were exacerbated by home noise exposure [55], [111] and appeared more severe among children with poorer reading aptitudes [114].

In the study carried out by Evans et al. [109] a pilot school located within the 65 Leq flight contour of a major New York metropolitan airport was selected. The school is affected by noise peaks exceeding 90 dBA during overhead flights while the number of overflights during school hours is one flight per 6.6 minutes averagely. In the same study a ‘control’ school located in a quiet neighbourhood and matching the other school in terms of percentage of children receiving subsidized school lunches, ethnicity and of pupils with English as second language has been also selected. Children’s reading skills were assessed according to a standard test in order to determine whether the relation between noise exposure and reading is caused by deficits in language acquisition and to ascertain whether the link between noise exposure and reading deficits is the result of chronic or acute noise exposure. Obtained results showed that the association between noise exposure and reading is due to chronic exposure. Moreover, authors demonstrated that ambient noise exposure is associated with impairments in speech perception which, in turn, are correlated with reading development.

The in–depth work of Haines [97] aimed to study the effects of chronic exposure to airport noise in relation to London’s Heathrow airport by selecting 10 schools located in an area very exposed to airport noise and 10 schools located in a low–impact area, for a total of 451 students. The results indicate that chronic aircraft noise exposure does not always lead to generalized cognitive effects but more selective cognitive impairments in children exposed to chronically high levels of noise exposure [35], [55], [104], [115]. The noise effect on reading confirms previous studies [35], [92], [102], [103], [109] that noise exposure is associated with poorer reading performance but that the effects are confined to difficult items and not on simple items. Taking the annoyance results of this study together with previous studies in children and adults, it can be concluded that chronic noise exposure is associated with raised noise annoyance in children.

Listening under noisy conditions is more effortful, as the individual must use increased cognitive capacity to decode verbal information, which may be misheard, misunderstood or not heard at all[116]. Noise removes attention from the target task and thus, when it occurs at the same time as learning, is likely to negatively affect how information is processed, stored and retrieved [117]. Concerning the interference of noise with speech intelligibility, it can be assumed that a conversation in which are present also unfamiliar words will be fully understood with a signal to noise ratio of +15 dBA [118]. However, assuming a constant sound to noise ratio, the percentage of intelligibility is inversely proportional to the reverberation time [119]–[124]. Moreover, the younger children appear to be less able to distinguish words against the background noise [59], [125], [126]. As a consequence, elementary–school children need a sound to noise ratio closer to + 20 dBA.

When the noise occurs during learning time, it may significantly impair cognitive processing and have long–term effects on the achievement of academic potential also affecting the mechanisms of memory. Memory functioning reflects a range of abilities involving information encoding, storage and recall. Of these, working memory, episodic memory and prospective memory are particularly central to learning. Working memory is defined as a processing resource of limited capacity, involved in the preservation of information while simultaneously processing the same or other information and it is involved in the initial acquisition of information [127]. Episodic memory is defined as the ability to recall and mentally re–experience specific episodes from one's personal past and is contrasted with semantic memory that includes memory for generic, context-free knowledge [128]. Prospective memory is defined as the ability to remember to carry out intended actions in the future [128]. While there is evidence that noise has an adverse effect on children's reading comprehension, investigations of the effects of noise on memory have produced equivocal findings [97], [99], [129]. As an effect, according to the ENNAH final report [43], greater understanding is needed of the mechanisms of working memory and episodic long–term memory. Concerning the effects of noise on attention and learning, it is strongly probable that noise levels varying over time, such as passing aircraft or heavy vehicles, have an influence on concentration while a reduction in noise according to an upgrade of the classroom seems to tangibly favour the children concentration [130], [131]. As an example, an intervention concerning the insulation of doors and windows of a classroom could result in a noise reduction up to 15 dBA. The objective of the work carried–out by Ando [132] was to find effects of noise stimulus during tasks and effects of daily aircraft noise in the living area on mental efforts of growing children. Pilot tests have been made on 1144 elementary school pupils respectively living in a noisy area around the Osaka International airport and in a quiet area divided in four schools, two of them located in the first zone and two in the second one, two age groups (7–8 years old and 9–10 years old) and two different conditions (presence or absence of noise stimuli). Firstly, the noise produced by a Boeing 727 which was taking off was measured, resulting in a 90 ± 5 dBA intensity, and recorded at a distance of 1.5 km from the airport; then the jet noise stimulus was reproduced during cognitive tests by locating the loudspeakers in front of the classroom. In case of actual aircraft transit the noise caused in the school yard was about 75 ± 15 dB(A) but the level in the room was about 25 dBA less than the simulated one. The evaluated parameters were: mean working amount, agitation, V–type relaxation which is supposed to be caused by an abandonment of effort when mental functions are unbalanced or disordered (e.g. by aircraft noise exposition). Obtained results showed that no fundamental differences emerged between the two schools located in the noisy area and in the two school located in the quiet one. However, significant differences occurred in the test results between the two living areas and the two conditions of stimuli/no stimuli. For a first simple test significance levels were present only for ‘Agitation’ and the proportion of agitated pupils in the noise stimulus group was rather high especially during the first part of the simple test while the proportions of all groups in the second half were almost the same. The proportion of agitated children were not so different between the two areas especially in the first part of test, while in the second a 15% difference was obtained in the second half under the quiet condition. Regarding the ‘V–type relaxed’, results were independent of the noise condition, especially during the first half of the test.

The influence of classroom’s characteristics on cognitive processes

Previous studies have shown that schools may be exposed to high levels of environmental noise, particularly in urban areas [133], [134]. Sources include road traffic, trains, aircraft, and construction noise. Inside schools a wide range of noise levels have been measured [51], [135]–[138]. Levels varying significantly between different types of space and different classroom activities [133]. For much of the day, in primary schools, young children are exposed to the noise of other children producing ‘classroom babble’ at levels typically of around 65 dB(A) LAeq [133], to be considered as the most disturbant noise in the classroom [139], while the typical overall exposure level of a child at primary school has been estimated at around 72 dB(A) LAeq.

Generally spoken, the noise in a classroom is made up of background noise (noise from external sources, e.g aircraft noise plus noise transmitted from other areas of the school), in addition to the internally generated one [140]. It is generally recognised that background noise level in a classroom should not interfere with the ability of the children to hear the teacher and it should be kept below 50 dB(A) [141]. In noisy and reverberant classrooms (i.e., when the noise takes time to fade away), elementary school children have greater difficulty in both speech perception and listening and, consequently, in learning to read [108] if compared to older school–aged peers or adults [116], [139], [142], [143]. Younger children appear to be less able to distinguish words against background noise due to the higher–order cognitive functions (e.g., short-term storage) involved in comprehension [108], [116], [144]. Children may not perceive environmental noise as a major hazard, however they may be annoyed to a degree that interferes with their tasks. Moreover, the typical classroom noise affects children’s performances in terms of letters, number and word recognition [108], [141], [145]–[147].

Mackenzie [138] compared the performance of children in primary school classrooms that had been acoustically treated, thereby reducing background noise levels, with children in untreated classrooms. Children performed better in word intelligibility tests in the acoustically treated rooms, the improvement being particularly marked when other pupils were talking in the classrooms. Similar results were obtained by Maxwell and Evans [146] in a study of pre–school children who had been exposed to levels in the classroom of 75 dB(A). Following acoustic treatment to reduce the noise the children's performance improved in letter, number and word recognition. Similarly, Bronzaft et al. [148] found that children staying on the noisy side of the school building had poorer performances on achievements tests than those in classes on the quiet side of the school.

Acoustic conditions at several elementary and high schools have been revealing unsatisfactory since the 70's according to the point of view of teachers [149], [150]. In particular, in the pilot study carried out by Ko [150], results show that aircraft, vehicle traffic noise and noise caused by school activities is associated with reactions of discomfort, fatigue, tension and interference with speech and teaching. In fact, often teachers are forced to interrupt the lesson while an airplane goes by [151], [152], reporting that under conditions of aircraft noise, part of the lesson time is lost [153]. More generally, teachers' reports collected during the study of Spilski et al. [154] indicate impairments of classroom instruction due to aircraft noise. Moreover, 20–25% of aircraft noise exposed teachers reported disorders of communication, attention, and concentration of students [155]. Overall, the impacts of aircraft noise on teaching conditions have hardly been explored, although it could be a possible reason for the predominantly negative effects of aircraft noise on reading performance.

In the frame of the GIOCONDA project [156], several internal and external measurements of daily noise levels, together with façade and wall insulations, reverberation time and speech intelligibility (STI) [157] have been made in eight different schools demonstrating that most of the evaluated parameters do not comply with the law requirements for schools, with particular reference to the reverberation time which is strictly related to the learning processes. In this frame, also a Global Noise Score (GNS) was evaluated for each classroom starting from all the measured noise parameters. Values assumed by the GNS index resulted insufficient for at least 4 classrooms over the 24 analysed.

According to the final ENNAH Report [43], to date there has been little research testing sound insulation of classrooms and future research needs to examine whether learning impairments related to aircraft noise can be reduced by sound insulation of the classroom in large scale studies. Moreover, it is necessary to carry out further study of speech intelligibility and memory in less than perfect acoustical classroom conditions. Further studies examining classroom acoustical factors such as reverberation and speech–to–noise ratios in relation to performance are required in larger scale studies.

3.2.6 Results achieved in most recent European projects

In the current section the most recent and structured tests aimed at assessing the influence of aircraft noise on certain cognitive aspects of children and used in major research projects at European level are reported, with particular regard to the RANCH, SAMBA and NORAH projects.

The RANCH project (Road traffic and Aircraft Noise exposure and Children's cognition and Health: exposure–effect relationships and combined effects) is the largest cross–sectional study of noise and children's health and it was set up to investigate the relation between exposure to aircraft and road traffic noise and cognitive and health outcomes. A sample of almost 3 thousand children aged 9–10 years attending 89 primary schools near Schiphol, Barajas, and Heathrow–airports in the Netherlands, Spain, and the UK has been involved in the study. Measured variables have been external and internal noise due to aircraft noise and road traffic, reading comprehension with nationally standardised and normed tests, episodic memory (recognition and recall) by a task adapted from the child memory scale [158], sustained attention by adapting the Toulouse Pieron test for classroom use [159], working memory by using a modified version of the search and working memory by the search and memory task [160], [161] to measure and prospective memory by asking children to write their initials in the margin when they reached two predefined points in two of the tests. Moreover, health outcomes include noise annoyance, blood pressure, overall mental health and self–reported health. Main obtained results have been a statistical significant linear exposure-effect associations between exposure to chronic aircraft noise and impairment of reading comprehension and recognition memory and a non-linear association with annoyance maintained after adjustment for mother's education, socio–economic status, long–standing illness and extent of classroom insulation against noise. Aircraft noise, because of its intensity, the location of the source, and its variability and unpredictability, is likely to have a greater effect on children's reading than road traffic noise, which might be of a more constant intensity [162], [163]. Moreover, it was estimated that a 5 dB difference in aircraft noise perception could led to a 1–month reading delay in The Netherlands and in a 2–months reading delay in the UK. An additional outcome was that chronic road traffic noise exposure at school had no significant effect on reading comprehension [164]. This is coherent with the outcomes of the study of Banbury et al. [163] who suggests that sound that varies appreciably over time will impair cognitive performance, whereas sound that does not is associated with little or no impairment. Aircraft noise exposure may also cause higher arousal levels than road traffic noise, significally interfering with performance tasks such as reading comprehension [165].

The NORAH (Noise–Related Annoyance, Cognition, and Health) is a joint project of researchers from different disciplines designed to elucidate the effects of transportation noise on citizens of the metropolitan area of Rhine–Main around Frankfurt/Main airport in Germany. The study examines the chronic effects of aircraft noise on primary school children in 29 schools near the Frankfurt airport [154]. A specific NORAH sub–project started in 2012 addressed potential effects of aircraft noise exposure on reading, reading–related phonological abilities, and quality of life in primary school children in the Rhine–Main region. The study does not focus on how loud it is in the classroom when children are learning, but on the possibility that continuous aircraft noise could influence the intellectual development of the children, demonstrating that they learn to read more slowly than children growing up in a quieter environment. During the Project noise levels describing the exposure of the children at home and in the school over a prolonged time period have been measured. Some of the tests scheduled in the NORAH project are carried out with headphones in order to eliminate as far as possible factors that hinder comprehension, such as acute aviation noise, noise from adjacent rooms, reverberation time in the classrooms, or the distance of the child from the teacher's desk. One of the tests concerns long–term memory and consists in reading a story to children who then are asked to answer questions on it, considering that earlier studies on the impact of aviation noise on the long–term memory had given rise to contradictory findings. Reading and verbal precursors of reading

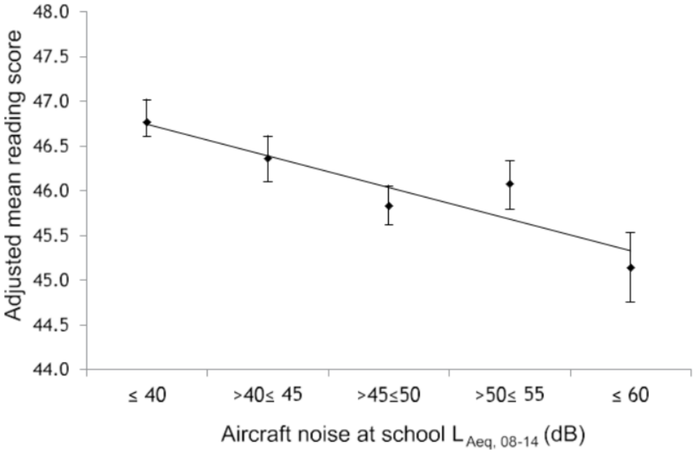


Figure 3.6: Exposure–effect relationship for global reading scores. Note. Adjusted mean reading scores (T-scores), with 95% CI (confidence interval) for 5 dB bands of aircraft noise at school [153].

acquisition (e.g. speech perception, short–term memory, phonological awareness) were assessed through standardized paper–and–pencil tests administered in groups of whole classes. Aircraft noise levels measured at school ranged from 39 to 59 dB (LAeq, 8-14) and thus considerably revealed to be lower than in previous studies. Aircraft noise exposure at school was significantly associated with a decrease in children's reading (see Figure 3.6).

A 20 dB increase of aircraft noise at school was associated with a two–months reading delay in this test. For reading outcome variables, the associations between aircraft noise was described best with a linear function. At the end of the study, aircraft noise was significantly associated with lower ratings of children's mental and physical well-being also at school. Multilevel analyses revealed linear exposure–effect associations between aircraft noise exposure and children's reading, well-being at school, physical and mental well-being, and annoyance after full adjustment. Moreover, a 20 dB increase in aircraft noise was associated with a 2-months delay for the whole sample. Otherwise, no effect of aircraft noise was found for auditory–verbal precursors of reading acquisition, that is, phonological processing and listening comprehension. Thus, no evidence was found for the assumption that the association between aircraft noise and reading is mediated by direct effects on verbal precursors of reading. Finally, increasing aircraft noise was significantly associated with increasing annoyance responses in children. The significant correlation between children's ratings and aircraft noise levels at school confirms that children as young as 8 years old are able to give valid judgements of environmental quality.

The objective of the S.Am.Ba study (Study on the effects of the environment on the health of 700 children living in Ciampino and Marino) [166] is to investigate the effects of exposure to noise on the health of children attending the IV and V classes of the primary schools located in the municipalities of Ciampino and Marino (Lazio, Italy), exposed to aircraft noise due to the proximity of the G.B. Pastine airport. In particular, the hypothesis of association between exposure to environmental noise and cognitive performance of children, perceived annoyance and blood pressure level is evaluated. Regarding the assessment of cognitive performance, children are given cognitive tests in class similar to those used in the RANCH project during the normal course of lessons. Evaluations have been made with regard to cognitive level of children, text comprehension, visual–spatial memory/working memory, sustained attention, episodic memory, discrimination between sounds of interest and background noise. Specifically, with regard to the text comprehension, children are made to read a story in their minds and then answered 14 questions regarding the text they have just read; with regard to the episodic memory, the deferred memory and the associative re–enactment, children are made to listen to a story and, after 20–25 minutes, answer ten questions regarding what they had listened to using only the memory; while with regard to annoyance, the children are asked, through a questionnaire, to express their level of annoyance due to aircraft noise. One of the main results is the significative level of risk to show difficulties in the discrimination between sounds of interest and background noise among children attending noisier schools. Moreover, multilevel analysis show that there is a strong association between exposition to noise and perceived disturbance. The exposure to noise has been associated to a reduced capacity of reading challenging texts and in an increasing in annoyance. However, high noise levels have not been associated to a reduction in the average score of the reading test, to the recall ability, to the level of attention or to the stress response. Moreover, if deep concentration is requested, the proportion of 'V–type relaxed' pupils will be increased by the daily noise as a chronic effect on mental performance in noisy areas. However, the proportion of relaxed pupils will be almost the same at the time the noise occurs as when it is absent. If little concentration is needed to perform a task, the percentage of 'agitated' pupils will increase by the noise stimulus only at the beginning of the test and no cumulative effects of daily noise appear on the simple task. As a consequence, an adaptation is expected after some trials since agitation does not appear in the second part of the test.

3.2.7 Resilience mechanisms

Whilst there have been a number of studies [29], [106], [109], [167], [168] demonstrating an association between exposure to chronic noise, and annoyance, memory, reading comprehension and attention, recent studies [89], [90], [93] have suggested otherwise and that children may be more resilient to noise than expected. Learning under noisy conditions requires more effort since children must use increased cognitive capacity to process information. When noise disturbs teaching and learning, cognitive processing may be impaired and academic potential in the long–term may be compromised [52], [116], [117]. Under noisy conditions, listening requires greater effort than in quiet environments [90]. Noise removes attention from the target task and when it occurs at the same time as learning, it has a negative effect on how information is processed, stored and retrieved [117]. Children may be more susceptible to noise than adults, because children's understanding of speech in a noisy environment only reaches adult levels in the late teens [109]. Thus, children may have a reduced capacity to anticipate the impact of noise, as well as a lack of well-developed coping repertoires for dealing with noisy environments, relative to adults. When the noise occurs during learning time, it may significantly impair cognitive processing and have long-term effects on the achievement of academic potential. Resilience develops when children find ways of coping in the learning situation – called cognitive coping [44] – so that noise is dealt with by tuning it out.

Shield and Dockrell [44] argue that this should result in generalised poor attention, which implies that a full range of cognitive tasks would be affected but does not appear to happen. The noise–exposed children performed better than children at the quieter schools on the cued recall measure of episodic memory and working memory. However, noise exposed children performed significantly worse than their peers at the quieter schools on prospective memory. The groups did not differ on free recall of episodic memory or attention. An additional conclusion reached in the study of Goldschagg et al [91] is that children in noisy environments may develop coping mechanisms, including increased control mechanisms such as working memory. This supports models of cognitive arousal which propose that noise enhances attention and performance via stochastic resonance. While children's memory capabilities may be more resilient than anticipated, chronic noise may impair aspects of memory vital for learning, such as prospective memory.

The cognitive coping strategy is the most important theoretical psychological model of environmental stress that has been applied to explain the effects of noise on child performance and health according to Cohen [55]. In fact, children may adapt to noise interference during activities by filtering out the unwanted noise stimuli and it is possible that the impairments in attention, auditory discrimination and/or speech perception may mediate the association between noise and child cognitive performance [92], [103], [109], [110]. Cohen at al [55] also found that the noise–reading linkage was largely explainable by auditory discrimination and that children chronically exposed to loud noise would cope with the interfering and annoying impacts of noise by learning to tune out auditory stimuli.

In the work of Prodi et Visentin [169], during the implementation of the cognitive tests it seemed that 'adaptation' may occur in terms of an increasing of the listening efficiency during the lesson period under the so defined 'worse listening conditions' concerning tapping, babble/classroom activity and road traffic noise.

3.2.8 Considerations

A review of the literature shows that our knowledge concerning effects of chronic aircraft noise exposure on children is still limited and does not allow well–founded predictions for children [153].

According to the state of the art analysis concerning the main effects of children chronic exposition to aircraft noise, it is confirmed a straight relation between this noise source and effects on health, annoyance and cognitive processes. Moreover, these effects could have a longitudinal character and substantial differences could be identified between the reactions of children and adults to aircraft noise. Finally, the influence of classroom characteristics on children annoyance and the possible establishment of resilience mechanisms have been investigated.

Concerning health, effects such as sleep disturbance [21]–[23], insomnia [33], tiredness [34], difficulties in focusing attention [34], muted cardiovascular reactivity [35], lower hearing ability [24]–[26], [37], [38] and stress [92], [98] have all been detected in children. Moreover, the effect due to aircraft noise specifically in terms of annoyance is about 50% higher than the one due to road traffic noise although the last source of noise is considered the most relevant from an environmental point of view [62]. This is mainly due to the fact that aircraft noise is characterized by very high noise levels which are concentrated in small time intervals and in areas close to the airports [62]. Concerning the development of new curves of annoyance, it has been found that the curves updated some years ago provide a higher number of annoyed adults [6], [68]–[71], [73] if compared to the original curves developed by Miedema et al [65]. Concerning children, some annoyance curves dated 2009 exist [85] but need to be updated [38], [43], [72]. Moreover, the existing curves of annoyance are usually evaluated in terms of parameter such as LAeq or Lden which might be considered not fully explanatory of the disturbance generated by the airport source, responsible for short and high–energy sound events. The main cognitive consequences of chronic aircraft noise exposition on children arose from literature affect memory [97], [99], [127], [129], concentration [130], [131] and reading ability [35], [102], [103], [108]–[112]. Also cognitive test carried–out during some important EU projects [153], [154], [164], [166] confirmed a solid relation between chronic aircraft noise exposure and cognitive (reading comprehension, memory,...) and health (annoyance,...) effects. Many studies have been carried out before and after an airport shut–down and it was found that also after some years from the airport closure children continued to use coping mechanisms against noise; similarly, effects such as reading impairment, annoyance and poorer sustained attention remained as follow–up [87]–[93].

To the previously summarized effects it is added the evidence that children are more sensitive to noise than adults, that they need a higher signal to noise ratio in order to understand a conversation also because they have not developed yet a stored knowledge that could help them to understand a speech in case it is masked by background noise [44], [50]–[52], [56], [57]. More recent studies support, instead, the hypothesis that children chronically exposed to airport noise are able to develop mechanisms of resilience or to get used to this disorder to the point of obtaining better results in some learning tests than undisturbed children [58], [86].

To sum up, the study of the state of the art shows contrasting results in particular regarding cognitive tests and the possibility that children are able or not to develop resilience mechanisms against aircraft noise. Moreover, the tests that were also conducted in the context of European projects such as RANCH, NORAH and SAMBA were carried out during the normal course of school lessons, without the passage of aircraft could be controlled and without the possibility of reproducing the tests in similar conditions in other school environments selected as control–case study, not subject to the disturbance due to airport noise. Finally, the scientific literature clearly shows the need to update the existing annoyance curves for aircraft noise specifically for children.

According to the ENNAH final report [43], some of the main open research topics in the current field (already cited in the respective sub–sections of Section 3) are:

- the future needs in annoyance research include updating dose–response relationships, particularly noting the trends in levels of increasing aircraft noise annoyance over recent years;
- the assessment of exposure–response curves specifically for child populations;
- investigating the long–term health effects of noise exposure especially for children younger than 8 years old;
- understanding the burden of disease and disability–adjusted life years in relation to noise exposure and cognitive impairment. So far, the assumption has been made that there is no lasting effect of noise exposure on cognition after the cessation of noise exposure. This has not, as yet, been empirically tested;

- to date there has been little research testing sound insulation of classrooms and future research needs to examine whether learning impairments related to aircraft noise can be reduced by sound insulation of the classroom in large scale studies;
- greater understanding is needed of the mechanisms of working memory and episodic long–term memory;
- there needs to be further study of speech intelligibility and memory in less than perfect acoustical classroom conditions. Further studies examining classroom acoustical factors such as reverberation and speech–to–noise ratios in relation to performance are required in larger scale studies;
- an emphasis should be put on cognition and well–being;
- whilst recent evidence of exposure–effect relationships between noise exposure and children's cognition has provided knowledge about thresholds for effects, further examination of exposure–effect relationships in different contexts, for different samples and vulnerable groups, and for different noise metrics remains a research and policy priority.

With reference to the topics reported by the ENNAH final report, in the present work of thesis, the research focused on the evaluation of the disturbance due to aircraft noise in children, on the evaluation of the effect of different acoustic insulation characteristics on perception, on the possibility of better understanding the mechanisms of working and episodic memory. To these aims, during the PhD research it has been developed an innovative method to evaluate the children exposure to aircraft noise at school and thanks to the application of the latter to pilot cases several data have been collected.

Chapter 4

Methodology

In this Chapter practical activities carried out during the PhD research period are illustrated. First of all, a description of two important standards for the calculation of aircraft noise, the INM and the CNOSSOS–EU ones, is made (Sub–section 4.1.1) and the test of CNOSSOS–EU aircraft calculation method is designed (Sub–section 4.1.2). In the second part (Section 4.2) the method to evaluate the children exposure to aircraft noise at school is described.

4.1 The CNOSSOS–EU aircraft calculation method: comparison with the INM one and test's design

4.1.1 Theoretical comparison between CNOSSOS–EU and INM aircraft noise predictive methods

Currently in Italy and in several European Countries only the Integrated Noise Model (INM) is recognized as an airport noise impact assessment model. However, since 31 December 2018 all Member States will necessary adapt the new calculation models introduced by CNOSSOS–EU to their national legislation and wil apply them mandatorily since the 2021/2022 noise mapping round [170]. Concerning the capacity of softwares to implement the new proposed calculation methods, as already mentioned in sub–section 3.1.1, currently the Aircraft Noise Modelling Task Group (AIRMOD) is developing test cases specifically dedicated to the aircraft noise calculation methods with the aim of verifying how the software implements the technical formulas by applying them to different scenarios [15]. Also the current experience carried out during the PhD research gives a contribution to the specific need expressed at European level to systematically test the CNOSSOS–EU calculation methods in simple pilot cases. In this section, after an analysis of the state of the art about the most current issues concerning aircraft noise modelling standards has been made in Section 3.1, a comparison between the theoretical structure of the two calculation methods INM and CNOSSOS–EU is reported, with the aim of highlighting the main differences and similarities between them. Instead, the results of an experimental application of the two compared methods will be reported in the Section 5.1.

In order to compare the two calculation standards from a theoretical point of view, it has been decided to start the dissertation from the description of the INM standard and from the aspects that the two standards have in common and then to focus on the differences. Most of the software used for the acoustic modelling of airport noise currently uses the INM calculation standard. As a prerequisite for the calculation of noise levels around the airport, INM provides for the calculation of several parameters associated with an aircraft flight path taken as a reference, including LA_{max}. To do this it uses the acoustic database of values 'NPD - Noise Power Distance' presented in the ECAC document [13] and incorporated by the Directive 996/2015 [12] at Appendix I, 'Database for aircraft associated sources - NPD data', Table I.9. It provides the noise levels present at ten predefined distances (200, 400, 630, 1000, 2000, 4000, 6300, 10000, 16000, 25000 feet) for each aircraft type (identified by an NPD code from table I.2) and for two or more take–off and landing configurations characterized by different power parameter values. Since the NPD noise curves represent aircraft data on infinitely long flight paths, in order to correct them considering the actual trajectory of the aircraft, the INM calculates the following geometric parameters of the flight segment [171] also reported in Figure 4.1 in which the observer is respectively behind the flight path segment (Figure 4.1a), astride the flight path segment (Figure 4.1b) and ahead the flight path segment (Figure 4.1c):

1. the nearest approach point on the route segment (CPA) or the extended flight path segment($PCPA$);
2. the tilt distance from the position of the observer to the nearest point, SLR_{segm} or SLR_{path}.

In the following the graphic features reported in Figure 4.1 are explained:

- P_1 is the starting point of the flight segment;
- P_2 is the end point of the flight segment;
- $P_s = PCPA$ is the point on the segment of the flight path or the segment of the extended flight path, in the perpendicular direction closest to the observer;
- CPA is the point closest to the observer on the segment, i.e. $P1$ (Figure 4.1a), P_s ((Figure 4.1b)), P_2 (Figure 4.1a);
- L is the length of the segment;
- q is the distance between $P1$ and P_s;
- d_{as} is the distance between $P1$ and CPA;
- SLR_{segm} is the distance between the observer P and the CPA point;
- SLR_{path} is the distance between the observer P and the $PCPA$ point.

To obtain the exposure noise level due to an airplane proceeding along a finite flight path segment, in INM the noise curves must be corrected by a fraction representing the difference in geometry of the trajectory followed between SLR_{path} and SLR_{segm}.

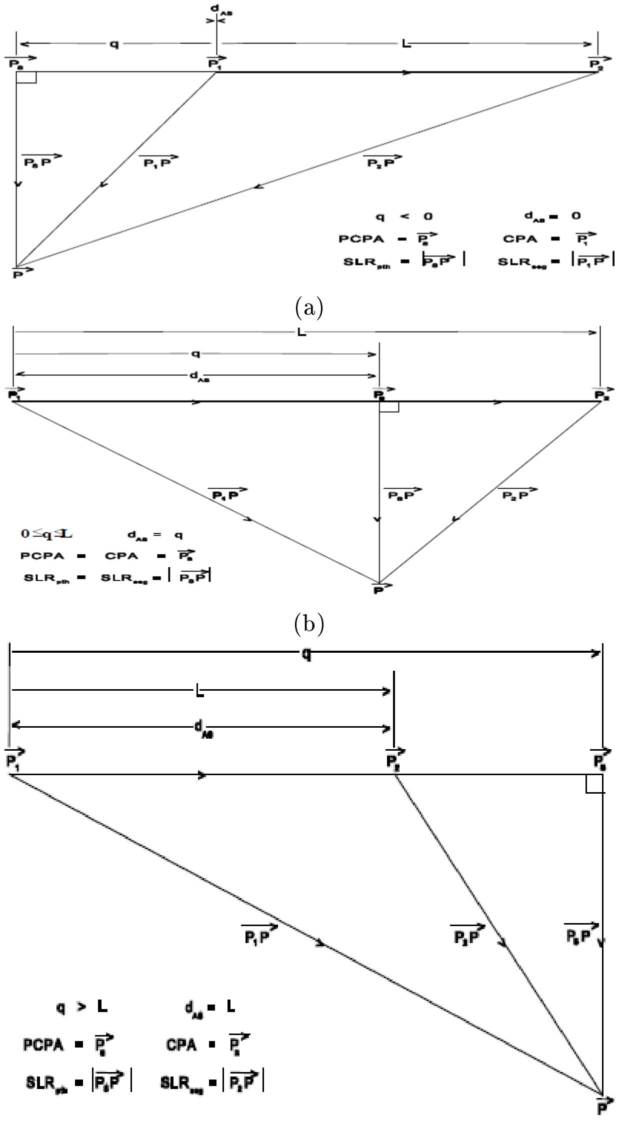


Figure 4.1: Representation of the geometry of the observer/flight segment for the three general cases proposed in the INM manual: (a) the observer is behind the segment of the flight path; (b) the observer is straddling the segment of the flight path; and (c) the observer is at the top of the segment of the flight path [171].

In particular, this correction is defined by the geometric ratio:

$$d_{segm} = d_1 + \frac{d_{as}}{L}\Delta Z_{segm} + h_{terr} + h_{airp} = d \tag{4.1}$$

$$P_{segm} = P_1 + \frac{d_{as}}{L}\Delta P_{segm} = P \tag{4.2}$$

Where:

- d_1 is the height of the starting point of the segment;
- P_1 is the power of the starting point of the segment;
- ΔZ_{segm} is the height variation between the start and end point of the segment;
- ΔP_{segm} is the power variation between the start and end point of the segment;
- h_{terr} is the altitude of the terrain;
- h_{airp} is the altitude of the airport.

The general noise interpolation process described above is applicable for the subsequent four parameters:

- A–weighted sound exposure level SEL;
- Effective tone–corrected perceived noise level L_{EPN};
- Maximum A–weighted sound level LA_{max};
- Maximum tone–corrected perceived noise–level $LPNTS_{max}$.

However, the distance and power used are different for the exposure–based acoustic parameters L_{AE} and L_{EPN} compared to the indicative parameters of the maximum noise level, LAS_{max} and $LPNTS_{max}$.

For L_{AE} and L_{EPN}:

$$L_{p,d} = \begin{cases} L(P_{segm}, d) = SLR_{path} & \text{for Figures 4.1a, 4.1c,} \\ L(P_{segm}, d) = SLR_{segm} & \text{for Figure 4.1b.} \end{cases} \tag{4.3}$$

For LA_{max} and $LPNTS_{max}$:

$$L_{p,d} = \begin{cases} \max\left[L(P_1, d_1); L(P_2, d_2)\right] & \text{for Figures 4.1a, 4.1c,} \\ \max[L(P_1, d_1); L(P_2, d_2); L(P_{PCPA}, d_{PCPA})] & \text{for Figure 4.1b.} \end{cases} \tag{4.4}$$

At this point, note the P and d values of each segment of the trajectory, the model calculates the corresponding $L(P, d)$ values by linear interpolation:

$$L_{P1,d} = L_{P1,d1} + \frac{(L_{P1,d2} - L_{P1,d1})(log(d) - log(d_1))}{(log(d_2) - log(d_1))} \tag{4.5}$$

$$L_{P2,d} = L_{P2,d1} + \frac{(L_{P2,d2} - L_{P2,d1})(log(d) - log(d_1))}{(log(d_2) - log(d_1))} \tag{4.6}$$

$$L_{P,d} = L_{P1,d1} + \frac{(L_{P2,d} - L_{P1,d})(P - P_1)}{(P_2 - P_1)} \tag{4.7}$$

in which:

- P_1, P_2, d_1, d_2 are the known values of power and distance in the NPD data between which there are the values P and d to be searched;
- $L_{P1,d1}$ is the noise level at power P_1 and distance d_1;
- $L_{P2,d1}$ is the noise level at power P_2 and distance d_1;
- $L_{P1,d2}$ is the noise level at power P_1 and distance d_2;
- $L_{P2,d2}$ is the noise level at power P_2 and distance d_2.

As for the INM calculation standard, of proven decennial validity, the new CNOSSOS–EU standard accesses a noise–power–distance database to simulate the noise emission values of each type of aircraft, called 'ANP– database' or Aircraft Noise and Performance (ANP) Database (website www.aircraftnoisemodel.org), an international data search engine used for acoustic modelling of aircraft noise. Each aircraft model is characterized by an emission dataset included in the Appendix 1 of the European Directive of 996/2015 [12], 'Database for aircraft associated sources - NPD data'.

The parameters associated with an aircraft flight path which can be calculated are $LA_{max}(P,d)$ and/or $SEL(P,d)$, applicable to an infinite flight path, according to the official specification of the Directive 49/2002 [172] which imposes L_{den} and L_{night} as noise indicators for the preparation and revision of Member States' strategic noise maps. Since the NPD noise curves represent aircraft data over infinitely long flight paths, to be able to correct them considering the actual trajectory of the aircraft, CNOSSOS–EU calculates the geometric parameters of the flight segment as already illustrated in Figure 4.1. For each segment, the distance d and the corresponding power P are defined.

In the case of segments corresponding to flight phases, where the parameter is the SEL exposure level, the parameter d is defined as 'minimum slant range':

$$d = distance(P, P_s) \tag{4.8}$$

or the perpendicular distance from the observation point to the segment or its extension, in other words to the infinite (hypothetical) flight path of which the segment is considered to be part. However, where observation points are behind ground segments during take–off taxiing and for observation points in front of ground segments during post–landing taxiing, parameter d becomes:

$$d = \min[PP_1; PP_2] \tag{4.9}$$

that is the shortest distance between the observation point and the segment (i.e. the same distance used for the maximum level metrics). The recommended methodology divides the actual flight paths into a number of finite segments, each of which is considered part of a uniform and infinite flight path for which NPD data can be used. The methodology foresees, however, regime variations along a segment that occur in a linear way in relation to the distance, from P_1 at the beginning of the segment to P_2 at the end of the same. It is therefore necessary to define a stable equivalent value P for the segment, which is assumed to be the value recorded at the point of the segment closest to the observation point. If the observation point is along the segment (Figure 4.1b), this value is obtained by interpolation:

$$P = \sqrt{P_1^2 + \frac{q}{L}(P_2^2 - P_1^2)} \tag{4.10}$$

If the observation point is in front of or behind the segment, this value corresponds to the nearest end point, P_1 or P_2. At this point, note the P and d values of each segment of the trajectory, the model calculates the corresponding $L(P, d)$ values by linear interpolation as already explained for the INM method. In summary, the two calculation methods draw starting data from the same database and simulate noise levels through the same process of trajectory's segmentation and interpolation. However, the power and distance values are differently calculated and this divergence could contribute, together with the process of implementation of the methods in different softwares, to obtain different final results.

4.1.2 Design of a test for the CNOSSOS–EU aircraft calculation method

Once the structure of the INM and CNOSSOS–EU calculation methods has been analysed and compared (Sub–section 4.1.1), a test procedure for the CNOSSOS-EU method has been designed taking into account also the indications given in ISO 17534 parts 1 and 2 [173], [174]. The latter is reported in the current section.

In fact, according to the above-mentioned standards, test cases are an important tool to check the correctness of an implementation. An optimal set of test cases that covers all important parts of the method is a powerful support for the software developer in controlling step by step the implemented procedures. But it is also a tool for the software user to validate the correct calculation with the method to be tested. Test cases for a given calculation method are not an examination, but a support of software developers and users. The implementation of a calculation method without test cases cannot be quality assured according to this part of ISO 17534. Moreover, test cases shall comprise scenarios as simple as possible and only as complicated as necessary to prove the correct calculation related to the issue under test. Test scenarios comprise realistic situations covering many aspects not detectable with precisely defined situations. The determination of the spread of results and the precision of the method according to ISO 17534-1 with realistic a test scenario is best achieved with a confidential and reliable design of a round robin test performed according to the ISO 17534 series. The selection of software applied shall be representative and the requirements of ISO 17534-1 shall be respected. The test calculations shall be performed under control of producer of that software.

In particular, in the current research it was decided to test two configurations of sound propagation produced by an airport source in free field and screened field respectively, according to the CNOSSOS–EU calculation standard and following the scheme illustrated in Figure 4.2. In Figure 4.2 it is possible to see that noise generated by the airport is measured in six different positions located both in free field, screened and double screened configurations. Results of the test will be deeply described in Section 5.1.

4.2 Children and aircraft noise

Concerning the aspects related to the study of children exposure to aircraft noise at school, all the approaches presented in 3.2.5 and in 3.2.6 are characterized by

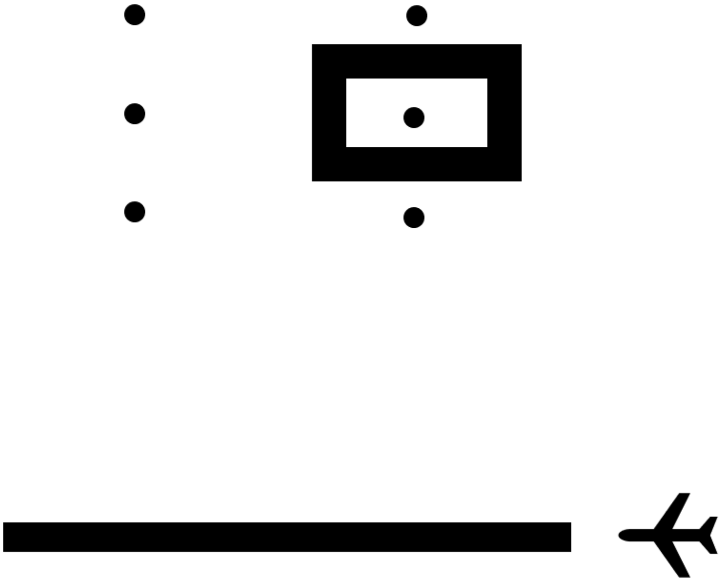


Figure 4.2: Scheme of the designed method for CNOSSOS–EU test. At the bottom is the airport runway, at the top are the six measuring positions (dots), four free–field positions, one located in a screened position within the building's courtyard and another behind the building itself.

the fact that cognitive tests are made during the ordinary course of lessons, so not necessarily concurrently with real aircraft transits. According to the state of the art analysis carried out during the current PhD research, the only study in which aircraft noise has been reproduced during tests by using loudspeakers was the one of Ando [132]. However, in the previously cited work the loudspeaker was located outside the classroom, while in the current PhD research it has been positioned inside. The methodology applied during the research is synthesised in a method's protocol to be followed in case of replication of the latter which is illustrated in Sub–section 4.2.1 and which consists in the phases illustrated in Figure 4.3. Each phase is then deeply described in the Sub–sections 4.2.2–4.2.6, according to the carried out experimental experience, together with the adopted ethical protocol (Sub–section 4.2.7). Some procedures have been already briefly described in conference papers [175], [176]. The methodology has been applied in all its stages in a pilot school, the V.Veneto one, located near the A.Vespucci airport in Florence and, exception made from the first phase, in a second pilot school located in an area not influenced by aircraft noise in Prato and selected as a control case to compare the outcomes of the tests between children annoyed by aircraft noise at school and undisturbed ones, as illustrated in the next Section (Section 5.2).

4.2.1 The method's protocol

In the current section a schematic protocol of the developed methodology is presented. In the protocol's drafting it has deemed important to consider that the final users could be an expert in the subjects dealt with, who wishes to repeat the procedure in a school context in which children are exposed to aircraft noise and also, possibly, in a second school context in which children are not disturbed by this source of noise. Two separate protocols have been prepared for this purpose accordingly.

Protocol for school subject to aircraft noise

In the current section schematic indications and suggestions for a clear application of the proposed method in a school affected by aircraft noise are reported as a list of operations to be followed. For some further explanations is it possible to refer to the Sub–sections 4.2.2–4.2.6.

Source level measurements within the school environment

- Consultation of timetable for take–offs and landings from the website of the considered airport, to obtain an approximate indication of flight times and types of aircraft that will be observed during the measurement campaign.
- Instrumentation: class I measurement chain, class I calibrator.
- Measurement positions: at least 3 for average classroom size ($45 - 50\ m^2$ from [177]) equally distributed in the classroom, microphone height: 1.20 m (average height of the receiving ear).
- Duration and number of measurements: duration of each measurement equal to at least the entire duration of the event, at least 5 events related to 5 take–offs and 5 events related to landings for each measurement position to be measured.

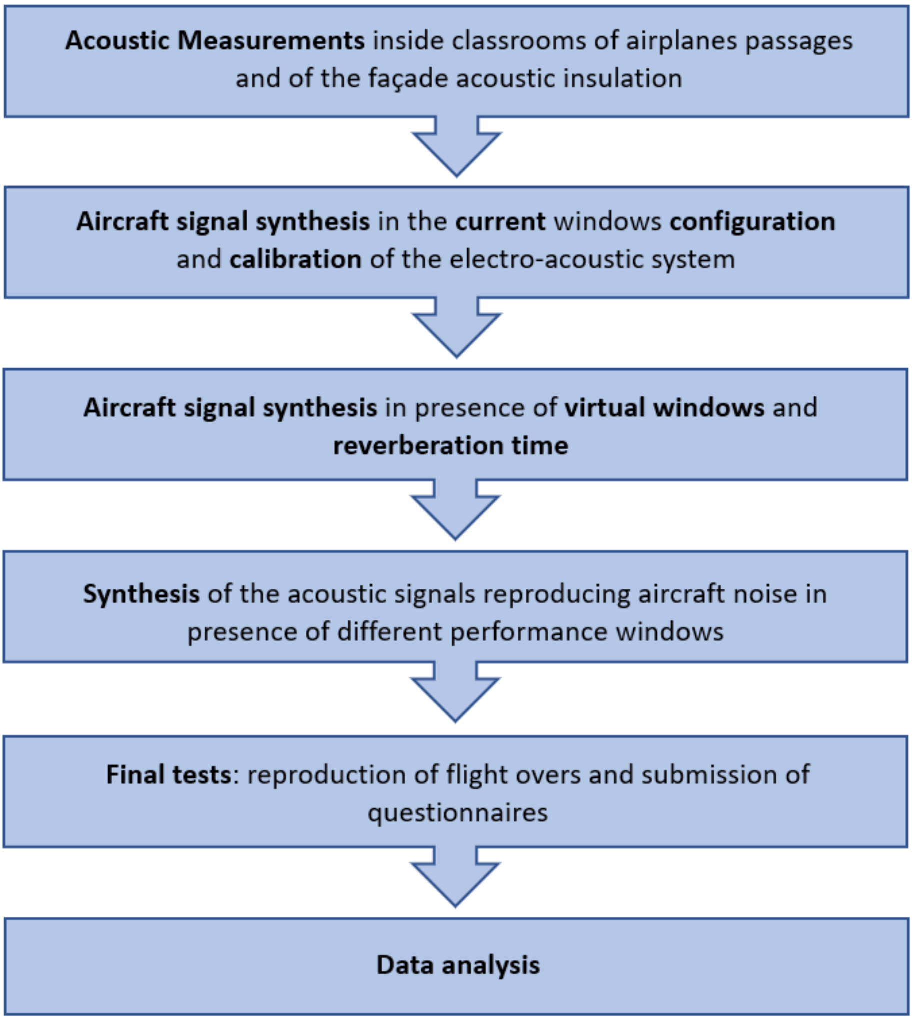


Figure 4.3: Main steps of the proposed methodology [175].

- Selection of a signal representative of a take–off or landing event and the measurement position considered as most representative.

- Output data - SEL, $LAeq_{1s}$, LAF_{max}, wave file recording. In particular, reported parameters will be used for the comparison between the measured signal and for the calibration phase, while the recorded wave files will be used in the subsequent phases of 'signal synthesis'.

Measurements of façade sound insulation and reverberation time

- Measurement of façade sound insulation to be carried out according to the UNI EN ISO 16283-3 [178] standard in each of the classrooms concerned according to the sound pressure level evaluated outside and inside the building and the reverberation time of the classrooms. In particular:

- Speaker emitting pink or white noise positioned outside on the ground, according to an angle of 45 ± 5 degrees to the normal façade, at a minimum horizontal distance of 5 m from the façade itself; external microphone positioning at a distance of 2 m from the façade and at a height of 1.5 m from the ground; internal microphone positioning at least 5 measurement points.

- Output data - façade sound insulation expressed in terms of sound pressure levels with linear weighting in $\frac{1}{3}$ octave in the range $50 \div 5000$ Hz and integration time of not less than 6 seconds.

- Measurement of reverberation time to be carried out according to the UNI EN ISO 3382–2 [179] in each of the classrooms.

  Instrumentation: omnidirectional source, microphones (1.5 m high)

  Source–microphone combinations: at least 6

  Source positions: at least 2

  Microphone positions: at least 2

- Output data - reverberation time values in $\frac{1}{3}$ octave in the range $50 \div 10000$ Hz.

Signal synthesis under current façade sound insulation conditions and reverberation time

- For the current section in particular, refer to the correspondent Sub–section 4.2.3. Here just the recall of the main input and output elements and of the needed instrumentation is made.

- Instrumentation: class I measuring chain, class I calibrator, chirp signal reproduction system.

- Configuration of the reproduction system : e.g. 5.1 surround speaker system set, taking care to place the mid–high frequency speakers close to and facing the window. Take–care of keeping the classroom's widow closed while the electro–acoustic system is running in order to avoid the reproduced signal to be overlapped by the real aircraft noise.

- Input data - Signal x' measured in the classroom according to the procedure described in the first phase.

- Output data - Signal y_a s.a. $y_a \simeq x' * g * h_a$, taking into account the impulsive response of the reproduction audio system and the environment. The latter is obtained by introducing an equalizing filter $W = \frac{1}{g * h_a}$, choosing as signal x' to emit a chirp signal (known) and measuring y_a due to the latter,in order to re–obtain the initially measured signal. The obtained signal y_a will be also used in the next phase in order to obtain a synthesised signal in presence of virtual façade sound insulation and reverberation time conditions.

Signal synthesis in virtual façade sound insulation and reverberation time conditions

- For the current section in particular, refer to the correspondent Sub–section 4.2.4. Here just the recall of the main input and output elements and of the needed instrumentation is made.

- Look for sound insulation curves and reference reverberation time from literature or acquired databases.

- Input data - y_a (obtained according to the procedure illustrated in the previous phase).

- Obtain filters h_a and h_v from façade insulation curves (respectively measured and virtual) by using convex optimization approach. In particular, h_v is the filter able to modify the environmental conditions of the façade sound insulation and of the reverberation time.

- Output data - $y_v = y_a * h_a^{-1} * h_v$ signal that would be measured in the classroom with the same source, but with virtual characteristics of façade sound insulation or reverberation time.

Cognitive tests

Preparation

- Meeting with reference teachers of the classes involved to assess together the level of schooling of the pupils and the type of reading that might be more suitable according to their age.

- Disclosure to be sent to the parents and authorisation to be requested so that the children can take part in the study.

- Preparation of tests taking into account as examples the questionnaires reported in the appendix of the dissertation and any changes based on consultations with experts in child psychology.

Running tests

- Involved technicians: at least two people (one reading the text and the other activating the acoustic signal at present times, both dealing with the delivery and management of the multiple-choice questionnaire on noise).
- Instrumentation: pc, reading text.
- Explanation to children: introduction to the tests, inform children with simple terms that they will not be evaluated at the end of the tests.
- Reading test submission.
- Noise questionnaire submission and reproduction of 13 sounds.

Protocol for school to be selected as control case

Signal synthesis under current façade sound insulation and reverberation time conditions

- Instrumentation: class I measuring chain, class I calibrator, chirp signal reproduction system.
- Configuration of the reproduction system : e.g. 5.1 surround speaker system set, taking care to place the mid–high frequency speakers close to and facing the window. Take–care of keeping the classroom's widow closed while the electro–acoustic system is running in order to avoid the reproduced signal to be overlapped by the real aircraft noise.
- Input data - Signal x' measured in the school affected by aircraft noise.
- Output data - Signal y'_a s.a. $y'_a \simeq x' * g * h_a$. The latter is obtained by introducing an equalizing filter $W = \frac{1}{g*h_a}$ choosing as signal x' to emit a chirp signal (known) and measuring y'_a due to the latter.

Signal synthesis in virtual façade sound insulation and reverberation time conditions

- Adopt the virtual sound insulation curves and reference reverberation defined for the first Protocol.
- Input data - y'_a (obtained according to the procedure illustrated in the previous phase).
- Obtain filters h_a and h_v from façade insulation curves (respectively measured and virtual) by using convex optimization approach.
- Output data - $y'_v = y'_a * h_a^{-1} * h_v$ signal that would be measured in the classroom with the same source, but with virtual characteristics of façade sound insulation or reverberation time.

Cognitive tests

Preparation

- Meeting with reference teachers of the classes involved to assess together the level of schooling of the pupils and the type of reading that might be more suitable according to their age.
- Disclosure to be sent to the parents and authorisation to be requested so that the children can take part in the study.
- Preparation of tests taking into account as examples the questionnaires reported in the appendix of the dissertation and any changes based on consultations with experts in child psychology.

Running tests

- Involved technicians: at least two people (one reading the text and the other activating the acoustic signal at present times, both dealing with the delivery and management of the multiple-choice questionnaire on noise).
- Instrumentation: pc, reading text.
- Explanation to children: introduction to the tests, inform children with simple terms that they will not be evaluated at the end of the tests.
- Reading test submission.
- Simplified noise questionnaire submission and reproduction of 13 sounds.

4.2.2 Acoustic measurements

In the first phase of the method, the noise levels produced in a classroom of the V.Veneto school by take–off and landing movements due to different types of aircraft have been measured. Once the dates and the time slots during which to carry out the noise measurements had been established, the timetables for aircraft take–off and landings published by the airport website have been viewed. For these first measurements, a wave signal has been acquired in the open and closed window configurations. The measurements have been carried out with a class I microphone and a measurement chain at one or more microphone positions. The microphone has been positioned at the student's ear in a sitting position, approximately 1.20 m. In Figure 4.4 an example of two noise signals representative of the open and closed window configurations is reported.

Once all measurements have been carried out (approximately 15 take–offs and 15 landings have been measured in each of the selected classroom), a unique classroom in which the tests with all classes have been made and the most representative signal in terms of 'cleanliness' and absence of background noise for both open and closed windows configurations has been selected.

In addition, standard measurements [180] of the *Standardized Level Difference* (DnT) of the considered façade and of the reverberation time (T60) [179] have been carried out. In Figure 4.5 some pictures of the noise measurement campaign carried out in the V.Veneto school are shown, in Figure 4.6 a comparison between the values of the measured Weighted Standardized Level Difference and of the reference values is made, while in Table 4.1 the values of the T60 measured in the classroom inside which tests have been made are reported.

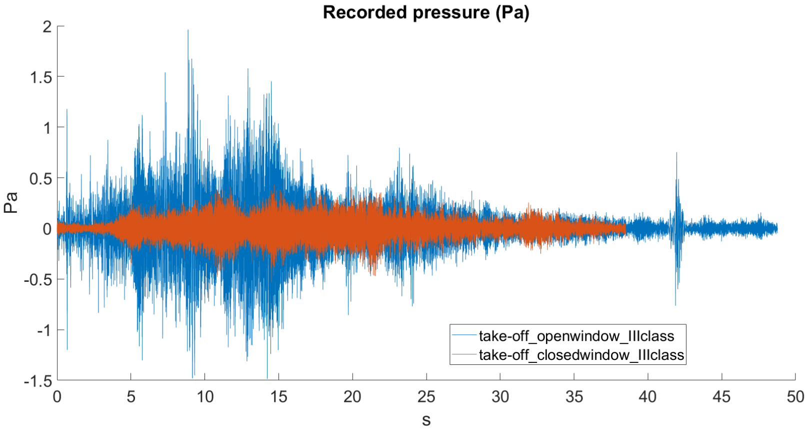


Figure 4.4: Recorded pressure level in a classroom of the V.Veneto school in different window configuration.

Figure 4.5: Measurement of sound insulation in the V.Veneto school.

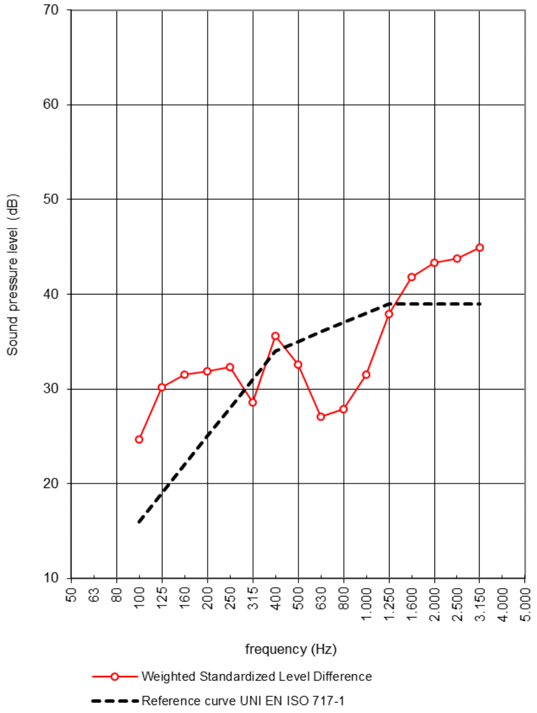


Figure 4.6: Comparison between measured *Standardized Level Difference* and reference values in the V.Veneto school.

Table 4.1: Reverberation time (T60) frequency values measured in eight different position in the classroom of the V.Veneto school in which tests have been carried–out and average values.

Frequency [Hz]	**T60 for each measurement position [s]**								**Average T60 [s]**
50	1,31	1,40	1,39	1,45	1,5	1,42	1,29	1,52	1,41
63	1,58	1,54	1,71	1,51	1,13	1,33	1,53	1,61	1,49
80	1,47	1,55	1,07	0,92	1,32	0,94	1,5	1,75	1,32
100	1,01	1,21	1,37	1,27	1,17	1,06	0,92	1,08	1,14
125	1,79	1,20	1,15	0,85	1,33	1,19	1,15	1,38	1,26
160	1,27	1,29	1,36	1,65	1,31	1,23	1,47	1,59	1,40
200	1,03	0,97	1,38	1,18	1,33	0,95	1,43	1,41	1,21
250	1,09	1,26	1,28	1,15	1,14	1,11	1,25	1,43	1,21
315	1,11	1,71	1,15	1,2	1,18	1,05	1,1	0,95	1,18
400	1,17	1,35	0,97	0,94	1,23	1,37	1,01	1,27	1,16
500	1,08	1,02	1,06	1,15	0,98	0,91	1,02	1,06	1,04
630	0,92	0,93	1,04	0,98	0,97	0,92	0,87	0,84	0,93
800	0,88	1,00	0,97	0,87	0,97	0,94	1,02	0,93	0,95
1 k	0,93	1,14	1,05	1,12	1,04	1,08	1,08	1,11	1,07
1.25 k	1,33	1,22	1,14	1,02	1,17	1,12	1,09	1,09	1,17
1.6 k	1,20	1,08	1,13	1,24	1,17	1,04	1,2	1,08	1,14
2 k	1,23	1,05	1,08	1,13	1,18	1,10	1,09	1,10	1,12
2.5 k	1,20	1,13	1,13	1,15	1,13	1,13	1,05	1,08	1,13
3.15 k	1,11	1,14	1,10	1,13	1,03	1,03	1,05	1,05	1,08
4 k	1,11	1,05	1,07	1,11	0,97	0,98	1	1,05	1,04
5 k	1,00	0,96	1,04	1,07	0,99	0,96	0,95	0,97	0,99
6.3 k	0,92	0,91	0,88	0,90	0,87	0,86	0,93	0,9	0,90
8 k	0,78	0,76	0,77	0,76	0,73	0,73	0,75	0,76	0,76
10 k	0,67	0,64	0,68	0,67	0,63	0,64	0,67	0,66	0,66

Table 4.2: Comparison between measured T60 values in V.Veneto school and optimal reference values from D.M. 18/12/1975 and UNI 11367.

f [Hz]	125	250	500	1000	2000	4000
T60 [s] in V.Veneto school	1,26	1,21	1,04	1,07	1,12	1,04
T60 [s] from D.M. 18/12/1975	1,44	1,20	0,96	0,84	0,80	0,88
T60 [s] from UNI11367	1,44	0,84	0,70	0,70	0,84	0,84

From Figure 4.6 it is possible to see that measured value of façade acoustic insulation are substantially lower than the reference values, especially in the interval between 500 and 1250 Hz.

In Table 4.2 measured values of T60 limited to the frequency range between 125 and 4000 Hz are compared with the optimal reference values from D.M. 18/12/1975 [177] and UNI11367 [181].

From Table 4.2 it is possible to see that values of the measured T60 are significantly higher than the reference ones. This characteristic could have an important influence on the outcomes of the cognitive tests according to the state of the art analysis reported in 3.2.5.

With regard to the audibility conditions in the two test classrooms (Florence and Prato), although no specific acoustic measurements have been made in relation to the STI parameter, the classrooms have been chosen so that they have similar characteristics in terms of both geometry and material. In addition, the layout of the desk, the desks and the position of the window in the classroom of the Prato school were also defined in such a way as to faithfully represent the configuration found in the Florence school. Finally, from the acoustic measurements carried out in both test rooms, in correspondence with the last rows of benches in reference to the reading test, it is possible to highlight very similar conditions of environmental noise (sound pressure level detected during the reading) and background noise (sound pressure level detected in the presence of children during the reading pause). In addition, similar reverberation times were detected in the two classrooms. For all the above reasons, 'audibility' conditions and very similar STI parameter values are assumed in the two classrooms.

4.2.3 Aircraft signal synthesis in the current scenario

In the literature, most popular and validated methods [182] for measuring noise levels produced by external sources and reproducing the latter inside a building include external signal recording, façade sound insulation measurements, processing of digital filters from the latter or from literature, and internal playback.

For the purposes of this work, since the objective was to reproduce the noise produced by aircraft in an indoor environment, the idea was to experiment with a new method, in order to try to limit the procedural steps, measuring the signal of interest directly in the classroom (listening laboratory) of the school in Florence chosen to perform tests with all classes involved. Subsequently, once the emission setup had been defined with the electro–acoustic system, an equalization procedure was adopted in order to filter out the characteristics of the room and also the emission characteristics of the reproduction system used. At this point the original filtered signal was emitted and new recordings were made that showed an optimal alignment between the original signal measured at the passage of the aircraft and the signal reissued with the electro–acoustic system. Moreover, the adopted method has allowed a simpler replication in the school of Prato, for which it was sufficient to perform again the equalization procedure defining a new filter valid for the new environment. In this way it was possible to faithfully reproduce the acoustic signal recorded in the classroom of Florence also in the classroom of Prato. Also in this case, in fact, an optimal alignment between the original signal measured at the passage of the plane in the classroom of Florence and the signal reissued with the electro–acoustic system in the classroom of Prato has been demonstrated. The alternative of carrying out measurements outside had been previously evaluated, but discarded because it would have provided for an additional step (i.e. bring the signal from outside to inside) and, even in this case, would have required the procedure of equalization. In fact, the main purpose of this procedure is to correct the effect due to the location of the source inside the room and it could only be excluded if the sound source was placed outside the building. In addition, we initially evaluated, but then excluded the possibility of carrying–out measurements outdoors and reproduce the sound always from the outside. This last choice is linked to the extreme difficulty in this case of faithfully reproducing the sound

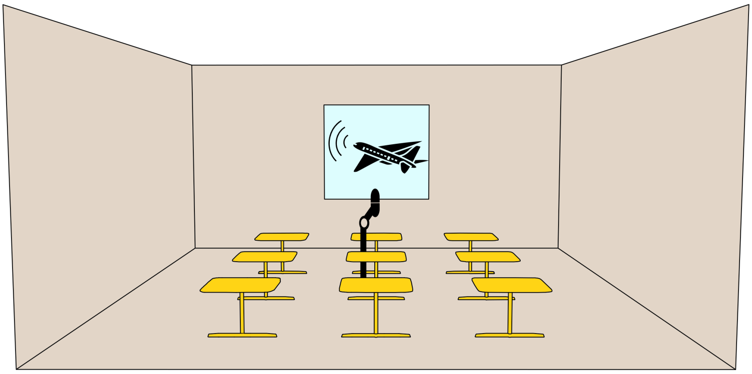


Figure 4.7: Real scenario in which the acoustic disturbance is due to the outside aircraft noise source – 3D scheme.

generated by a moving source at significant heights (classrooms located on the second floor of the building) and with the instrumentation at our disposal.

As a consequence, starting from the real scenario in which the aircraft noise source (e.g. an airplane during the take–off phase) is outside the classroom (Figure 4.7), the innovative idea underpinning the research carried out during the current PhD research has been to reproduce the noise generated by the real source located outside the school by means of a properly designed electro–acoustic system to be located inside the classroom (Figure 4.10). Specifically, the electro–acoustic system could be a 5.1 system characterised by 4 mid–high frequency loudspeakers to be positioned near the classroom's window and a subwoofer. The 5.1 system has been chosen to guarantee good flexibility in terms of the frequency range to be reproduced, making sure to have good fidelity of the reproduced signal with respect to the one measured both at low (through the subwoofer) and at mid–high frequencies through the smaller speakers. Moreover, while the electro–acoustic system is running the classroom's windows must be kept closed in order to benefit from the sound insulation offered by the classroom's windows and to avoid the reproduced signal to be overlapped by the real aircraft noise.

Finally, it is important to underline that a representative position for the measuring microphone has been selected in correspondence of one of the last desk of the classroom located at about 2 meters from the window. The same position has been identified for the calibration phase (Figures 4.8 and 4.11).

The first problems to be addressed in the method development concern the difficulty to synchronize the test of listening ability with real time aircraft passages and the constraint due to the classroom's characteristics.

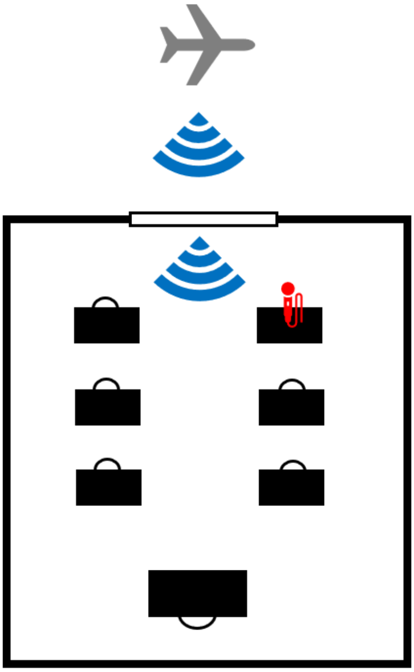


Figure 4.8: Real scenario in which the acoustic disturbance is due to the outside aircraft noise source – 2D scheme.

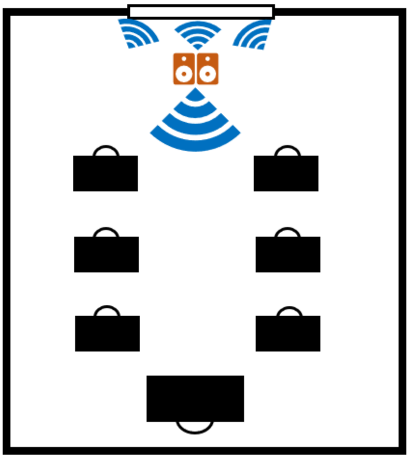


Figure 4.9: Simulated scenario in which the noise signal due to aircraft noise is reproduced by means of an electro-acoustic system located inside the classroom.

Figure 4.10: Comparison between the real and the simulated scenario.

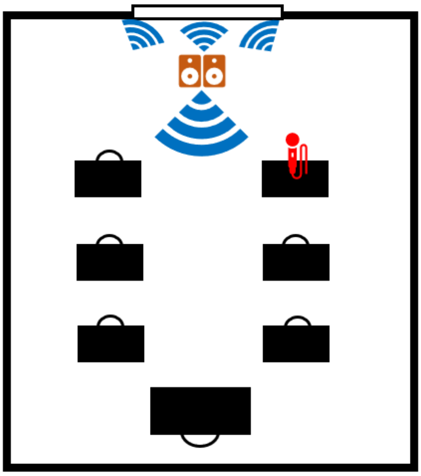


Figure 4.11: Calibration position of the michrophone.

According to one of the issues highlighted in Section 4, a problem of *equalization* [183] is addressed in the current section. In fact, once the signal representative of the real noise produced by a typical aircraft take–off inside the classroom of the V.Veneto school has been measured, an electro–acoustic signal as close as possible to the real one is synthesized and reproduced, by taking into account also the contributions of the loudspeaker and of the room characteristics in order to be able to reproduce the desired aircraft noise signal at specific moments of the reading test. In the current section, the model of the considered scenario is introduced while in Sub–section 4.2.4 the procedure adopted in order to synthesize some electro–acoustic signal representative of approximated virtual acoustic insulation conditions is explained according to the theory of the *inverse* problem. The developed procedures which are reported in the current and in Sub–section 4.2.4 are object of a published paper [176].

Accordingly to Figure 4.12, the acoustic signal x' generated by a source located *outside* a building is recorded by a microphone placed *inside* it, providing the audio signal y_a.

The whole system is assumed linear and time–invariant; hence, the input–output relation is given by the following discrete linear convolution:

$$\begin{aligned} y_a[n] &= x'[n] * g[n] * h_a[n] \\ &= x[n] * h_a[n], \end{aligned} \tag{4.11}$$

where h_a is the impulse response of the filter modeling the actual façade and g is the filter accounting for the remaining acoustic effects (e.g. free-space loss, reverberation). In other words, the signal x indicates the recorded acoustic signal after the contribution of g_n were removed.

Once the mathematical system has been established, the goal to achieve is given by the following equation:

$$y_a[n] \simeq x[n] \tag{4.12}$$

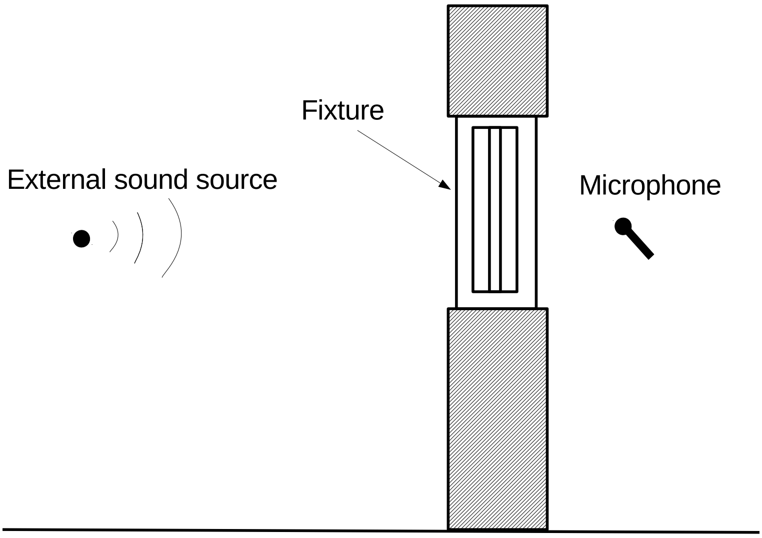


Figure 4.12: Schematic view of the recording scenario.

To this aim, an equalizer filter $W(n)$ is introduced so that:

$$y_a[n] = x[n] * h_a[n] * W(n) \tag{4.13}$$

and the mean quadratic error with respect to $W(n)$ is minimized so that:

$$\widehat{W} = arg \min_{W(n)} \int |y_a[n] - x[n]|^2 df \tag{4.14}$$

In order to obtain the equalizer filter $\widehat{W}$ a chirp signal has been reproduced (x') and measured (y_a). In the current application all the operations just described have been implemented in the Matlab environment.

Then the synthesised signal is reproduced and measured in the calibration phase at the initially established microphone position in correspondence of one of the last desk located at a distance of approximately 2 meters from the window. Thereafter it is compared with the original recorded signal both in the open and closed window configuration. A comparison between the synthesised and the original signals is shown in Figures 4.13 and 4.14.

According to Figure 4.14, the two signals can be considered to be significantly concordant exception made for values obtained for frequencies below 50 Hz. This apparent discordance is due to mechanical limits of the instrumentation which is not able to work in a frequency range below 50 Hz. In fact, a possibility could be to introduce a filter able to correct this portion of the signal, but it has been considered useless due to the characteristics of the instrumentation. Moreover, the blue curve is slightly above the red curve, but this occurrence can be corrected thanks to the equalization procedure, able to digitally compensate the residual imbalance.

In the Mascagni school, that is the control case, the described procedure has been replicated, with the only difference of considering as a signal x' not the one measured in a classroom of that school (since it is not affected by aircraft noise) but the one measured in the V.Veneto school.

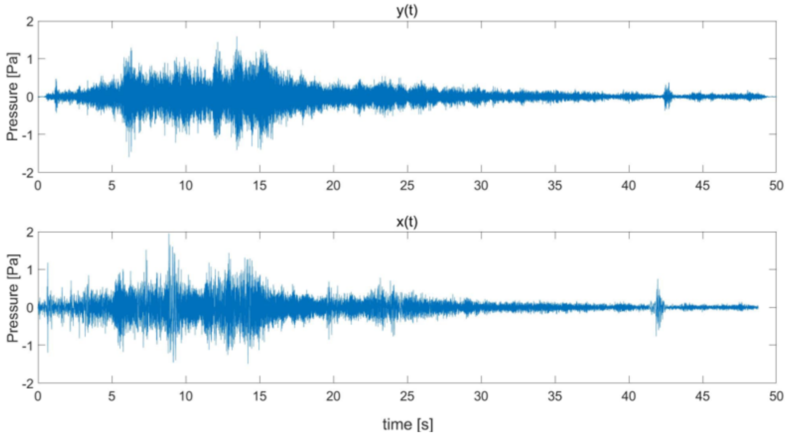


Figure 4.13: Time history of the measured synthesised signal y_a and of the original one x.

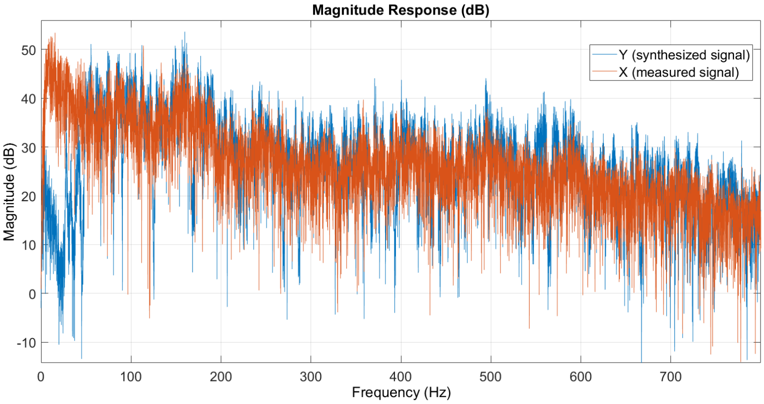


Figure 4.14: Frequency distribution of the measured synthesised signal y_a and of the original one x.

4.2.4 Aircraft signal synthesis in presence of virtual windows and reverberation time

In system modeling, using direct and indirect measurements to infer the values of hidden or unobservable system parameters is usually referred to as an *inverse problem* [184]. Inverse problems arise in several engineering branches, such as biomedical imaging, optics, meteorology, and also audio processing. Incidentally, estimation of direction of arrival, blind source separation or computation of room impulse response are examples of inverse problems.

In this section an application of an inverse problem to the field addressed by the thesis is illustrated. It focuses on the approximation of the acoustic insulation provided by a *virtual* façade on an audio signal that has been previously recorded in presence of an *actual*, generally different, façade. The problem can be cast as inverse because, in order to solve it, the contribution of the actual façade is substituted with the virtual one, relying uniquely on the knowledge of the *Standardized Level Difference* ($\mathrm{D_{nT}}$) [178]. $\mathrm{D_{nT}}$ curves are indirect and differential measurements of sound pressure level (SPL) carried out over prescribed frequency bands.

In the application considered here, the classical magnitude filter design cannot be used because of integral constraints on the magnitude of the frequency response that need to be enforced. Thus, a solution based on convex optimization [185] has been explored. Magnitude filter design by convex optimization has been already investigated in the literature, considering approaches relying on linear programming [186], semidefinite programming [187], [188], linear matrix inequalities [189] and directed iterative rank refinement [190]. Unfortunately, such methods cannot be directly applied in the context of this study due to the particular modeling of the problem. Nevertheless, ideas proposed in those works have been exploited to approximate the problem and to solve it by standard convex optimization routines.

Convex optimization problem modeling and proposed method

In this section, the model of the virtual considered scenario is presented.

By assuming that the actual façade (for the discrete linear convolution input–relation refer to 4.11) of the considered classroom of the V.Veneto school were replaced by the virtual one, the virtual signal y_v that would be recorded is

$$y_v[n] = x[n] * h_v[n], \tag{4.15}$$

being h_v the impulse response of the filter modeling the virtual façade. Substituting (4.11) into (4.15), the virtual signal is theoretically provided by

$$y_v[n] = y_a[n] * h_a^{-1}[n] * h_v[n]\,, \tag{4.16}$$

that is, the target signal can be obtained by inverse and direct filtering the recorded signal by means of the actual and virtual façade filters, respectively. It has to be noted that $\{h_a, h_v\}$ generally depend upon several parameters, e.g., the position and the directivity of both the source and receiver, the façade's and building's geometry and materials; thus, aggregate parameters like $\mathrm{D_{nT}}$ are commonly preferred for the analysis and the comparison of façades' insulating performance.

In this application the $\mathrm{D_{nT}}$ curve is considered as evaluated through a single measurement, according to the setup depicted in Figure 4.15 and explained in Sub–section 4.2.2. The $\mathrm{D_{nT}}$ value in the frequency band Δ_m, shortly $D_m^{(a)}$, is computed

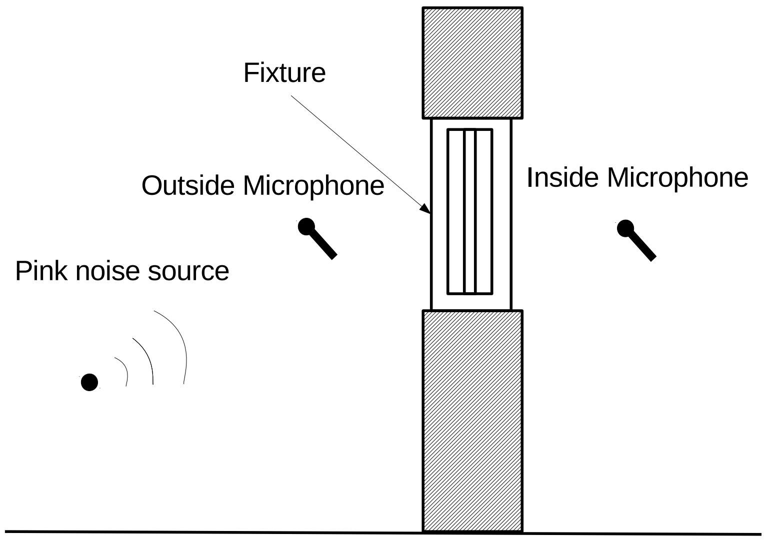


Figure 4.15: Schematic view of the measurement setup of $\mathrm{D_{nT}}$ curves.

as the ratio between the energies of the signals recorded by two distinct microphones suitably placed outside and inside the actual façade, respectively, in the presence of an external pink noise source. By neglecting other sources of disturbance, $D_n^{(a)}$ can be approximated as the ratio of integrated power spectral densities, i.e.

$$
\begin{aligned}
D_m^{(a)} &\approx \frac{\int_{\Delta_m} \sigma F^{-1} \, \mathrm{d}F}{\int_{\Delta_m} \sigma F^{-1} |H_a(F)|^2 \, \mathrm{d}F} \\
&= \frac{\int_{\Delta_m} F^{-1} \, \mathrm{d}F}{\int_{\Delta_m} F^{-1} |H_a(F)|^2 \, \mathrm{d}F} \qquad m = 1, \dots M \,, \qquad (4.17)
\end{aligned}
$$

where H_a is the Fourier transform of h_a; σF^{-1} is the power spectral density of the pink noise; $m = 1, \dots M$ indexes the set of frequency bands which the $\mathrm{D_{nT}}$ values are computed over. An analogous procedure is performed to obtain the $\mathrm{D_{nT}}$ curve of the virtual façade, namely $D_m^{(v)}$, over the same bands.

$\mathrm{D_{nT}}$ curves do not cover the entire range $[0, F_s]$, being F_s the sampling frequency [178]; hence, $\overline{M}$ complementary bands $\overline{\Delta}_m$ are introduced, that is,

$$
\overline{\Delta}_m \cap \bigcup_{p=1}^{M} \Delta_p = \emptyset \qquad m = 1, \dots, \overline{M}
$$

such that

$$
\bigcup_{m=1}^{M} \Delta_m \cup \bigcup_{m=1}^{\overline{M}} \overline{\Delta}_m \equiv [0, F_s] \, .
$$

By considering (4.16) and (4.17), the goal is formally defined as follows: synthesize

$$
\hat{y}_v[n] = y_a[n] * \hat{h}_a^{-1}[n] * \hat{h}_v[n]. \qquad (4.18)
$$

where the estimated filters $\{\hat{h}_a, \hat{h}_v\}$ are constrained by

$$\text{find } \hat{h}_a \text{ and } \hat{h}_v \text{ s.t.} \tag{4.19}$$

$$\int_{\Delta_m} F^{-1}|\hat{H}_a(F)|^2 \,\mathrm{d}F = \frac{\int_{\Delta_m} F^{-1}\,\mathrm{d}F}{D_m^{(a)}}, \qquad m = 1, \dots M \tag{4.20}$$

$$\int_{\Delta_m} F^{-1}|\hat{H}_v(F)|^2 \,\mathrm{d}F = \frac{\int_{\Delta_m} F^{-1}\,\mathrm{d}F}{D_m^{(v)}}, \qquad m = 1, \dots M \tag{4.21}$$

$$\hat{H}_a(F) = \hat{H}_v(F), \quad \forall F \in \bigcup_{m=1}^{M} \overline{\Delta}_m \tag{4.22}$$

$$\angle\hat{H}_a(F) = \angle\hat{H}_v(F), \quad \forall F \in [0, F_s]\,. \tag{4.23}$$

The above equations represent a non–convex set of integral, semi–infinite and phase constraints. Equations Equations (4.20) to (4.21) come from (4.17) and enforce the similarity to the measured data; eq. (4.22) ensures that the synthesized signal adheres to the recorded one for all the frequencies, even where no information is available; eq. (4.23) prevents phase distortions between $\hat{y}_v$ and y_v. In case of ideal estimation, i.e., $\hat{h}_a = h_a$ and $\hat{h}_v = h_v$, (4.18) and (4.16) consistently coincide.

The adopted procedure is iterative: at each iteration a convex optimization problem and a spectral factorization have to be solved; the termination condition is achieved when the estimated filters sufficiently adhere to the acquired data. The algorithm, which is summarized in Algorithm 1, is described in the following.

The autocorrelation sequence of the actual façade, $\hat{r}_a$, and the related power spectral density $\hat{R}_a$ are defined, respectively, as

$$\hat{r}_a[n] = \hat{h}_a[n] * \hat{h}_a[-n] \tag{4.24}$$

$$\hat{R}_a(F) = |\hat{H}_a(F)|^2 \tag{4.25}$$

$$= \hat{r}_a[0] + 2\sum_{n=1}^{N-1} \hat{r}_a[n]\cos(2\pi F n) \tag{4.26}$$

where N is the filter length, with N odd. Analogously, $\hat{r}_v$ and $\hat{R}_v$ are defined for the virtual façade. Moreover, the following quantities are introduced:

$$L_n(F) = \begin{cases} 1 & \text{for } n = 0 \\ 2\cos(2\pi F n) & \text{otherwise} \end{cases} \tag{4.27}$$

$$C_{n,m} = \frac{D_m^{(a)} \int_{\Delta_m} F^{-1} L_n(F)\,\mathrm{d}F}{\int_{\Delta_m} F^{-1}\,\mathrm{d}F}\,, \tag{4.28}$$

as well as the tolerances ϵ_0 and α_0 ($\epsilon_0 > 1$, $\alpha_0 > 0$). According to the previous definitions, eqs. (4.20) to (4.22) are approximated with the following finite set of convex constraints:

$$\frac{1}{\epsilon} \leq \sum_{n=0}^{\lceil N/4 \rceil -1} \hat{r}_a[n] C_{n,m} \leq \epsilon, \quad m = 1, \dots M \tag{4.29}$$

$$\frac{1}{\epsilon} \leq \sum_{n=0}^{\lceil N/4 \rceil -1} \hat{r}_v[n] C_{n,m} \leq \epsilon, \quad m = 1, \dots M \tag{4.30}$$

$$\frac{1}{\epsilon} \leq \frac{\sum_{n=0}^{\lceil N/4 \rceil -1} \hat{r}_v[n] L_m(F_i)}{\sum_{n=0}^{\lceil N/4 \rceil -1} \hat{r}_a[n] L_m(F_i)} \leq \epsilon,$$

$$F_i \in \bigcup_{m=1}^{\overline{M}} \overline{\Delta}_m, \; i = 1, \dots P_m \tag{4.31}$$

$$\alpha_0 \leq \sum_{n=0}^{\lceil N/4 \rceil -1} \hat{r}_a[n] L_m(F_j), \; F_j \in [0, F_s], \; j = 1, \dots Q \tag{4.32}$$

$$\alpha_0 \leq \sum_{n=0}^{\lceil N/4 \rceil -1} \hat{r}_v[n] L_m(F_j), \; F_j \in [0, F_s], \; j = 1, \dots Q \,, \tag{4.33}$$

where F_i and F_j are frequencies over the complementary bands and over the entire spectrum, respectively, and $\epsilon = \epsilon_0$ at the first iteration. Inequalities eqs. (4.29) to (4.30) are derived from eqs. (4.20) to (4.21) by substituting (4.25)–(4.27), respectively, and introducing the tolerance bounds. Similarly, eq. (4.31) is the discrete–frequency version[1] of (4.22), having replaced the filters' frequency responses with their power spectral densities. Inequalities eqs. (4.32) to (4.33) enforce the positiveness of the power spectral densities [186], [187].

In order to obtain smooth shapes of $\hat{R}_v/\hat{R}_a$, solving the following convex problem with respect to $\{\hat{r}_a, \hat{r}_v\}$ has been verified to provide good solutions:

$$\begin{aligned} &\text{minimize} \sum_{n=0}^{\lceil N/4 \rceil -1} n^2 \left(\frac{\hat{r}_a[n]}{W_a} + \frac{\hat{r}_v[n]}{W_v} \right)^2 \\ &\text{subject to eqs. (4.29) to (4.33)}\,, \end{aligned} \tag{4.34}$$

where

$$W_a = \sum_{m=1}^{M-1} \left| \frac{\int_{\Delta_{m+1}} F^{-1}\,\mathrm{d}F}{D_{m+1}^{(a)}} - \frac{\int_{\Delta_m} F^{-1}\,\mathrm{d}F}{D_m^{(a)}} \right|$$

$$W_v = \sum_{m=1}^{M-1} \left| \frac{\int_{\Delta_{m+1}} F^{-1}\,\mathrm{d}F}{D_{m+1}^{(v)}} - \frac{\int_{\Delta_m} F^{-1}\,\mathrm{d}F}{D_m^{(v)}} \right| .$$

It has to be noted that in eqs. (4.29) to (4.34), the autocorrelation sequence is truncated at $\lceil N/4 \rceil - 1$ to limit the computational burden of the convex optimization procedure. Furthermore, the problem (4.34) might generally result unfeasible for the given N; in such a case, it is iteratively solved by increasing N until a valid solution is achieved.

---

[1] The convexity is implicit for sake of brevity.

After solving (4.34), the phase constraint (4.23) has to be enforced. Equation (4.23) is strengthened by assuming

$$\angle \hat{H}_a(F) = \angle \hat{H}_v(F) = 0, \quad \forall F\,, \tag{4.35}$$

i.e., zero–phase filters, which implies that there exist two causal sequences $\{\hat{b}_a, \hat{b}_v\}$ of length $\lceil N/2 \rceil$ such that

$$\begin{aligned} \hat{h}_a[n] &= \hat{b}_a[n] * \hat{b}_a[-n] \\ \hat{h}_v[n] &= \hat{b}_v[n] * \hat{b}_v[-n]\,. \end{aligned} \tag{4.36}$$

Substituting (4.36) into eq. (4.24) and recursively into (4.25), after taking the logarithm, yields

$$\begin{aligned} 4 \ln |\hat{B}_a(F)| &= \ln \hat{R}_a(F) \\ 4 \ln |\hat{B}_v(F)| &= \ln \hat{R}_v(F)\,. \end{aligned} \tag{4.37}$$

Replacing (4.37) in the approximation of real cepstrum [191], i.e.

$$\tilde{b}[n] = \mathrm{IFFT}\{\ln |\hat{B}(F)|\}\,,$$

where IFFT$\{\cdot\}$ is the Inverse Fast Fourier Transform, the real cepstra of $(\hat{b}_a, \hat{b}_v)$ are approximated by

$$\begin{aligned} \tilde{b}_a[n] &= \mathrm{IFFT}\{\ln[|\hat{R}_a(F)|]/4\} \\ \tilde{b}_v[n] &= \mathrm{IFFT}\{\ln[|\hat{R}_v(F)|]/4\}\,. \end{aligned} \tag{4.38}$$

Therefore, $\{\hat{h}_a, \hat{h}_v\}$ are computed by means of the following spectral factorization: after computing the real cepstra $\{\tilde{b}_a, \tilde{b}_v\}$ through (4.38), $\{\hat{b}_a, \hat{b}_v\}$ are synthesized by means of minimum phase reconstruction [186], [192][2]

$$\begin{aligned} \hat{b}_a[n] &= \mathrm{Re}\,\mathrm{IFFT}\{\exp(\mathrm{FFT}\{\tilde{b}_a[n]\, w[n]\})\} \\ \hat{b}_v[n] &= \mathrm{Re}\,\mathrm{IFFT}\{\exp(\mathrm{FFT}\{\tilde{b}_v[n]\, w[n]\})\}\,, \end{aligned} \tag{4.39}$$

being

$$w[n] = \begin{cases} 0\,, & \text{for } n < 0 \\ 1\,, & \text{for } n = 0 \\ 2\,, & \text{otherwise}\,, \end{cases}$$

and $\{\hat{h}_a, \hat{h}_v\}$ are eventually computed according to (4.36).

The solution obtained after the first iteration may not fulfill the integral constraints due to the approximation introduced by the spectral factorization [186]. Thus, the whole procedure is iterated by decreasing ϵ, until the following inequalities are satisfied:

$$\begin{aligned} \frac{1}{\epsilon_0} &\le \sum_{n=0}^{N-1} \hat{r}_a[n] C_{n,m} \le \epsilon_0, \quad m = 1, \dots M \\ \frac{1}{\epsilon_0} &\le \sum_{n=0}^{N-1} \hat{r}_v[n] C_{n,m} \le \epsilon_0, \quad m = 1, \dots M\,. \end{aligned} \tag{4.40}$$

---

[2] The procedure proposed in [193] can be used as alternative.

Algorithm 1 Procedure of the proposed method

```
Input: $N$ odd, $\epsilon_0 > 1$, $\alpha_0 > 0$, $y_a$, $\{D_m^{(a)}, D_m^{(v)}\}$ for $m = 1, \dots M$
Output: $\hat{y}_v$, $\{\hat{h}_a, \hat{h}_v\}$
$\epsilon \leftarrow \epsilon_0$
repeat
    while (4.34) is unfeasible do
        increase $N$
    end while
    compute $\{\hat{r}_a, \hat{r}_v\}$ by solving (4.34)
    compute real cepstra $\{\tilde{b}_a, \tilde{b}_v\}$ by means of (4.38)
    compute $\{\hat{b}_a, \hat{b}_v\}$ through (4.39)
    compute $\{\hat{h}_a, \hat{h}_v\}$ by means of (4.36)
    decrease $\epsilon$
until (4.40) is satisfied
compute $\hat{y}_v$ by means of (4.18)
```

Results

The proposed method has been tested by selecting one low–performance façade as the actual one, whose $\mathrm{D_{nT}}$ has been directly measured. Four façades have been chosen as the virtual ones. All curves have been accordingly reported over one–third octave bands, as depicted in Figure 4.16, where their nominal central frequencies are reported. The lowest and the highest one–third bands have nominal central frequency equal to 50 and 3150 Hz, respectively; the total number of bands is $M = 19$. A pair of complementary bands ($\overline{M} = 2$) are set between 0 and 44 Hz (i.e. the lower bound of the lowest band) and between 3563 Hz (i.e. the upper bound of the highest band) and 4000 Hz. The sampling frequency is $F_s = 8000$ Hz. As to the tolerances, ϵ_0 and α_0 are set to 0.1 dB and -110 dB, respectively.

In order to provide a homogeneous distribution, the number of sampling points P_m for each complementary band is set to

$$P_m = \frac{30N|\Delta_m|}{F_s},$$

being $|\Delta_m|$ the bandwidth of Δ_m, whereas Q is set to $30N$.

The filters $\{\hat{h}_a, \hat{h}_v\}$ for all the considered scenarios have been successfully synthesized by using a filter length $N = 2047$. For the convex optimization, the CVX [194], [195], a package for specifying and solving convex programs, and the MOSEK solver have been used in the MATLAB environment. The magnitude of the frequency response of the synthesized filters, as well as of the equivalent filter H_v/H_a, are reported in Figure 4.17. The synthesized filters exhibit a smooth profile in the one–third octave bands, especially in the lower part of the spectrum, providing a regular behaviour across different scales. The equivalent filter provides a 0 dB response in the complementary bands thanks to the fact that H_a ans H_v nearly coincide in such frequency regions. Furthermore, the ripple of H_a is conveniently limited in the third–octave bands, avoiding the outbreak of resonance peaks in the frequency response of the equivalent filters.

In Figure 4.18 obtained continuous curves for h_a and h_v filters are compared to the discrete values of measured sound insulation D_a and of a virtual sound

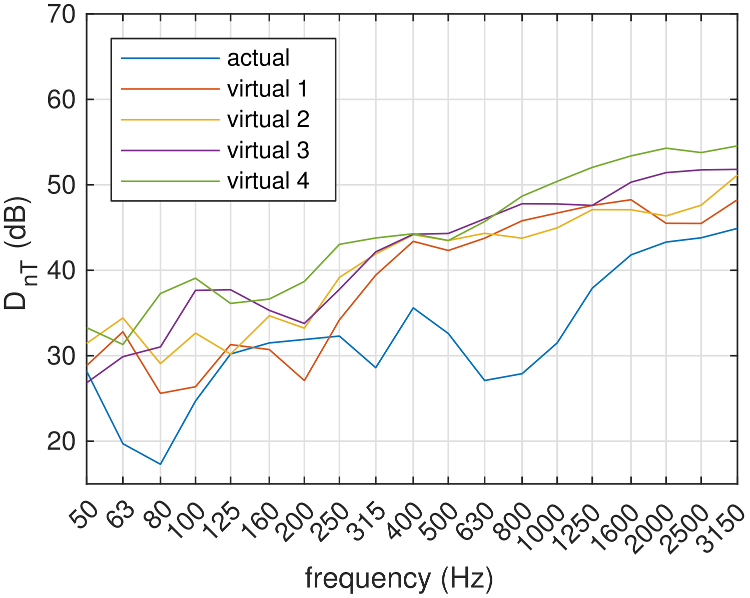
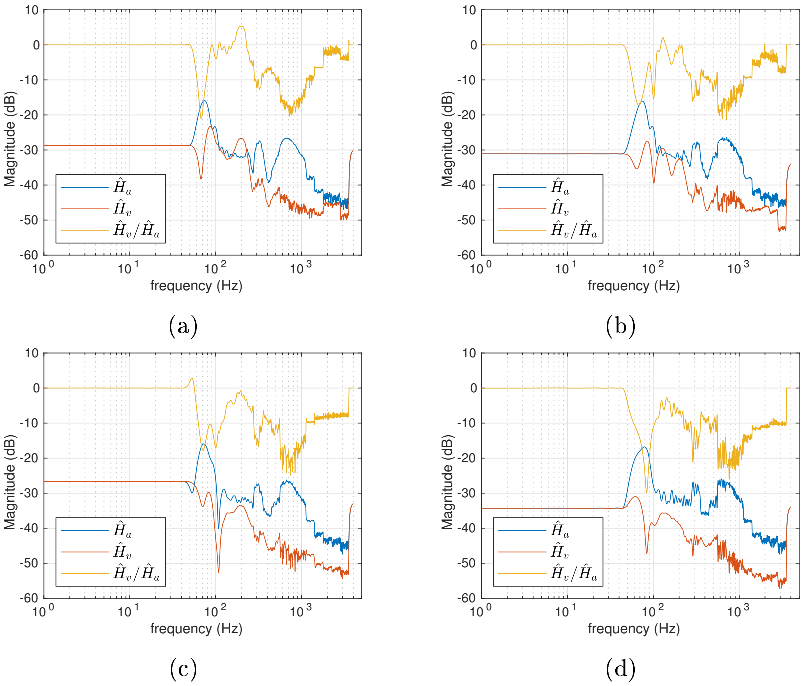


Figure 4.16: D_{nT} curves of the actual and virtual façades.



(a) (b)

(c) (d)

Figure 4.17: Frequency response of the synthesized filters for the virtual façades 1–4 (a–d).

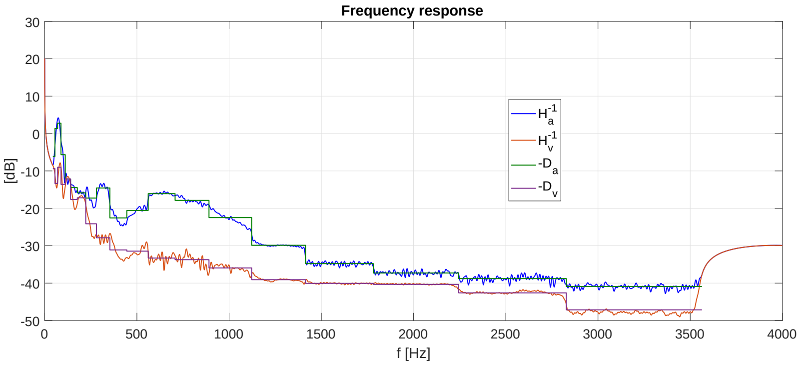


Figure 4.18: Comparison between the synthesised filters and the original sound insulation curves.

insulation curve D_v.

In the Mascagni school the same convex optimization procedure has been applied, by considering the same virtual values of the façade acoustic insulation selected for the V.Veneto school.

4.2.5 Pilot cases description

At the beginning of the PhD programme, once the theme to be addressed had been outlined and an initial application of the method developed in some pilot cases became necessary, all primary and secondary schools in Florence located near the airport and potentially affected by the problem of aircraft noise were contacted. Despite the efforts made to involve at least three schools, unfortunately only one (the smallest) took part in the research project so that the sample of students was not very numerous and, above all, composed of students of different ages (the classes involved are a third, a fourth and a fifth grade of a primary school). To this a larger school of Prato was added, not affected by the problem of airport noise at the moment.

Finally, Two different schools have been identified for the pilot study, the V.Veneto primary school and the Mascagni primary and secondary school. The first one is located in San Bonaventura street n.24 in Florence, along the take–off and landing routes of aircrafts from and directed to the A. Vespucci airport of Florence (See Figures 4.19 and 4.20) and at a distance of approximately 1.9 km from the airport's runway. The second one is located in Galcianese street n. 6/F in Prato, in a residential area only characterized by a street on one side, mainly used by parents who go to accompany and take their children to/from school and by residents (See Figure 4.21). The Mascagni school has been selected as a control school, in order to compare the results obtained from tests carried out on one side in a school, that in Florence, were children are constantly exposed to aircraft noise and on the other in a school where children are not exposed to this noise source.

The V.Veneto is a small school, in which there is only one section for each class. The sample selected for the current study is composed of the third, fourth and fifth grade classes. Differently, the Mascagni one is characterized by six sections for each class both for the primary and the secondary schools. The selected sample is composed of six sections of the fifth grade for the primary school and of six sections

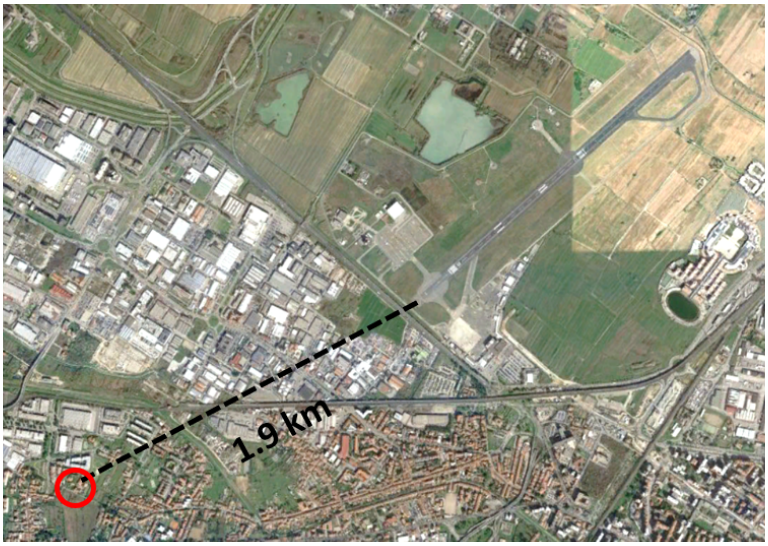


Figure 4.19: Position of the V.Veneto school with regard to the A.Vespucci airport. Source: google map.

Figure 4.20: Picture of the V.Veneto school.

Figure 4.21: Mascagni school. Source: google map.

of the third grade for the secondary school. The number of students involved in the tests is summarized in Table 4.3, where there is a correspondence between the number of collected questionnaires and the number of involved students.

Furthermore, some background information such as the gender and the age distribution of students for each class have been collected from teachers. Finally, the number of students with special educational needs (BES), recently arrived in Italy (NAI) or with poor knowledge of the Italian language, with specific learning disabilities (DSA) and with a personalized study plan (ISP) have been counted for each class of both schools according to teachers indications. Teachers have also provided the level of schooling of each class (see Table 4.4).

4.2.6 Cognitive, listening and informative questionnaires

Three typologies of tests have been designed, to be submitted to students of both in the school affected by aircraft noise and specifically located along the take–off and landing airplanes routes and in the school not affected by aircraft noise (See Appendix A). The first test, similar to the one also adopted by the projects referred to in Sub–section 3.2.5, focuses on episodic memory and consists in reading a story suitable for the students age inside the classroom. In all the classes of the V.Veneto school ad in nine classes of the Mascagni school some moments and words of the reading are disrupted by the reproduction of the aircraft noise signal in the open window configuration. It has been proposed to reproduce the aircraft noise in the open window configuration since it is the most realistic one for mild weather (from April to October), it represents the worst–case scenario, it offers the better

Table 4.3: Classes involved in the tests for each school, typology of school (p=primary and m=middle) and number of collected questionnaires.

School	**Class**	**Typology**	**Number of questionnaire per class**	**Number of questionnaires per school**
V. Veneto	3	p	18	50
	4		16	
	5		16	
Mascagni	5A	p	23	247
	5B		18	
	5C		25	
	5D		21	
	5E		17	
	5F		22	
	3A	m	16	
	3B		23	
	3C		18	
	3D		18	
	3E		22	
	3F		24	

Table 4.4: Number of BES, NAI, DSA students, number of students with a ISP and classes level of schooling in the considered classes of the V.Veneto and Mascagni schools.

School	**Class**	**BES**	**NAI**	**DSA**	**ISP**	**Level of education**
V. Veneto	3	0	0	0	0	average–high
	4	0	0	3	0	
	5	1	0	0	0	
Mascagni	5A	1	2	3	0	low
	5B	0	2	0	0	
	5C	0	1	0	2	
	5D	0	6	0	0	
	5E	0	5	0	0	
	5F	0	5	0	0	
	3A	0	0	0	0	
	3B	0	3	0	0	
	3C	0	0	0	0	
	3D	0	2	0	0	
	3E	0	5	0	0	
	3F	0	2	0	0	

Figure 4.22: Positioning of the electro–acoustic system and of the measurement microphone in a classroom of the V.Veneto school [175].

Figure 4.23: Positioning of the electro–acoustic system and of the measurement microphone in a classroom of the Mascagni school.

sound to noise ratio with regard to the considered aircraft noise source and it causes minor problems in phase of questionnaire's submission (especially in case of a concurrent and real aircraft transit). As for the definition and positioning of the audio reproduction system, a 5.1 surround speaker system is used, with the trick of placing the mid–high frequency speakers so that they are directed towards the window from which the sound actually comes from outside (See Figures 4.22 and 4.23)as already illustrated in Sub–section 4.2.3.

In fact, the window, which is closed during the tests, helps to spread the sound of the speakers to the interior and give the impression that the sound comes from the window itself. Just after the conclusion of the reading, a questionnaire is submitted to students, asking them to answer to ten questions, five of which are referred to moments of the reading disrupted by the aircraft noise and the remaining five

Figure 4.24: A picture taken during the reading test in V.Veneto school.

ones to undisturbed moments. Otherwise, three classes (one of the primary school and two of the secondary school) of the Mascagni school have been identified as control group and they have heard to the reading without being disturbed by the aircraft noise reproduction. The second test consists in the submission of a questionnaire including questions about the personal perception of students regarding noise in general, aircraft and road traffic noise, their ability in concentrating also in presence of noise, adjectives suitable/unsuitable for expressing the sensations that noise of various types arouses in them. The test submitted to students of the Mascagni school included just a selection of the questions asked to the students of the V.Veneto school since it has been considered not significant to interview them about ‘obvious’ aspects such as the absence of airplanes in the vicinity of their school. The third test consists of making students listen to four types of signals played in random order: the signal that reproduces the noise due to the passage of the aircraft in the real conditions of open window at different noise amplitude, the signal that represents the condition of a closed window with the current configuration of façade sound insulation and in presence of virtual conditions of absorption of the internal walls and therefore of virtual values of the reverberation time. Figures 4.24 and 4.25 represent some moments of the tests submission. Finally, questionnaires have been submitted to the children’s parents, asking them for the education level and the occupation of both fathers and mothers and if they are divorced or not. All the tests have been included in the Annexes (A).

4.2.7 The ethic protocol

In order to carry out the surveys with children in schools according to the ethical procedural techniques [196], formal authorization together with appropriate documentation have been requested at the beginning of the PhD course to the Ethic Committee of the University of Florence and the authorization has been received after some months. Moreover, the authorization to perform activities at school involving minors has been agreed by the most part of parents by signing an informed consent one month before the beginning of the tests. In addition, an ethical protocol to be followed with children had been firstly agreed with the social psychologist who collaborated in the research [196], [197]. In fact, at the beginning of the test-

Figure 4.25: A picture taken during the reading test in Mascagni school.

ing session it has been explained to the children with simple words that they were free to withdraw from the study at any point and they did not have to answer any question they do not want to answer. Prior to testing, teachers have been asked to identify children that they thought could be upset by the testing and these children should be carefully observed during the testing session. Children who wanted to take part in the study and who, prior to the testing phase, have been identified as having learning or language problems have been helped by the researchers and the teachers throughout the testing, to ensure they don't feel a sense of 'failure'. The research team has carefully watched the children during the testing to see if any child is upset by the testing and then ask them if they want to carry on with the project. Standard ethical procedures such as children being de–briefed after the testing session and having opportunity to privately approach the researchers have been applied. In this debriefing session the aims of the project has been reinforced, confidentiality ensured, any questions or concerns addressed. After the tests, the class teachers have been asked to follow up the debriefing session with children to ensure that they have not been upset by the testing.

Chapter 5

Experimental results

In the current Chapter, obtained results are split in two different sections: the first one (Section 5.1) regarding the main outcomes obtained from the applicative comparison between the INM and the CNOSSOS–EU aircraft calculation methods and the second one concerning the main results obtained from the analysis of questionnaires collected during the test described in Sub–section 4.2.6.

5.1 Outcomes of the comparison between the INM and the CNOSSOS–EU aircraft noise calculation standards

In the current section, in order to make a comparison between the INM and the CNOSSOS–EU calculation methods and to provide a simple case study for the verification of the latter in accordance with the EU indications [15], a scenario has been built on the basis of the A.Vespucci airport in Florence (Sub–section 5.1.1) and simulations of aircraft noise levels generated in a neighbourhood have been run both with the INM and the CNOSSOS–EU calculation methods (Sub–section 5.1.2), based on the same input data. Simulations have been run inside the CADNA software, which disposes of different calculation methods including the INM and CNOSSOS–EU ones. Moreover, a calibration of the simulations' output has been made according to a noise measurement campaign carried out in proximity to the A.Vespucci airport (Sub–section 5.1.3).

5.1.1 Technical data

Preliminary steps for the model building in CADNA environment concern the uploading of the regional technical cartography for the interested districts (Figure 5.1), the runway positioning (Figure 5.2) and the nominal take–off and landing trajectories (Figure 5.3). Moreover, the annual aircraft traffic according to the Masterplan 2014–2029 for the year 2013 [198] has been considered. Since the noise parameter adopted for the calculation is the L_{den} on an annual basis, the number and typology of aircraft movements has been split in the day, evening and night period.

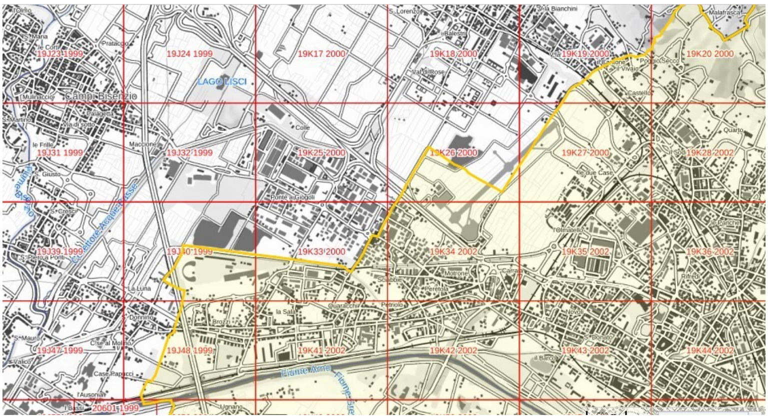


Figure 5.1: Selected cartography of the Tuscany Region.

Figure 5.2: A.Vespucci airport - runway positioning.

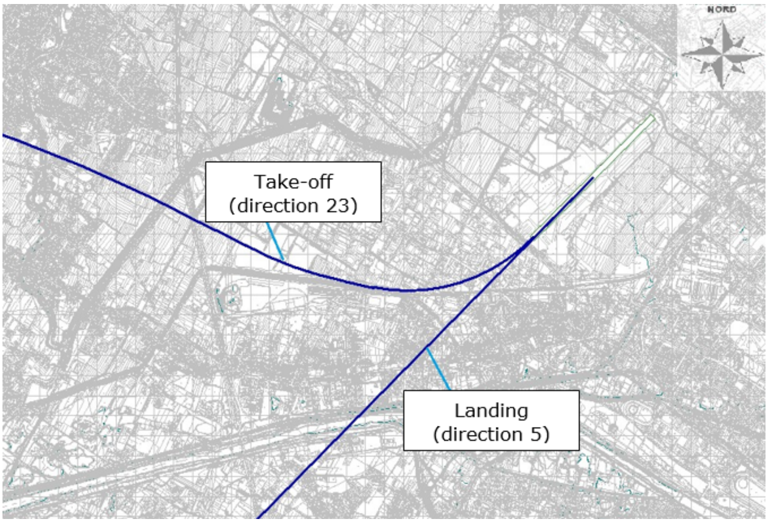


Figure 5.3: A.Vespucci airport - Take–off and landing trajectories from Masterplan.

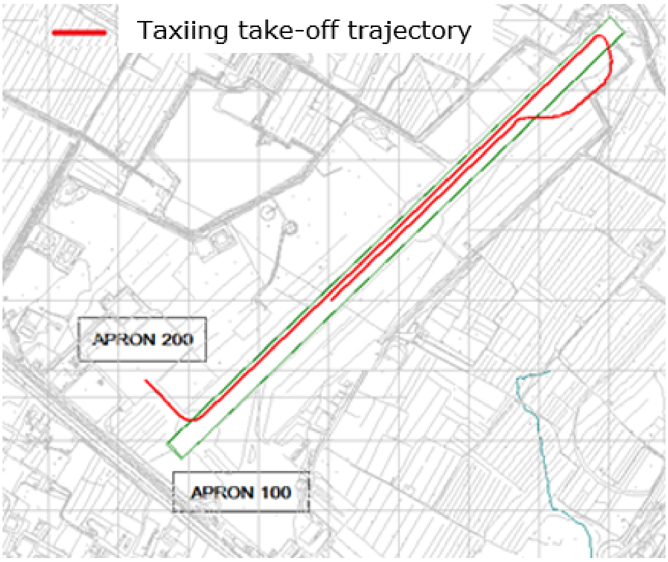


Figure 5.4: A.Vespucci airport - Take–off taxiing trajectory.

In addition, ground taxiing trajectories both for take–off and landing have been inserted as shown in the Figures 5.4 and 5.5.

5.1.2 Comparison between results obtained with INM and CNOSSOS models

Obtained results have been compared, in terms of the L_{den} parameter, both in the take–off and in the arrival scenario. From the comparison it can be seen that the output of the two analysed models CNOSSOS–EU and INM almost matches in the ‘arrivals’ configuration (Figure 5.6). The only difference that can be noticed is a

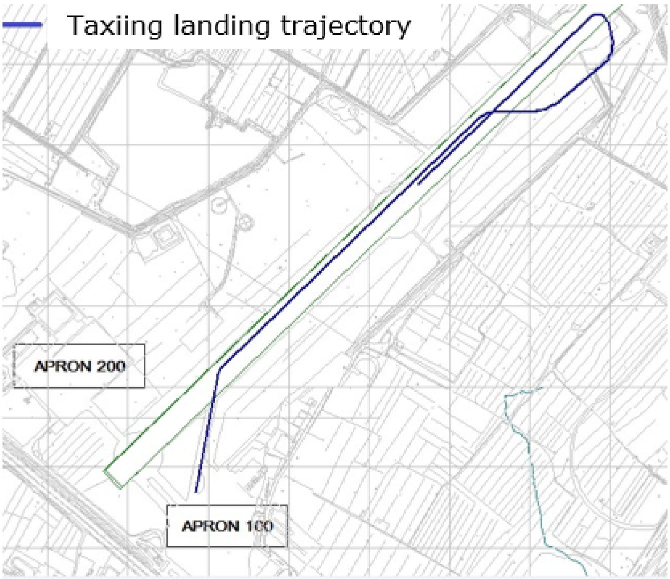


Figure 5.5: A.Vespucci airport - Landing taxiing trajectory.

very small area where noise levels are greater than 85 dB(A) in the CNOSSOS–EU model in correspondence of the runway (Figure 5.7). This could indicate a greater sensitivity of that model to ground taxiing.

As far as the starting scenario is concerned, the isophonics of the INM model tend to coincide with those of the higher noise level interval of the CNOSSOS–EU model. Therefore, the two models give different results, in particular a divergence of approximately 5 dB(A) between the two is observed and the CNOSSOS–EU calculation method reveals to be the most precautionary (Figure 5.8).

5.1.3 Models calibration

After comparing the outputs provided by the two calculation methods in terms of simulations carried out in a CADNA environment with the same input data (Sub–sec 5.1.2), a calibration of the two models was made, comparing the results of a measurement campaign carried out at the University of Florence – detachment of Sesto Fiorentino with the outputs of the software with reference to individual overflights.

The measurement campaign has been carried out at a linear distance of approximately 800 m from the A.Vespucci airport runway (Figure 5.9) and it has been designed according to the indications provided by the ISO–17534 part 1 [173] and part 2 [174].

The acoustic measurement campaign has taken place near a building of the University of Florence – detachment of Sesto Fiorentino in three consecutive days (on 24, 25 and 26 May 2017), for a total of 5 measurement positions. Measurements have been made during the daytime period and the location of the microphones has been chosen specifically so that aircraft noise could be generally dominant over the background noise typically caused by local road conditions. For each position, sound pressure measurements have been carried out with a class I sound level meter

Figure 5.6: Comparison between the outputs of INM (thinner curves) and CNOSSOS–EU (thicker curves) in the case of arrivals.

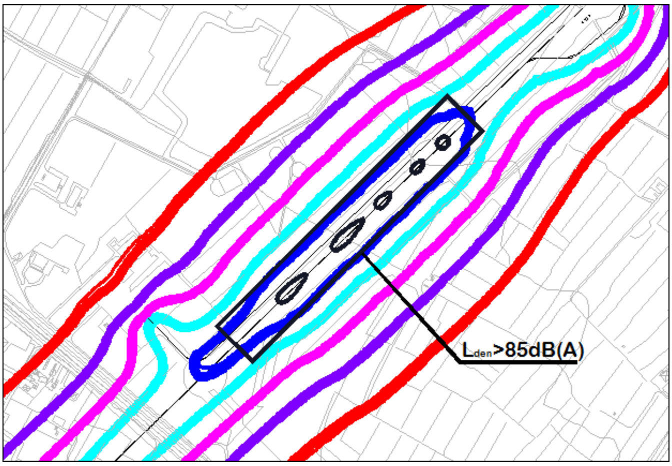


Figure 5.7: Details of the comparison between the outputs of INM (thinner curves) and CNOSSOS–EU (thicker curves) in the arrival scenario.

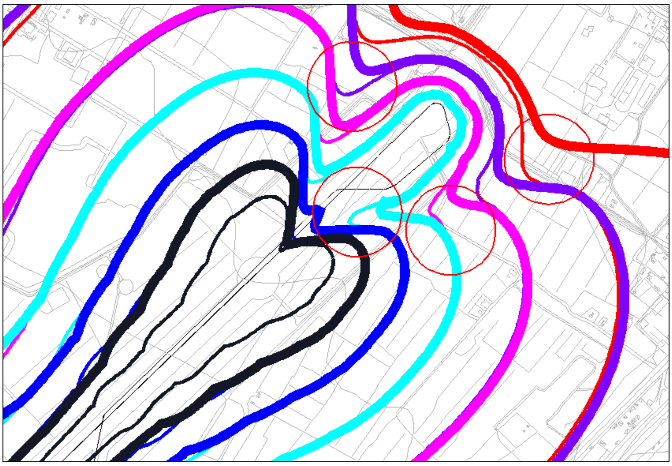


Figure 5.8: Details of the comparison between the outputs of INM (thinner curves) and CNOSSOS–EU (thicker curves) in the take–off scenario.

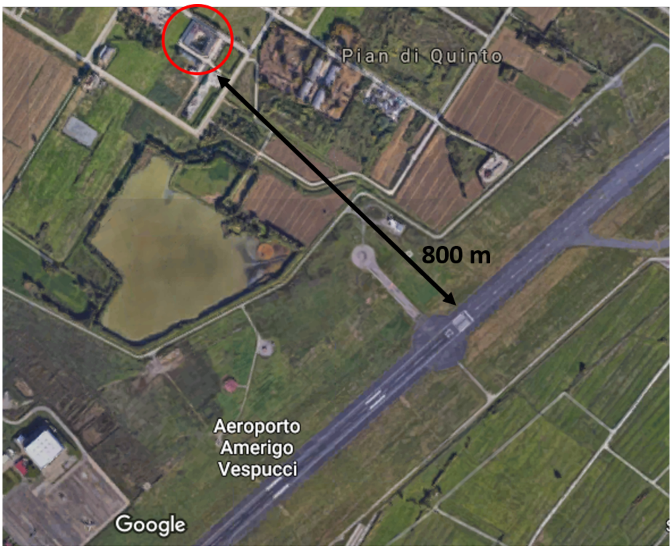


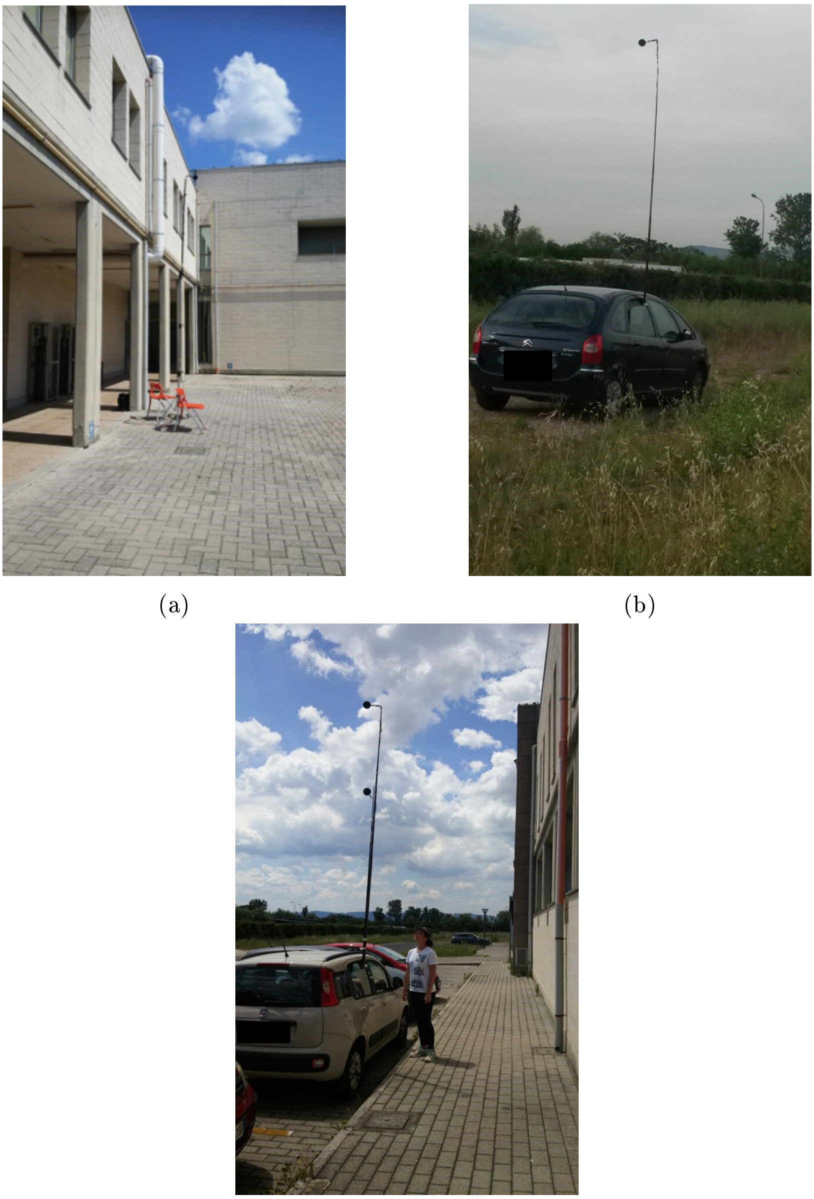
Figure 5.9: Location of the building of the University of Florence – detachment of Sesto Fiorentino with respect to the A.Vespucci runway. Source: google map.

placed at a height of 4 m above ground level. Microphone Position A has been fixed at approximately 2 meters–distance from the building wall and in correspondence of the take-off taxiing location, Position B has been chosen in correspondence of an open space location parallel to the runway, along the same line as position A at an approximate distance of 100 m from the latter, Position C has been chosen in open space behind the B position at an approximate distance of 10 meters from the latter, Position D has been set in the internal building courtyard and Position E behind the building at a distance of 2 meters from it. In Figure 5.10 pictures of the microphone positioning are represented specifically referring to Positions A, B and D.

The operators who have overseen the measurements have taken note of the start time of the single aircraft movement (take–off and landing) which was then verified by comparing it with the official data published by flight radar. All measurements have been made in accordance with the procedures and modalities established by the Ministerial Decree of 16 March 1998 [199] and its annexes:

- since these are outdoor measurements, the rules and distances laid down in Annex B have been respected;
- during the measurements, the microphones have been placed at a height of 4 m
- all measurements have been carried out in normal weather conditions, i.e. in the absence of atmospheric precipitation and with wind speed in the location of less than 5 m/s;
- the researchers who witnessed the measurements have been kept at a distance during the campaign that did not affect it.

Figure 5.11 shows the five measurement positions selected for the acoustic measurement campaign that have been similarly set in the CadnaA software.



(a)

(b)

(c)

Figure 5.10: Examples of microphone positioning: inside the building courtyard – Position D (a), free–field – Position B (b) and near the building – Position A (c).

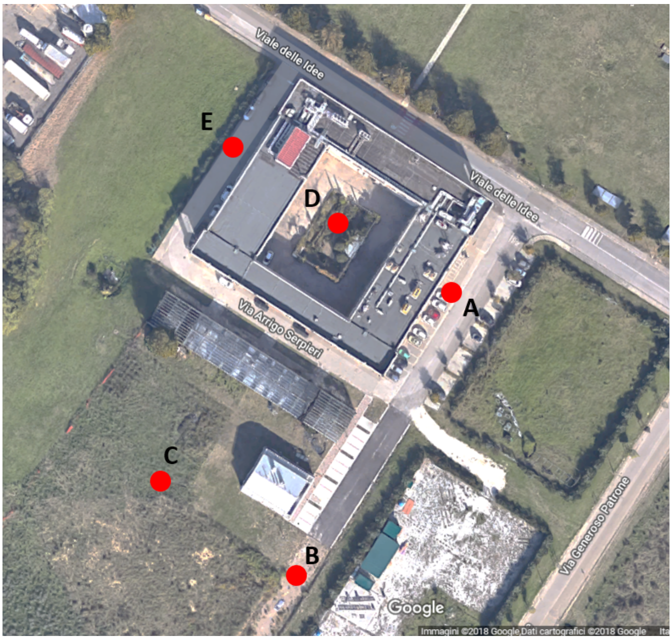


Figure 5.11: Microphone positions established during the acoustic measurement campaign.

In the post–analysis phase the time history has been analysed and the SEL parameter has been evaluated for each recognised take–off event in order to quantify the sound energy associated to the effective event duration. For the specific purposes of the comparison between measured and simulated values returned with the CNOSSOS–EU standard, reference was made to the individual take–off events of the $A319$ aircraft's model expressed with the LA_{max} parameter and related to the daytime period.

Obtained results for each acoustic measurement positions are reported in Table 5.1 in which the difference 'column' is evaluated as a subtraction between noise levels simulated according to the CNOSSOS–EU standard and measured values. In addition, noise levels predicted according to the INM calculation method in the same scenario are reported.

According to the EU Directive 996/2015 [12], the uncertainty related to the emission level of the source is equal to ±2 dB, while the ISO 9613–2 [200] indicates an uncertainty concerning the propagation path of ±3 dB for the concerned heights and distances. On the whole, an extended reference uncertainty of 3.5 dB has been considered. In the current application the differences found for all the events related to stations A, B and C are considered acceptable when the position of the instrumentation has not been affected by the barrier effect of the building. Specifically, results differ by about 2 dB(A), except for three measurements for which differences are of about 3 dB(A). For one flight, the difference, even if small, is negative or the measured value is greater than the predicted one. This is due to the fact that the measured event is subject to the uncertainty of other sound events such as the car passage in the adjacent areas of the receiver that overlap the aircraft noise. Otherwise, the differences between the predicted and the observed

Table 5.1: Comparison between predicted (with INM and CNOSSOS–EU standards) and measured noise levels due to A319 take–off in correspondence of Positions A, B, C, D, E.

Day	Take-off			**Position A**			
	Time	Destination	Flight	Pred. LAmax CNOSSOS [dBA]	Mis. LAmax [dBA]	Diff	Pred. LAmax INM [dBA]
1st	09:09	Barcelona	VY6004	81,7	80,3	1,4	81,0
	09:42	Catania	VY6864	81,2	81,8	-0,6	80,2
2nd	11:31	London	VY6236	81,3	81,3	0,0	80,2
	15:34	Madrid	IB3259	81,3	79,2	2,1	80,2
3rd	10:16	Palermo	VY6922	81,3	80,6	0,7	80,2
	11:48	Madrid	VY1506	81,4	78,5	2,9	80,3
	Take-off			**Position B**			
1st	09:09	Barcelona	VY6004	82,0	79,9	2,10	81,4
	09:42	Catania	VY6864	81,6	81,0	0,6	80,5
3rd	10:16	Palermo	VY6922	81,7	79,3	2,4	80,6
	11:48	Madrid	VY1506	81,7	78,3	3,4	80,6
	Take-off			**Position C**			
1st	09:09	Barcelona	VY6004	81,4	79,9	1,5	80,8
	09:42	Catania	VY6864	81,1	81,0	0,1	80,0
3rd	10:16	Palermo	VY6922	81,2	79,5	1,7	80,0
	11:48	Madrid	VY1506	81,2	77,6	3,6	80,1
	Take-off			**Position D**			
2nd	11:31	London	VY6236	80,7	74,5	6,2	79,6
	15:34	Madrid	IB3259	80,7	73,8	6,9	79,6
	Take-off			**Position E**			
2nd	11:31	London	VY6236	80,2	74,1	6,1	79,1
	15:34	Madrid	IB3259	80,3	72,9	7,4	79,1

values for station D and E are significant (higher than 6 dB(A)) and this seems to be due to the impossibility of the CNOSSOS–EU calculation standard to take into account the presence of large obstacles such as the building, evidently not considered during the simulation.

Concerning the differences between the data respectively predicted with the CNOSSOS–EU and the INM calculation methods in correspondence of the A, B and C receivers positions (Table 5.1), it turns out to be approximately 1 dB(A) with higher noise levels returned by the CNOSSOS–EU standard coherently with the considerations already made in Sub–section 5.1.2.

According to the manufacturer of the CADNA software used for the simulations, wherewith a continuous contact has been kept during the research since there are still few applications carried out in Italy in this field, it would seem from the observations that the difference in the results obtained respectively with the INM and CNOSSOS–EU calculation standard is mainly due to the different methods of calculation of the term relating to air temperature. In fact, the CNOSSOS–EU standard adopts coefficients related to both low and high temperatures, using the higher thrust level for temperatures below the flat rating temperature and the lower calculated thrust level for the temperature above the flat rating one. Differently, INM calculates both the coefficients related to low and high temperature and then apply the smaller one as the corrected net thrust for a given power state. A possible further development of the study would consist in trying to understand how the term related to the air temperature calculation really influence the outputs of the simulation carried out by using the two standards and also to look for a possible solution to make the CNOSSOS–EU standard able to recognize the presence of large obstacles placed on the ground.

5.2 Outcomes of the analysis of questionnaires collected at the V.Veneto and Mascagni schools

In the current section, the descriptive statistics about the parents education and employment are illustrated (Sub–section 5.2.1), together with the descriptive statistics about children and how they perceive noise (Sub–section 5.2.2). Moreover, in Sub–section 5.2.3 the results of the reading test are explained and comparisons are made between the two involved schools. Furthermore, in Sub–section 5.2.4 considerations about the possibility of developing simple curves of annoyance from collected data are made.

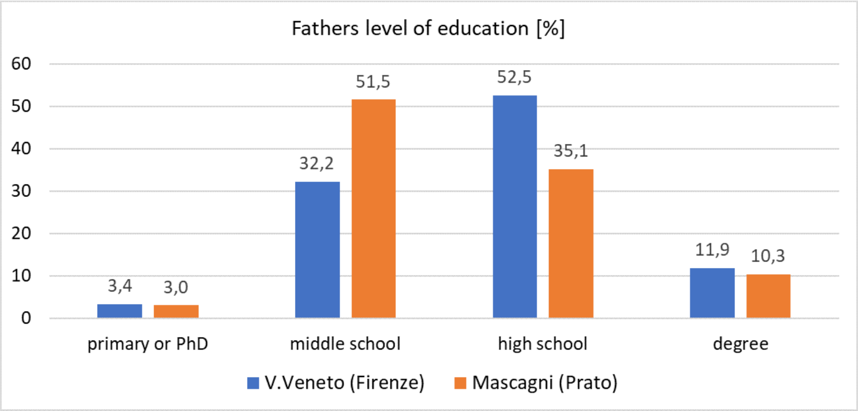


Figure 5.12: Comparison between the fathers education of the classes of both schools involved in the study.

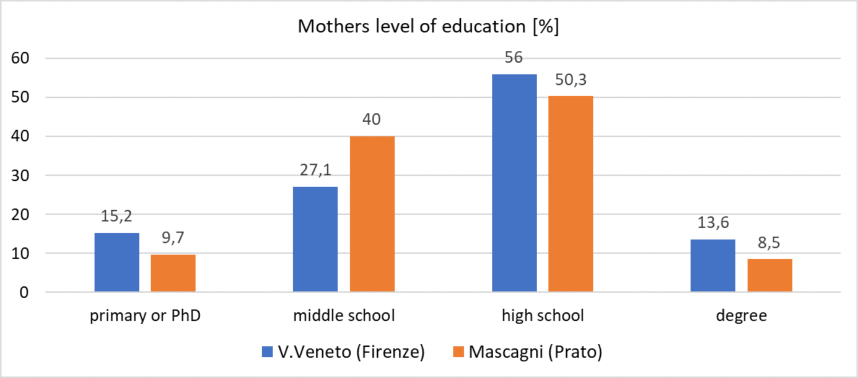


Figure 5.13: Comparison between the mothers education of the classes of both schools involved in the study.

5.2.1 Parental background

As already reported in Sub–section 4.2.6, at the beginning of the study a questionnaire has been given to the children's parents of both schools involved (See Appendix A), asking them informations about father's and mother's education degree, employment and whether or not they are divorced. The questionnaires have been collected and analysed and the main outcomes are illustrated in the current section.

About the percentages of separated parents, no significative differences have been detected: in the classes of the V.Veneto school the separated parents are the 13%, while in the Mascagni school they are the 9%. Concerning the other collected information they have been represented in the Figures 5.12, 5.13, 5.14 and 5.15 and commented below.

Regarding the education of the father, between the classes of the two schools involved in the study the situation is quite consistent. The main difference is that for the classes of the Mascagni school, the 51% of the parents have a middle school license, while about the 35% have a higher school license, while for the classes of

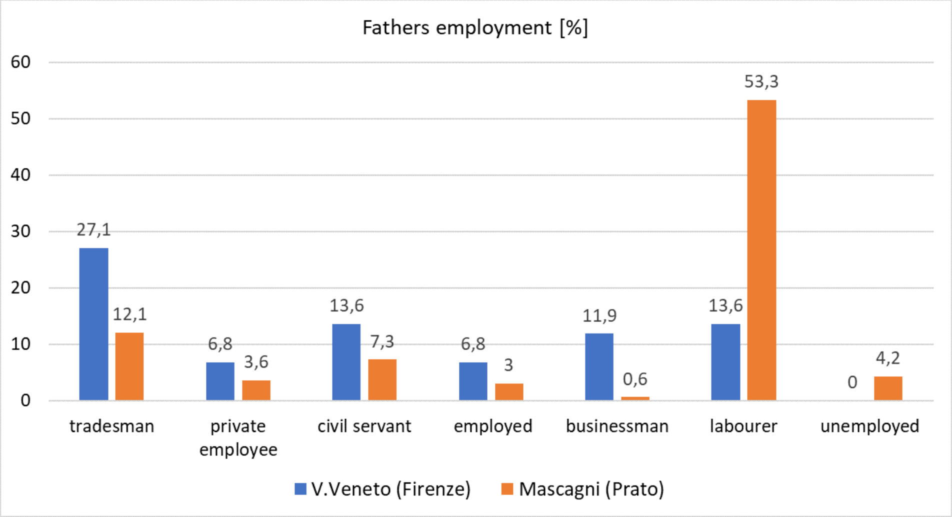


Figure 5.14: Comparison between the fathers employment of the classes of both schools involved in the study.

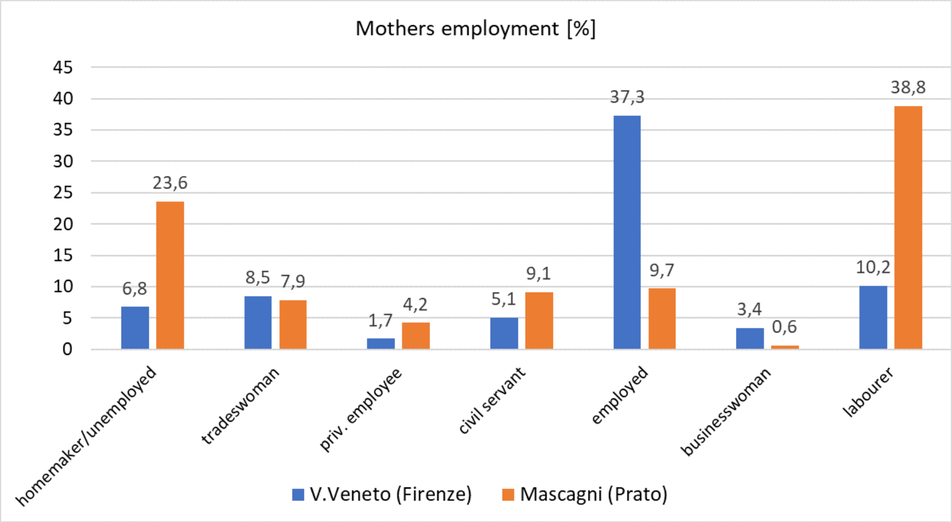


Figure 5.15: Comparison between the mothers employment of the classes of both schools involved in the study.

the V.Veneto school the situation is reversed, in fact, about 52% have a higher school license and only 32% have a middle school license. As far as the education of the mother is concerned, in the classes of the Mascagni school the percentage of mothers with a middle or higher school license is respectively equal to about 40% and 50%, more homogeneous than that of the fathers; in the classes of the V.Veneto school the proportions are respectively about 27% and 56%. In general, therefore, it emerges that for both fathers and mothers, the classes of the V.Veneto school seem to have the highest percentage of graduates compared to the classes of the Mascagni school. Instead, for the higher education levels, the situation is more homogeneous between the two schools. These differences encountered in the two groups may have an influence on the schooling level declared by teachers about the classes of the two schools; in particular, according to literature [29], [85] the mothers' level of education could have an influence on children's scholastic performances. With regard to the working situation of the father, we note that while more than 50% of the fathers of the classes of the school Mascagni is a labourer, only 13% is in the classes of the V. Veneto school, where the 27% (higher percentage) is a trader. Moreover, as far as mothers are concerned, we notice a clear difference between the percentages of labourers in the classes of the Mascagni school (about 39%) and V.Veneto school (about 10%), but we also see that at the Mascagni school there is about 24% of unemployed and housewives, while at the V.Veneto school there is only 7% of housewives, while no mother is classified as unemployed. Finally, again with reference to mothers, at the V.Veneto school the 37% (the highest percentage) is employed while only the 10% is employed at the Mascagni school. In this regard, the discrepancy found for the 'labourer' category, but reversed, emerges approximately the same.

The analysis carried out on the parental background of children have been made on order to present some basic information about the context of the study and they will be possibly turn out to be of any use in a future development of the current research in order to build further statistical analysis with the aim of building complex models able to find a relation between the children annoyance on one side and the parental background and the scholastic education on the other.

5.2.2 How children perceive noise

Results of the questionnaire concerning the general perception of noise according to children have been analysed with the main aim of understanding which are the main subjective differences between answers given by the children of Prato and Firenze.

Since both schools did not dispose of computer rooms with PCs for all the students involved in the study, paper questionnaires had to be handed over to the students. However, for the purposes of the analysis, it was decided to develop a system that could speed up the acquisition of the provided answers and could reduce the risk of potential errors due to the manual insertion of the answers on the computer system. To this aim, the paper–based questionnaires, once collected, have been digitalized and, in the frame of the optical character recognition (OCR) systems, a semi–automatic technique of answers acquisition has been implemented in the Matlab environment in order to have a more systematic and rapid data acquisition.

Moving to the analysis of the obtained results, to the question on the perception of road traffic noise around the school, both the children of Florence and those of

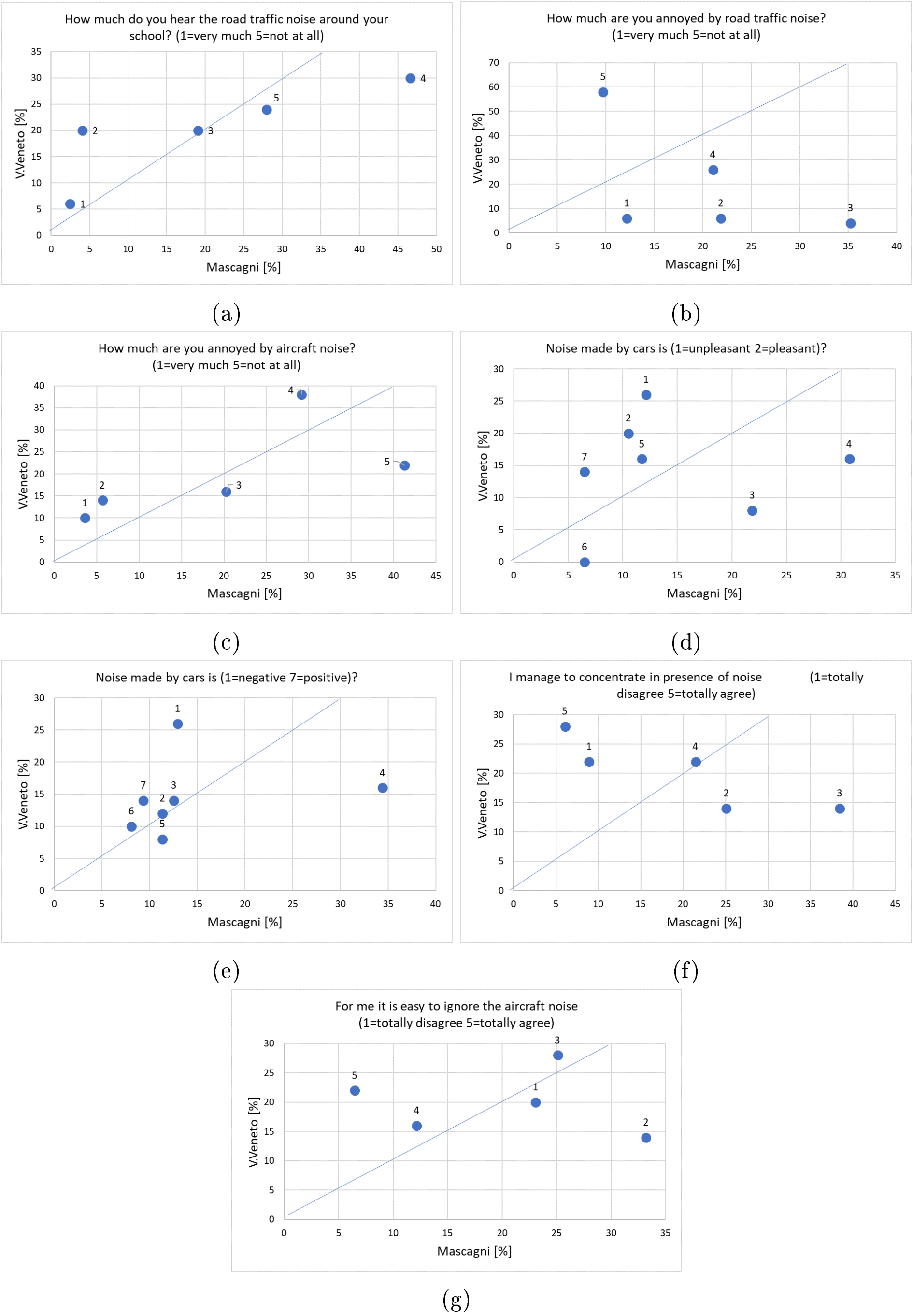
Prato responded for the most part with a value of 4 (‘little’ on a scale from 1 to 5). However, we note that while the answers of the children of the V.Veneto school are more homogeneous as regards the values from 2 (‘very’) to 5 (‘not at all’), for those of the Mascagni school the answers are mainly concentrated in the last two classes (‘little’, ‘not at all’) (Figure 5.16a). When asked about the perception of annoyance due to the road traffic noise, it is noted that more than 50% of the children of the V.Veneto school answer 5 (‘not at all’) while about 35% of the children of the Mascagni school answer 3 (‘enough’) 5.16b). Moreover, although the highest percentages of answers given to the previous question were for both schools equal to the value 4 (‘little’), in this case the perceived discomfort is more pronounced for the Mascagni school than for the V.Veneto school.

When asked about the perception of annoyance due to aircraft noise, it is observed that in both schools most of the children answer 4 or 5 (‘little’, ‘not at all’) even if for the Mascagni school about 41% answer 5 (‘not at all’) (Figure 5.16c). Presumably this is due to the fact that the children of the Mascagni school are not used to hear in the vicinity of the school the noise due to airplanes.

With regard to the section of the questionnaire concerning the attitude towards noise, in particular the answers related to the dichotomies (negative/positive or unpleasant/pleasant) regarding the noise of cars were analysed. We see (Figure 5.16d) that in the first case 26% of the children of the V.Veneto school answered 1 or ‘negative’ while 34% of the children of the Mascagni school answered 4 (‘neither negative nor positive"). Given the similarity to the question about the objective perception of car noise in the vicinity of the school, this difference could be attributed to a different sensitivity of children in the two schools. The same situation is also found with regard to the unpleasant/pleasant dichotomy still concerning the noise of cars (Figure 5.16e).

With regard to the section dedicated to the young people’s attitude towards noise, in particular focusing on the ability of children to concentrate in case they hear noises around them and if it is easy for them to ignore the noise around them, we see that, for the first case, the children of the V.Veneto school say that they manage to concentrate better in the presence of noise than the children of the Mascagni school(Figure 5.16f). In fact, for the V.Veneto school 28% answered 5 (i.e. they completely agree with the statement), while for the Mascagni school 38% answered 3, i.e. they indicated the central value of the scale. As far as the second aspect is concerned, for the V.Veneto school the distribution of the answers is more homogeneous, even if the greater percentage falls in correspondence to the central value, for the Mascagni school, instead, more than 50% of the children concentrated the answers in the values 1 and 2 (‘totally disagree’, ‘very disagreeing’) (Figure 5.16g).

The most interesting considerations according to the collected data are that the students of the Mascagni school appear to be more sensitive to road traffic noise than to aircraft noise and this is most probably due to the fact that they are not used to hear airplanes around their school. Moreover, the students of the V.Veneto school declare, similarly to the students of the Mascagni school, not to be so much annoyed by aircraft noise and to be more able than the students of the Mascagni school to concentrate in presence of noise and to ignore the aircraft noise. These last outcomes could be due to a capacity of children to get used to the noise source to which they are mostly used to during school lessons and they seem to support some recent literary findings (Sub–section 3.2.7).



(a) (b) (c) (d) (e) (f) (g)

Figure 5.16: Comparison between answers given by students of V.Veneto and Mascagni schools about aircraft and road traffic noise perception.

Table 5.2: Number of students for each experimental condition of the reading test.

	Group	**Number of students**
Exp. condition	TG1	50
	TG2	182
	CG	60

Table 5.3: Descriptive statistics for each experimental condition of the reading test, dependent variable: 'Score–noise–y'.

Exp. condition	**Mean**	**Std deviation**	**Number of answers**
TG1	,98	,892	50
TG2	,73	,834	182
CG	1,75	1,310	60
Total	,98	1,037	292

5.2.3 Results of the reading test

With regard to the reading test, the choice of reading and the formulation of the questions to be addressed to the students were made in collaboration with a social psychologist Moreover, for the data analysis phase, since the answers given to the questionnaire were open, it was necessary to collaborate with a social psychologist in order to define a procedure as objective as possible to decide the correctness or not of each answer. In addition, the analysis and the cataloguing of the provided answers were carried out independently by three people belonging to the University of Florence in order to arrive, at the end, at a robust assignment.

For each student, two scores were calculated: one for the correct answers referring to the parts of text read in the presence of reproduced aircraft noise ('Score–noise–y') and one for correct answers referring to the parts of text read in the absence of aircraft noise ('Score–noise–no'). Remember that the control group, composed of 60 students (Table 5.2), always answered questions without reproduced aircraft noise during the reading test.

Calculated in this way, the dependent variable (number of correct answers) is continuous. Initially, descriptive statistics have been evaluated (Table 5.3).

Moreover, a t–test was performed for paired samples to see if the difference in score between the 'Score–noise–y' and the 'Score–noise–no' questions was statistically significant. A significant difference would be expected in the group of students of the V.Veneto school (TG1) and in the group of students of the Mascagni school (TG2), but not in the control group of the latter (CG). The t–test instead shows significant differences in CG and this suggests that another factor has intervened in determining the answers, such as the difficulty of the questions. The questions that the technicians who prepared and carried out the test considered more ambiguous during the course of the same have been eliminated from the calculation, but the results of the t–test were almost unchanged. Consequently, it was decided to focus the analysis only on the 'Score–noise–y' answer (dependent variable), comparing the three groups for which differences according appear to be significative (Tables 5.4 and 5.5).

As hypothesized, a significant effect of the experimental condition emerges (the class has been inserted as covariate): the number of correct answers given by the

Table 5.4: Results of the ANCOVA (*AN*alysis of *COVA*riance) test.

	Type III Sum of Squares	**df**	**Mean square**	**F**	**Sig.**	**Partial Eta Square**
Source	48,655	3	16,218	17,675	,000	,155
Correct model	10,358	1	10,358	11,288	,001	,038
Intercept	1,779	1	1,779	1,938	,165	,007
Class	43,136	2	21,568	23,505	,000	,140
Exp. Condition	264,259	288	,918			
Error	595,000	292				

Table 5.5: Estimations, dependent variable: 'Score-noise–y'.

			95% Confidence interval	
Exp. condition	**Mean**	**Std deviation**	Lower bound	Upper bound
TG1	1,100	,160	,784	1,416
TG2	,717	,072	,576	,858
CG	1,691	,131	1,434	1,948

Table 5.6: Pairwise comparison: dependent variable:'Score-noise–y'.

					95% Confidence interval	
(I) Exp. cond	**(J) Exp. cond**	**Average diff (I-J)**	**Std error**	**Sign**	Lower bound	Upper bound
1	2	,382	,180	,035	,027	,738
	3	-,591	,224	,009	-1,032	-,151
2	1	-,382	,180	,035	-,738	-,027
	3	-,974	,146	,000	-1,262	-,686
3	1	,591	,224	,009	,151	1,032
	2	,974	,146	,000	,686	1,262

participants is lower in the presence of aircraft noise (in the schools of Florence and Prato) than in the control condition. Moreover, the correct answers given by the children of Florence are significantly higher than those given by the children of Prato in the presence of noise. The students of the V.Veneto school therefore appear more capable of answering the questions correctly even in the presence of noise, compared to those of the Mascagni school, and the differences between the three considered groups of students are significative (Tables 5.6).

In this evaluation it is certainly necessary to keep in mind the possible influence of the parental background and of the education level on the obtained results.

Moreover, in this context, an analysis was carried out on a contingency table where in each cell there is the number of students who provided a certain number of correct answers. The analysis was made only for the Mascagni school since only for this school it was possible to compare the student test group (TG2) with that of control (CG). To construct the contingency table, the cases were grouped as follows: the first group includes the cases in which a number of correct answers between

Table 5.7: Chi–square test for independence, Odd Ratio and Relative Risk (RR).

	Correct answers				
Exp. cond.	0-4	5-10	Total		
CG	28	32	60		
TG2	129	51	180		
Total	157	83	240		
Chi-square test Pearson	12,4				
Pr	0,0				
Correct answers	Odds Ratio	chi2	P>chi2	[95% Conf. Interval]	
0–4	1,0	.	.	.	.
5–10	0,3	12,4	0,0	0,2	0,64
Test of homogeneity (equal odds): chi2(1)	12,4				
Pr>chi2	0,0				
Score test for trend of odds: chi2(1)	12,4				
Pr>chi2	0,0				
RR	[95% Conf. Interval]				
0,6	0,5	0,9			

0 and 4 was given, in the second group there are the cases in which a number of correct answers between 5 and 10 was given. Subsequently, the chi–square test for independence was evaluated, which resulted to be significant. Consequently, it can be said that the treated group (TG2) and the control group (CG) are not independent. Afterwards the odds ratio was calculated in both cases and it turned out that the odds of answering from 0 to 4 correct answers rather than from 5 to 10 correct answers for those who have not heard the aircraft noise during the reading test is 0.346 times compared to those who have heard the noise. Therefore, this output confirms that those children who hear the noise tend to respond correctly to fewer questions. In fact, since the odd ratio confidence interval does not contain the 1 value, this confirms the result obtained with the chi–square in the contingency table. For a more immediate interpretation, the relative risk (RR) has also been calculated, from which it emerges that the probability of answering from 0 to 4 correct answers for those who have not heard the noise is about 65% of the probability of answering from 5 to 10 correct answers. Therefore, the RR also confirms that children for whom aircraft noise was reproduced during reading tend to provide a greater number of incorrect answers. Synthetic results are reported in Table 5.7.

Table 5.8: Characteristics of the thirteen sounds reproduced during the general test on noise perception, Sound code from 1 to 13, window configuration (open or closed), OAN stands for Original Aircraft Noise, ASI stands for Actual Sound Insulation, VSI stands for Virtual Sound Insulation, T60 refers to the reverberation time respectively evaluated according to the UNI11736 and the D.M. 18, SEL 1 refers to the V.Veneto school and SEL 2 refers to the Mascagni school.

Code	**Window**	**Sound type**	**SEL 1 [dBA]**	**SEL 2 [dBA]**
1	open	OAN	89,0	88,8
2		OAN + 3 volume	91,9	92
3		OAN + 6 volume	94,7	94,5
4		OAN -3 volume	85,6	85,8
5		OAN -6 volume	82,9	82,6
6		OAN -9 volume	80,8	79,9
7	closed	ASI	71,2	70,8
8		VSI 1	68,7	69,4
9		VSI 2	66,0	64,1
10		VSI 3	71,8	66
11		VSI 4	65,4	64,1
12		T60 UNI-11367	70,5	68,7
13		T60 D.M. 18/12/1975	73,7	69,7

5.2.4 Curves of annoyance

There is increasing evidence about children's exposure to aircraft noise and some preliminary evidence that children may be able to judge their levels of aircraft noise exposure [197]. At the end of the general test about noise perception, children were made to hear thirteen different sounds and were asked about their perceived annoyance (from 'absolutely not' to 'highly'). The main aim of the analysis is to understand if at low levels of reproduced noise corresponds a low perception of disturbance and vice versa by referring to noise generated by the single aircraft event in terms of the SEL parameter.

In Table 5.8 the main characteristics of the thirteen sounds are reported.

It is important to highlight that the SEL values reported in Table 5.8 are those which have been respectively measured in the involved classrooms of the V.Veneto and the Mascagni schools while the thirteen sounds were being reproduced and the difference between the correspondent levels measured in the two schools are almost negligible. This means that the noise levels measured in correspondence of the V.Veneto school in Florence and then reproduced both in the V.Veneto and in the Mascagni school had been correctly filtered according to the specific intrinsic acoustic characteristics of each building. In this way the sounds that children were made to hear could be considered independent from the building acoustic characteristics.

In Table 5.9 the frequency distribution of the real and virtual acoustic insulation is reported.

In Table 5.10 the obtained virtual values of the reverberation time together with the correction applied to the actual values are reported. The latter have been obtained, in frequency, as a logarithmic ratio between the virtual and real reverberation time $10log(\frac{T60_{virtual}}{T60_{actual}})$.

Table 5.9: Frequency distribution of the actual sound insulation (ASI) measured in the selected classroom of the V.Veneto school and of virtual sound insulation (VSI) ones.

f	**ASI**	**VSI 1**	**VSI 2**	**VSI 3**	**VSI 4**
[Hz]	[dB]	[dB]	[dB]	[dB]	[dB]
50	28,2	28,8	31,4	26,8	33,3
63	19,7	32,8	34,4	29,9	31,3
80	17,3	25,6	29,1	31,0	37,3
100	24,7	26,4	32,6	37,6	39,1
125	30,2	31,3	30,2	37,7	36,1
160	31,5	30,7	34,7	35,3	36,6
200	31,9	27,1	33,2	33,8	38,7
250	32,3	34,2	39,2	37,8	43,0
315	28,6	39,4	41,9	42,2	43,8
400	35,6	43,4	44,2	44,2	44,3
500	32,6	42,3	43,5	44,3	43,5
630	27,1	43,8	44,3	46,0	45,7
800	27,9	45,8	43,8	47,8	48,7
1000	31,5	46,7	45,0	47,8	50,4
1250	37,9	47,6	47,1	47,6	52,0
1600	41,8	48,3	47,1	50,3	53,4
2000	43,3	45,5	46,4	51,4	54,3
2500	43,8	45,5	47,6	51,7	53,8
3150	44,9	48,3	51,1	51,8	54,6
4000	48,1	50,0	53,0	53,8	56,2
5000	49,6	53,6	54,7	54,6	58,2

Table 5.10: Actual and virtual (1 refers to the UNI11367 and 2 refers to the D.M. 18/12/1975) values of reverberation time and corrections applied to the actual values.

f [Hz]	**T60 actual [s]**	**Correction 1 [dB]**	**Correction 2 [dB]**	**T60 virtual 1 [s]**	**T60 virtual 2 [s]**
125	1,26	0,58	0,58	1,44	1,44
160	1,40	-2,20	-0,70	0,84	1,19
200	1,21	-1,60	-1,00	0,84	0,96
250	1,21	-1,60	-0,05	0,84	1,20
315	1,18	-1,50	-1,70	0,84	0,80
400	1,16	-1,40	-1,20	0,84	0,88

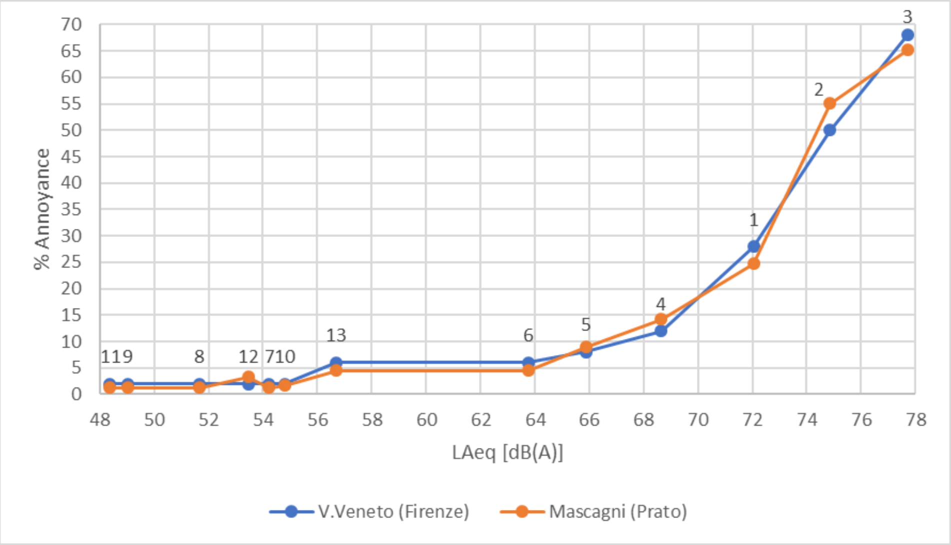


Figure 5.17: Curves of annoyance for the classes of the V.Veneto and Mascagni schools involved in the tests.

The answers to the test given by the students of both schools have been analysed and, for each of the reproduced sound, the percentages of children who told to be high and very high annoyed have been evaluated (see Figure 5.17).

First of all, it is possible to note, in line with expectations, that as the pressure levels increases, so does the percentage of children who declare themselves to be very disturbed. The only exception is given by the sound number 12, whose intensity, however, was not very different from that of the sound that was reproduced immediately before (sound number 8) and immediately after (sound number 7). Moreover, it is significant to highlight that the noise level of 87 dB(A) can be considered as a threshold, in terms of SEL, in correspondence of which the percentage of high annoyed children becomes significative (almost 20%). In addition, in the carried out experiment, above this threshold the percentage of high annoyed children rapidly increases, reaching almost the 70% for aircraft noise levels close to 95 dB(A) while in the previous study of Van Kempen et al. the percentage of highly annoyed children, expressed in terms of $LAeq$ grows more slowly. This difference could be due to the fact that noise levels in the current studies are referred to the single aircraft noise events, while those considered by the previous study to the longer time period 7 a.m – 11 p.m.

As for the comparison between the results obtained in the two schools, the resulting graphs show that the trend of responses is almost similar, the biggest difference is given by a 5% response for the sound number 2.

Chapter 6

Conclusions

The current work firstly deals with the test of the new CNOSSOS–EU aircraft calculation method, to be adapted by the national legislation of each EU Member State by the end of 2018. In fact, a minor slice of the research has been dedicated to the study and the test of the new aircraft calculation method introduced in 2015 by the European Directive 996/2015 by considering the A.Vespucci airport in Florence as applicative case study. The research included the comparison between the outputs given by the same software, with the same input data, from the new CNOSSOS–EU calculation method and the currently used one (INM) one. In the end, the CNOSSOS–EU method turned out to be the most conservative and this application contributes to clear the way for further tests of the new calculation methods required at European level before their entry into force in all the EU Member States for the 2021/2022 noise mapping round.

Secondly, the research presented in the current Ph.D dissertation deals with the study of children exposed to aircraft noise at schools. In this frame, an innovative assessment method has been developed and tested in two pilot schools selected as case studies, considering as reference airport the A.Vespucci one in Florence.

The analysis of the state of the art has, first of all, highlighted the multiplicity of possible effects on children due to chronic exposure to airport noise in terms of health [21]–[26], [33]–[35], [37], [38], [92], [98], annoyance [6], [62], [68], [70], [71], [73], [85], cognitive processes [35], [97], [99], [102], [103], [108]–[112], [127], [129]–[131] and long–term effects [87]–[93]. In addition, it is also demonstrated that children are more sensitive to noise than adults [44], [50]–[52], [56], [57]. In fact, the former need a greater signal–to–noise ratio to understand a conversation, also taking into account the fact that they cannot have a stored knowledge that allows them to reconstruct the meaning of a conversation in the event that it is disturbed by background noise. More recent studies show, however, that children exposed to aircraft noise may be able to develop resilience mechanisms and get used to this source of noise to the point of developing protective mechanisms that would allow them to obtain results in some cognitive tests even better than children not exposed to noise [58], [86].

The study of the state of the art has shown contrasting results in particular regarding the results of cognitive tests and the possibility that children are able or not to develop resilience mechanisms against aircraft noise. Moreover, the tests that were also conducted in the context of European projects such as RANCH, NORAH and SAMBA [153], [154], [164], [166] were carried out during the normal course of school lessons, without the passage of aircraft could be controlled and without the possibility of reproducing the tests in similar conditions in other school environments, perhaps not subject to the disturbance due to aircraft noise. Finally, the scientific literature clearly shows the need to update the existing annoyance curves for aircraft noise and to develop specifications for children.

The research activity was therefore mainly directed to the development of a method that could contribute, at least in part, to solve the problems highlighted by the analysis of the state of the art. The proposed method has been summarized in a protocol containing practical indications to replicate the application of the method in further pilot cases and it consists of the following phases: acoustic measurements of aircraft noise levels in classrooms, reverberation time and façade sound insulation; synthesis of the measured signal and calibration of the electro–acoustic system; synthesis of a signal obtained in the presence of virtual conditions of reverberation time and façade sound insulation; tests submitted to children (questionnaire on reading, questionnaire on the perception of different types of noise, reproduction of 13 sounds and questionnaire on the disturbance caused by each of them). The method in its entirety was applied in a pilot school actually exposed to aircraft noise, then the synthesized signals were used in a second school, located in a residential and quite area, along with the tests similarly proposed to the pupils. In the latter context, a control group was also identified in order to carry out the reading test. The collected data were analysed in order to compare the results obtained in the noise perception and reading tests by the children of the two schools and to build annoyance curves. With regard to the questionnaire about the noise perception, with specific reference to the road traffic noise disturbance, it seems to be more evident for the students of the Mascagni school, although it is not too marked. When asked about the perception of annoyance due to aircraft noise, it is considered quite little in both schools, especially in the Mascagni one. It could be due to the fact that the children of the Mascagni school are not used to hear in the vicinity of the school the noise due to airplanes. Moreover, when answered about the most suitable adjective to describe the noise due to cars, among the dichotomies negative/positive or unpleasant/pleasant, the children of the classes of the Mascagni school seems to be more indifferent to this typology of sounds and this difference could be attributed to a different sensitivity of children in the two schools. With regard to the section dedicated to the young people's attitude towards noise, in particular on the ability of children to concentrate in case they hear noises around them, the children of the V.Veneto school manage to concentrate better in the presence of noise than the children of the Mascagni school. About the reading test, after a careful analysis of the collected results, it is possible to conclude that the students of the V.Veneto school therefore appear more capable of answering the questions correctly even in the presence of noise, compared to those of the Mascagni school under the same test's conditions and the differences between the considered groups of students are significative. Moreover, the number of correct answers given by the participants is lower in presence of aircraft noise (in the schools of Florence and Prato) than in the control group. Concerning the development of curves of annoyance, firstly it is possible to note, in line with expectations, that as the sound intensity of the pressure levels reproduced increases, so does the percentage of children who declare themselves to be very disturbed. Moreover, it is significant to highlight that the noise level of 87 dB(A) expressed in terms of SEL can be considered as a threshold in correspondence of which the percentage of high annoyed children becomes significative (almost 20%), coherently with results obtained by Van Kempen et al. [85]. In addition, in the carried out experiment, above this threshold the percentage of high annoyed children rapidly increases, reaching almost the 70% for aircraft noise levels close to 95 dB(A).

The new method defined during the PhD research is characterized by the following innovative aspects:

- it allows the design of a ‘portable’ listening laboratory with which to reproduce a signal, due to airport noise and recorded in a disturbed school environment, in a school not subject to this form of noise pollution, regardless of the characteristics of reverberation time and of acoustic insulation of the façade of the latter;
- it allows to reproduce the aircraft noise signal in correspondence of specific moments (user–defined) of the reading test;
- it allows to develop simple curves of annoyance due to aircraft noise for children.

Considering the specific research and the method described in this dissertation, a number of aspects to be improved or further implemented can be identified. As general consideration, due to the PhD activity’s timing and available resources, the application of the developed method to the pilot cases and the consequent collection and analysis of the data have constituted only a first attempt of investigation, certainly they do not have the claim to be a complete and concluded work but a cue to continue the investigation with other samples of students, possibly more congruent between them, and resources. In particular, the signals synthesised in the condition of virtual façade acoustic insulation and reverberation time should be tested in real classrooms in which the hypothesised conditions due to specific windows and absorption characteristics are present, in order to verify the accuracy of the synthesised signals with respect to those that are actually in place. Then, the developed method should be applied in additional pilot cases affected by aircraft noise with the aim of providing a larger sample of respondents on which to repeat the carried–out analyses. Moreover, in the following applications, the narrating voice used for the reading test is foreseen to be recorded and reproduced, with the same volume characteristics, with all classes. Furthermore, it would be interesting to carry out more complex statistical analyses and to try to build models (e.g. multilevel models) with which to try to find a correlation between annoyance perception and factors such as parental background and children’s school–education.

Appendix A

Questionnaires

Annex 1: Questionnaire about the general perception of noise submitted to the students of the V.Veneto school

1. Senti il rumore degli aerei nei dintorni della tua scuola?

   moltissimo ☐ molto ☐ abbastanza ☐ poco ☐ per niente ☐

2. Riesco a concentrarmi quando passano gli aerei

   moltissimo ☐ molto ☐ abbastanza ☐ poco ☐ per niente ☐

3. Oltre il rumore degli aerei, senti il rumore delle auto?

   moltissimo ☐ molto ☐ abbastanza ☐ poco ☐ per niente ☐

4. Il rumore degli aerei ti dà fastidio?

   moltissimo ☐ molto ☐ abbastanza ☐ poco ☐ per niente ☐

5. Il rumore delle auto ti dà fastidio?

   moltissimo ☐ molto ☐ abbastanza ☐ poco ☐ per niente ☐

Percezione soggettiva del rumore

Ti chiediamo adesso di considerare i rumori dovuti al passaggio degli aerei e delle auto e indicare come valuti la loro intensità quando sei in classe

Quando sono in classe e ascolto la lezione…

	molto lieve	lieve	moderato	forte	insopportabile
Il rumore degli aerei è…	☐1	☐2	☐3	☐4	☐5
Il rumore delle auto è….	☐1	☐2	☐3	☐4	☐5

Atteggiamento nei confronti del rumore

Troverai qui di seguito coppie di aggettivi opposti distanziati tra loro. Metti una crocetta nella posizione che ti sembra più adatta per indicare il tuo punto di vista.

Il rumore degli aerei è…

Negativo	☐1	☐2	☐3	☐4	☐5	☐6	☐7	Positivo
Nocivo	☐1	☐2	☐3	☐4	☐5	☐6	☐7	Benefico
Brutto	☐1	☐2	☐3	☐4	☐5	☐6	☐7	Bello
Piacevole	☐1	☐2	☐3	☐4	☐5	☐6	☐7	Spiacevole
Sgradevole	☐1	☐2	☐3	☐4	☐5	☐6	☐7	Gradevole
Desiderabile	☐1	☐2	☐3	☐4	☐5	☐6	☐7	Indesiderabile

Il rumore delle auto è…

Negativo	☐1	☐2	☐3	☐4	☐5	☐6	☐7	Positivo
Nocivo	☐1	☐2	☐3	☐4	☐5	☐6	☐7	Benefico
Brutto	☐1	☐2	☐3	☐4	☐5	☐6	☐7	Bello
Piacevole	☐1	☐2	☐3	☐4	☐5	☐6	☐7	Spiacevole
Sgradevole	☐1	☐2	☐3	☐4	☐5	☐6	☐7	Gradevole
Desiderabile	☐1	☐2	☐3	☐4	☐5	☐6	☐7	Indesiderabile

Quando in classe sento il rumore degli arerei di solito provo…

	per niente	-	-	-	-	-	moltissimo
fastidio	☐1	☐2	☐3	☐4	☐5	☐6	☐7
gioia	☐1	☐2	☐3	☐4	☐5	☐6	☐7
ansia	☐1	☐2	☐3	☐4	☐5	☐6	☐7
sorpresa	☐1	☐2	☐3	☐4	☐5	☐6	☐7
rabbia	☐1	☐2	☐3	☐4	☐5	☐6	☐7
paura	☐1	☐2	☐3	☐4	☐5	☐6	☐7
tristezza	☐1	☐2	☐3	☐4	☐5	☐6	☐7
curiosità	☐1	☐2	☐3	☐4	☐5	☐6	☐7
disprezzo	☐1	☐2	☐3	☐4	☐5	☐6	☐7
altro (specifica)	☐1	☐2	☐3	☐4	☐5	☐6	☐7

Atteggiamento dei giovani verso il rumore

Per ciascuna delle seguenti affermazioni ti chiediamo di esprimere il tuo parere secondo la scala indicata.

	Del tutto in disaccordo	-	-	-	-Del tutto d'accordo
1. Riesco a concentrarmi anche se sento dei rumori attorno a me	☐1	☐2	☐3	☐4	☐5
2. Non mi piace quando attorno a me vi è troppo silenzio	☐1	☐2	☐3	☐4	☐5
3. Il rumore è parte naturale della nostra società	☐1	☐2	☐3	☐4	☐5
4. Per me è facile ignorare il rumore degli aerei	☐1	☐2	☐3	☐4	☐5

RIPRODUZIONE AUDIO-PERCEZIONE FASTIDIO

Adesso sentirai delle riproduzioni audio relative al passaggio di aerei. Per ciascuna di esse ti chiediamo di esprimere il grado di fastidio che suscita in te.

Fastidio N° audio	Per niente	Poco	Abbastanza	Molto	Moltissimo
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					

Annex 2: Questionnaire about the general perception of noise submitted to the students of the Mascagni school

1. Senti il rumore delle auto nei dintorni della tua scuola?

   moltissimo ☐ molto ☐ abbastanza ☐ poco ☐ per niente ☐

2. Il rumore delle auto ti dà fastidio?

   moltissimo ☐ molto ☐ abbastanza ☐ poco ☐ per niente ☐

3. Il rumore degli aerei ti dà fastidio?

   moltissimo ☐ molto ☐ abbastanza ☐ poco ☐ per niente ☐

Quando sono in classe e ascolto la lezione…

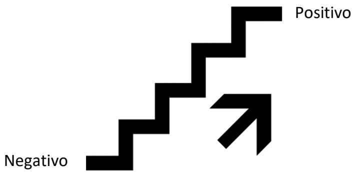
	molto debole	debole	medio	forte	fortissimo
Il rumore delle auto è….	☐	☐	☐	☐	☐

Il rumore degli aerei è…

Negativo	☐	☐	☐	☐	☐	☐	☐	Positivo
Dannoso	☐	☐	☐	☐	☐	☐	☐	Vantaggioso
Brutto	☐	☐	☐	☐	☐	☐	☐	Bello
Piacevole	☐	☐	☐	☐	☐	☐	☐	Spiacevole
Sgradevole	☐	☐	☐	☐	☐	☐	☐	Gradevole
Desiderabile	☐	☐	☐	☐	☐	☐	☐	Indesiderabile

Il rumore delle auto è…

Negativo	☐	☐	☐	☐	☐	☐	☐	Positivo
Dannoso	☐	☐	☐	☐	☐	☐	☐	Vantaggioso
Brutto	☐	☐	☐	☐	☐	☐	☐	Bello
Piacevole	☐	☐	☐	☐	☐	☐	☐	Spiacevole
Sgradevole	☐	☐	☐	☐	☐	☐	☐	Gradevole
Desiderabile	☐	☐	☐	☐	☐	☐	☐	Indesiderabile



	assolutamente no	no	né sì né no	sì	assolutamente sì
Riesco a concentrarmi anche se sento dei rumori attorno a me	☐	☐	☐	☐	☐
Non mi piace quando attorno a me vi è troppo silenzio	☐	☐	☐	☐	☐
Il rumore è parte naturale della nostra società	☐	☐	☐	☐	☐
Per me è facile ignorare il rumore degli aerei	☐	☐	☐	☐	☐

RIPRODUZIONE AUDIO-PERCEZIONE FASTIDIO

Adesso sentirai delle riproduzioni audio relative al passaggio di aerei. Per ciascuna di esse ti chiediamo di esprimere il grado di fastidio che suscita in te.

Fastidio / N° audio	Per niente	Poco	Abbastanza	Molto	Moltissimo
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					

Annex 3: Questionnaire about the reading test

1) Di chi attendeva il ritorno Michele all'inizio della storia? (No aereo)

2) Con chi vorrebbe giocare Michele quando si sente solo? (Sì aereo)

3) Come si chiama il frigorifero amico di Michele? (Sì aereo)

4) A cosa assomiglia il frigorifero amico di Michele dopo che la sua mamma ha fatto la spesa? (Sì aereo)

5) Quanti anni ha Michele? (Sì aereo)

6) Come si chiama il padre di Michele? (No aereo)

7) Dove vive la nonna di Michele? (No aereo)

8) La mamma di Michele lo minaccia di non portarlo nuovamente dalla nonna l'estate successiva, ma di mandarlo dove? (No aereo)

9) Cosa fa Michele insieme alla nonna la sera davanti al fuoco? (Sì aereo)

Annex 4: Questionnaire for parents

Informazioni su suo/a figlio/a

- Sesso: F ☐ M ☐

- Età (al 31/12/2018):

Informazioni sulla famiglia

- I genitori sono separati no ☐ sì ☐

- Grado di istruzione del padre:

diploma di scuola media ☐ diploma di scuola superiore ☐ laurea ☐ altro (specificare)

- Grado di istruzione della madre:

diploma di scuola media ☐ diploma di scuola superiore ☐ laurea ☐ altro (specificare)

- Tipologia lavoro del padre:

dipendente pubblico ☐ operaio ☐ commerciante ☐ disoccupato ☐ altro (specificare)

- Tipologia lavoro della madre:

dipendente pubblico ☐ operaio ☐ commerciante ☐ disoccupato ☐ altro (specificare)

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