A review of the impact of noise restrictions at airports

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Abstract

One of the biggest obstacles to the building of new airports and expanding runway capacity is environmental concerns, especially noise. In this paper, we review what has been previously studied in the literature concerning the noise reduction problem around airports from the Air Traffic Control (ATC) perspective. In order to facilitate the knowledge of the current situation, a regulation summary from the USA and EU is provided. We mainly focus our research on operational procedures, since they are one of the easiest improvements nowadays for reducing the impact of noise around airports. Moreover, the paper sums up the modelling, monitoring and simulation tools related to noise at airports proposed in the literature. Finally, special care is taken to review the optimization tools, the objective of which is to take into account the noise problem in order to help, or propose alternatives, to reduce its impact from airport operations.

Keywords: air traffic growth, airport capacity, noise impact, procedures, optimization.

1. INTRODUCTION

Airbus's Global Market Forecast 2015-2034 highlights that today, 47 aviation mega-cities are focused on over 90% of long-haul flights and nearly a million passengers a day, with 39 of the 47 experiencing various levels of congestion (Airbus, 2014). Demand is being met through more of the latest technology aircraft, and by airlines striving to increase their efficiency by filling every available seat, with average load factors now close to an impressive 80%. Air traffic demand is expected to more than double in Europe and the US, and perhaps triple in some regions, over the next 15 years (Airbus, 2014). Therefore, one of the central challenges facing the aviation industry is air traffic demand growth, which results in congestion in many airports, primarily hubs (Flores-Fillol, 2010).

Meeting this increased demand is challenging for all the industry stakeholders. Airlines around the world have responded by developing their networks and using larger aircraft. Building new airports and expanding the runway capacity of existing ones is another possible solution, but limited by environmental concerns, including noise disturbance, emissions, water pollution and habitat destruction (Laurenzo, 2006). Some impacts arise from the operation of the airport, others as a result of providing additional airport infrastructure (Upham *et al.*, 2003). Making the most efficient use of the current infrastructure by Air Traffic Management (ATM) would be the best alternative to balance demand and runway capacity with environmental restrictions.

Aircraft noise is a particular problem during landing and take-off (Ignaccolo, 2000). Noise, described as unwanted sound (Schmidt, 2005), is known to have several adverse effects on humans, such as hearing loss, communication interference, sleep interference, higher levels of self-reported stress, anxiety, depression, psychological morbidity, annoyance, hypertension and coronary heart disease (Janssen *et al.*, 2014; Salah, 2014; Ozkurt *et al.*, 2014; Vogiatzis, 2012). Ongoing technological advances are likely to result in quieter engines, and aircraft operating from short and underutilized runways (Schneider *et al.*, 2010). Other options that are in use today are sound insulation of buildings or land use procedures (Ganic *et al*., 2015). However, in order to reconcile system resource constraints with economic and environmental priorities, all the involved stakeholders (governments, aircraft manufacturers, ATC) are requested to collaborate (Bertsimas *et al.*, 2011).

The objective of this paper is to review how airport capacity is limited by noise restrictions, with the aim of analysing the potentiality of using scheduling optimization tools in order to confront the problem. Analysing what measures are being taken today to deal with noise reduction and what can be improved from the ATC point of view, focusing on operational alternatives and models, might be interesting in order to have a starting point to understand the problem. To facilitate knowledge of the current situation about noise restrictions, a regulation summary is provided. Operational procedures are also reviewed since they are one of the easiest improvements today for reducing the impact of noise in the areas surrounding airports without impacting on airport capacity. Moreover, the paper sums up the modelling, monitoring and simulation tools related to noise in airports, that exist in the literature, since a review of this field has not been found so far and it is necessary to understand how noise impact is calculated. Finally, as already mentioned, special care is taken to review optimization tools that take into account the noise problem in order to help, or propose alternatives, to reduce it and how this impacts on airport capacity.

This paper is organized as follows. Section 2 provides a description of the methodology followed. Sections 3 and 4 describe the environmental issues concerning air traffic growth. Section 5 provides a review of the legislation, mainly from USA and Europe. Section 6 analyses another way of minimizing noise, though noise abatement operational procedures. Section 7 describes the different modelling, monitoring and simulation tools found in the literature referring to noise around airports. Section 8 deals with optimization tools and algorithms that take into account noise restrictions. Finally, a short summary is given in Section 9, together with suggested topics for future research in this area.

2. REVIEW METHODOLOGY

A literature review is useful to provide a historical perspective of the respective research area as well as a benchmark for comparing the results with other findings (Creswell, 2013). In our case we have applied a Systematic Literature Review (SLR) (Denyer and Tranfield, 2009) consisting of five steps. The first is the definition of the context, intervention, mechanisms and outcome (CIMO) of the study. In our case, this is studying how noise reduction has impacted on runway capacity from an operations point of view.

The next two steps in an SLR are the location of studies, and their selection and evaluation. Here, the literature search was carried out through the Scopus database. We considered also conference papers and documentation from international organisations (such as ICAO, SESAR, FAA) since the subject under research is of a wide scope, and official reports could add something to the study. Regarding the time horizon, we have not limited it, but all the papers found that focus on the impact of noise were from 1998 until 2016. The keywords used are: {“airport capacity” OR “scheduling” OR “procedures” OR “optimization”} AND {“noise reduction” OR “aircraft noise”}.

After a first scrutiny, some of the collected papers were discarded because they did not fit exactly the theme of the review study, leaving a total of 131 papers or official documentation. We found a large amount of papers related to noise influence on health or sound insulation that were discarded since these topics are not related to runway capacity.

The last two steps are the analysis and synthesis of the papers, and to report and use the results, which we cover in the following sections.

3. **ENVIRONMENTAL CHALLENGES IN AIRPORTS**

The aviation industry understands that environmental responsibility is a critical component of its licence to grow. Aviation was the first sector in the world to agree to an ambitious set of global carbon dioxide (CO_2) emissions-reduction targets, which include carbon neutral growth from 2020 and a 50% reduction in net CO_2 emissions by 2050 compared to 2005 levels (ICAO, 2013). Aviation stakeholders have committed to achieve these through a four-pillar strategy including improved technology, more efficient infrastructure, and better operations.

Environmental assessment (evaluation and review, research and monitoring), environmental management (comprehensive planning that takes into account the effects of humankind’s activities on the environment) and supporting measures (education, training, public information, financial assistance and organizational arrangements), are key in any approach towards successful environmental management (Abeyratne, 2002).

According to Single European Sky ATM Research (SESAR), the two main environmental issues associated with aviation are *emissions* and *noise* (SESAR, 2016). On the other hand, according to the Next Generation Air Transportation System (NextGen), the primary environmental issues that influence the capacity and flexibility of the National Airspace System (NAS) are aircraft noise, air quality, climate, energy, and water quality (Hughes *et al.*, 2012). Both NextGen and SESAR agree therefore on two objectives: emissions and noise (Table 1).

------ Table 1 ------

Global emissions are related to climate change since aircraft emit gases and particles in direct proportion to the quantity of fuel burned directly into the upper troposphere and lower stratosphere; CO_2 is also emitted at airports through various airport operations, such as ground support vehicles and passenger surface transport vehicles. Globally, the aviation industry accounts for around 2% of all human-induced CO_2 emissions (ATAG, 2014).

Local emissions refer to aircraft operations at airports (landing and taking off, taxiing, fuel storage, engine testing and the use of auxiliary power units) that impact on local air quality through pollutants emitted during these operations. Additionally, other airport operations, such as the use of ground support equipment, airport air-conditioning, passenger cars, and many others, also affect local air quality.

Generally aircraft noise is influenced by particular factors such as the number of flights, their timing, the type of aircraft, and the flight path. Aircraft noise is a disturbance produced by any aircraft or its components, during flight, taxiing, landing and take-off. Sari *et al*. (2014) classify the origins of this noise into three main sources: the aerodynamic noise, the aircraft engine and other mechanical sources, while Arntzen & Simons (2014) classify aircraft noise into two categories: engine noise and airframe noise.

4. REDUCING THE IMPACT OF NOISE IN AIRPORT SURROUNDINGS

One of the reasons for an increase in the number of people affected by negative noise is the rise of populations in cities and their territorial expansion, since residential areas have become closer to airports (Ganic *et al*., 2015). Reducing the environmental impact of growing traffic demand leads to severe problems for balancing airport expansion requirements (Arntzen & Simons, 2014; Visser *et al*., 2008).

In 2001, the International Civil Aviation Organization (ICAO, 2001) Assembly endorsed the concept of a Balanced Approach to aircraft noise management, which was reaffirmed in 2007 (ICAO, 2007). In the Balanced Approach, the ICAO has defined four key elements that can be used to achieve an effective reduction in aircraft noise without compromising safety standards (which have to take precedence over environmental protection):

- Noise reduction at source, i.e. the aircraft. This includes the use of quieter aircraft and the implementation of noise-reducing measures on the engines, wings and landing gear of existing aircraft fleets.
- Local measures in the vicinity of the airport. These include a land-use plan tailored to noise protection zones, passive noise control and noise based take-off and landing charges.
- Noise abatement operational procedures in the air and on the ground. The range of innovative flight procedures being trialled at various airports includes the continuous descent approach as well as satellite-supported approach procedures or

measures that help to cut engine use on the ground. Both landing and take-off operations are critical from a noise point of view.

- Noise-based operating restrictions. These are any noise-related actions that limit or reduce an aircraft's access to an airport. They should not be used as a first resort, only after consideration of benefits gained from the other three elements, for example, noise quotas or curfews.

Following these ICAO (2007) key elements, we could classify the different noise mitigation opportunities that Capozzi *et al.* (2002) explore in their study, as shown in Table 2.

-------Table 2----------

Various authors refer to real data from airports in their analysis. For example, Netjasov (2012) establishes a relationship between noise reduction measures used by 615 airports worldwide and the Balanced Approach categories.

Lijesen *et al.* (2010) constructed a bottom-up cost function, based on measures for noise reduction, such as alternative approach paths, fleet substitution and reduction of the number of flights for Amsterdam Airport. The conclusion from their analysis is that fleet substitution and alternative approach paths are viable ways to reduce noise, since reducing the number of flights can be too costly.

Another important issue is how noise is measured and in which units. A large variety of acoustic descriptors are used to describe aircraft noise (Ruijgrok, 2004). In order to select an aircraft noise descriptor, it is necessary to adjust to the issue being examined. However, the most common noise indices are expressed in terms of dB. Noise policy and legislation are most often based on average noise levels: L_{eq} (represents the time average of the total sound energy over a specified period) and its three special variants: L_{dn} (day-night average sound level), L_{den} (day-evening-night average sound level), and L_{night} (long term average sound level determined over all the night periods of a year). All of them are described in detail by Visser *et al.* (2008). Obviously, much information about traffic noise patterns and sound levels of individual vehicles is not taken into consideration using these average noise indices (Hume *et al.*, 2012). In order to remediate this, regional indices are suitable to assess aircraft noise development around an airport: Zurich and Frankfurt airports are using the ZFI (Zurich Aircraft Noise Index) and FFI/FNI (Frankfurt Aircraft Noise Index/Frankfurt Night Index) indices respectively to measure noise impact (Schäffer *et al.*, 2012; Schreckenberg *et al.*, 2009). The ZFI is a noise effect index describing the integral effects of aircraft noise (annoyance and sleep disturbance) on the population in the vicinity of Zurich airport, integrating the considered noise effects to a single number valid for the whole airport (Schäffer *et al.*, 2012). FFI describes the number of subjects highly annoyed by aircraft noise in areas within L_{dn}-contour 55 dB based on the 24 hours of the day. FNI solely serves to assess nocturnal air traffic by displaying the number of awakenings additionally induced by aircraft noise emitted between 10pm and 6am, including regions where at least 0.5 additional aircraft noise induced awakenings are expected (Schreckenberg *et al.*, 2009).

5. NOISE REGULATION

At a global level ICAO is responsible for developing standards for noise emissions from civil aircraft. ICAO requires Member States to adopt a balanced approach to noise management.

At the EU level there is clear guidance provided by EU Directive 2002/30 for the establishment of rules and procedures with regard to the introduction of noise-related operating restrictions at community airports. The other key piece of European legislation in this area is EU Directive 2002/493 (Environment Noise Directive). This directive required Member States to create noise maps from all transport sources in urban areas by 2007 and to adopt action plans to manage noise by 2008. The directive also aimed to harmonise methods for measuring noise across the EU. In December 2011 the European Commission launched its ‘Better Airports Package’ (European Commission, 2011). The package contained legislative proposals on aviation noise, among other issues. It was proposed to replace the Directive with a new EU regulation which would be directly applicable in each Member State without the need for Member States to implement the rules under local law. That was why the European Community adopted Regulation (EU) No. 598/2014 on the procedures concerning the introduction of noise-related operating restrictions. As restrictions also impact on air carriers from non-EU countries, the Regulation is compliant with international principles on noise management.

In the USA, the Federal Aviation Administration (FAA) has the authority and responsibility to control aircraft noise (FAA, 2016). Airport sponsors are primarily responsible for planning and implementing action designed to reduce the effect of noise on residents in the surrounding area. Such actions include noise abatement ground procedures and restrictions on airport use, among others. To accomplish this, airport sponsors must comply with the national programme for the review of airport noise and access restrictions under the Airport Noise and Capacity Act of 1990 (ANCA). The FAA regulation that implements ANCA is 14 Code of Federal Regulations (CFR) Part 161, Notice and Approval of Airport Noise and Access Restrictions.

Girvin (2009), in her review, compares and contrasts aviation noise policies and noise abatement measures around the world. She finds that charges applied in different countries depend on aircraft noise categories, maximum per aircraft noise threshold above which aircraft pay noise surcharges per operation, time of operation, per operation, noise-limits per aircraft, or noise quotas.

Noise charges are often used with fees, depending on the aircraft noise registration category or certification levels (Genescà *et al.*, 2013). Generally, the noise tax increases with aircraft noise, and sometimes with aircraft weight, since heavier aircraft also tend to be noisier. The application of discounts for quieter aircraft and noise surcharges for noisier aircraft is an encouragement to airlines to use more silent aircraft (Morrell & Lu, 2000). Hsu & Lin (2005) highlight that from the airport's perspective, the busier the airport, the higher the noise fee, charged per landing, to offset the environmental damage and compensate surrounding communities for the noise impact. However, airports must deal with the trade-off between environmental improvement and revenue losses, when determining noise charge policies.

In some countries, **noise protection areas** are defined. These are urban areas that should be not flown over due to noise minimization. The distance that should be kept from these protected areas depends not only on the aircraft type but also on the weather (since the wind has an enormous influence on noise propagation) (Schilke & Feuerle, (2013).

6. OPERATIONAL PROCEDURES FOR AVOIDING AIRCRAFT NOISE

In an ideal world, an aircraft would take off, climb to its optimal cruising altitude, and stay up there as long as possible before beginning a constant, engines-idle descent until landing. In the real world, aircraft have to coordinate with ATC, which usually interrupts climbs and descents with level-offs and turns that force them to spend more time at lower altitudes (Laurenzo, 2006). The combination of low altitude and frequent thrust transients leads to significant noise impact on the ground (Coppenbarger, 2007).

Noise abatement operational procedures in use today cover both take-off and approach phases. The term Continuous Descent Approach (CDA) has been adopted to embrace the different techniques being applied to maximize operational efficiency while still addressing local airspace requirements and constraints during the approach of the aircraft to the airport. These operations have been variously known as, Continuous Descent Arrivals (Jackson *et al.*, 2009), Optimized Profile Descents (McConnachie *et al.*, 2015; Hughes *et al.*, 2012), Tailored Arrivals (Pinkerton, 2013; Elmer *et al.*, 2008), 3D Path Arrival Management (Tong *et al.*, 2007) and Continuous Descent Operations (Thompson *et al.*, 2013; Robinson & Kamgarpour, 2010).

CDA (see Figure 1) allows aircraft to approach moderately dense terminal areas, eliminating the level altitude segments and their associated thrust transients at low altitude, while flying efficient, near-idle descent trajectories that save fuel, and reduce emissions and noise (Ren *et al.*, 2011; Weitz *et al.*, 2005). However, these procedures are not in use everywhere because effective implementation may be difficult since aircraft require special equipment and can have a negative impact on the airspace throughput and controller workload (Jackson, 2009; Reynolds *et al.*, 2005). ATC lacks the required ground automation to provide separation assurance services during CDA operations. Thus, CDA is currently used in low traffic scenarios only (Kuenz *et al.*, 2007; Tong *et al.*, 2007).

----------Figure 1--------------

Research into terminal area operational improvements has predominantly focused on the descent phase of flight and improvements of operational performance using CDA, but few researches have considered the climb phase of flight. Noise Abatement Departure Procedures (NADPs) are the ICAO noise abatement take-off climb procedures defined in ICAO Doc 8168-OPS/611, Volume 1, Part 1, Section 7, Chapter 3 (ICAO, 2004). McConnachie *et al.* (2015) presented an approach for evaluating the current operational inefficiencies in the climb phase. Various references consider the Expedite Departure Path (EDP) component of the Center-TRACON Automation System (CTAS) in the USA (Capozzi *et al.*, 2002). EDP is a decision support tool aimed at providing TRACON Traffic Management Coordinators (TMCs) with departure traffic loading and scheduling information, and radar controllers with advisories for tactical control of TRACON departure traffic. The benefits of EDP are a reduction in delay for departure operations, reduced fuel burn and reduced noise impact due to accelerated climb trajectories (Jung & Isaacson, 2002).

Boeing (2016) provides a database of real noise and emissions restrictions from 654 airports all around the word. After analysing these data, we found that 517 airports have noise abatement procedures but only 72 airports have CDA procedures implemented or are in a trial stage of development, and just five have NADP ICAO's standard as their departure procedure. The others have procedures referring to arrival and/or departure trajectories, as well as recommended flying techniques or preferred use of certain runways.

7. MONITORING, MODELLING & SIMULATION FOR REDUCING NOISE

We have found in the literature review that there is an important relationship between monitoring, modelling and simulation tools related to deal with the noise problem around airports. Monitoring is done in a real-time environment to measure the impact of noise. Modelling serves planning purposes and needs, from monitoring measures to validating the models developed. *Simulation* needs both *monitoring* and *modelling* in order to assist decision making for land-use planning, design of operational procedures, and the assessment of low-noise technology and vehicle concepts (Figure 2).

------Figure 2-----

As mentioned before, the social impact of airport noise leads to the development of strict legislation globally. The legislation is based on noise monitoring, which usually combines information deriving from noise level meters and radars (Tarabini *et al.*, 2014). This is why *noise monitoring* is considered to be the most important mechanism both for planning and noise management around airports (Asensio *et al.*, 2010; 2011). It allows the measuring of sound level time history, identifying sound events and classifying the events produced by aircraft. Aircraft noise monitoring is carried out using a set of noise monitoring terminals (NMTs) that continuously measure the noise in the airport surroundings. Since the ultimate aim of aircraft noise monitoring is to help control the population's exposure to aircraft noise, ideally NMTs should be placed in urban areas. Urban centres, however, have high background noise levels, and the identification of aircraft specific noise is therefore a problem (Genescà *et al.*, 2013). It is necessary then to consider the factors that can affect the uncertainty of the monitoring results. ISO 20906 deals with this by considering measuring instrumentation, residual sound, emission at the source, ground effect, etc.

Various studies in the literature deal with the monitoring problem. Asensio *et al*. (2009)

propose a model that uses radar tracks to reduce the uncertainty to less than half of the ISO model. Asensio *et al.* (2010) designed a system that can detect aircraft sounds in real-time, so that its integration with a monitoring unit can improve aircraft detection rates during unattended measurements. Genescà *et al.* (2013) propose the use of an array of 12 microphones to measure direct aircraft noise, avoiding the effect of the ground reflections and urban background noise. In order to detect thrust reverse noise among other noise sources present in airports, Asensio *et al.* (2015) use a microphone array linked to a noise-monitoring unit, which enables sound pressure measurements to be transformed into sound power level estimations with good classification rates.

Since noise monitoring is essential to measure and control noise limits around airports, measures must be precise to be useful. Hence, the next step after a correct noise monitoring should be to validate the noise models developed.

Noise modelling is used to forecast current or future aircraft noise around airports (due to increases in flight volume or modification of flight paths) and to produce noise maps (Genescà, 2016; Sari *et al*., 2014). Different models, different implementations of the same noise calculation algorithms, different calculation methods, different data structure and different specific parameters to be adjusted by the user in order to represent the real situation, are in use worldwide. Krebs *et al.* (2008) present a new standardised test environment for aircraft noise calculation programmes.

The evaluation of noise in urban environments and in areas with main noise sources also represents a huge challenge, due to the high population density and the combination of different noise sources contributing to the overall acoustical environment. In particular, densely populated areas around large airports are exposed to noise from a combination of different sources. Sari *et al.* (2014) propose that noise generation and propagation are separately modelled according to basic physical effects.

Finally, fast but accurate *simulation* methods are required. Filippone & Bertsch (2014) classify them as best practice and scientific prediction methodologies.

Firstly, best practice tools are usually based on fully empirical models derived from ground noise measurements. The Aviation Environmental Design Tool (AEDT) is the FAA's official method to calculate noise impact (until May 2015, it was the Integrated Noise Model (INM)). The AEDT is a software system that dynamically models aircraft performance in space and time to produce fuel burn, emissions and noise. It makes full flight gate-to-gate analyses possible for study sizes ranging from a single flight at an airport to scenarios at the regional, national, and global levels (Belle *et al.*, 2015). The European Civil Aviation Conference (ECAC) proposes a similar method (using identical equations) to INM in their Document 29 (2005). Arntzen *et al*. (2014) updated these methods, supplying the noise model with an augmented ray tracing solution to predict the atmospheric propagation effects, rather than just using an empirical model.

Secondly, scientific predictions methodologies of aircraft noise play a large role in the policy making process and resulting regulations. These regulations are usually based on noise contours (a line on a map that represents equal levels of noise exposure) expressed in yearly averaged metrics. Noise contours around airports are used as planning and evaluation tools, and as a component of long-range efforts by local, regional or national authorities. Aircraft noise contour assessment is a complex procedure due to the different route schemes, procedures, aircraft and types of engine in operation around an airport (Zaporozhets & Tokarev, 1998). The usage of a reliable, validated, and updated noise model is an essential step for producing accurate noise contours for the purposes of environmental noise analysis. But, noise maps are made mostly by calculations based on known and estimated parameters such as geographical data and the accurate accounting of noise source data. All these data cannot be readily available for the study areas. Therefore, assumptions and predictions are generally used to fill the gaps of model inputs (Mioduszewski *et al.*, 2011).

However, a few approaches in the literature consider the trade-off between the different aspects needed to evaluate environmental impact, such as fuel burnt, noise exposure, and emissions produced, of future ATM concepts and procedures. Celikel *et al.* (2005) studied the combined use of airspace simulation, and environmental and economic tools, adding value to operational project evaluation.

8. OPTIMIZATION ALGORITHMS FOR NOISE ABATEMENT

Noise abatement procedures provide an effective means of achieving further reductions in the impact of aircraft noise on communities surrounding airports. Use of noise abatement procedures, however, has been limited by guidance and navigation considerations. The primary obstacle to the implementation of these procedures remains the inability of air traffic controllers to maintain manually the precise sequencing and spacing required for maximum take-off and landing rates in heavy traffic conditions. Thus, the introduction of automation that predicts the performance and noise impact of aircraft, and uses this information to assist the controller in determining and maintaining appropriate sequencing and spacing, is critical to the successful utilization of noise abatement procedures (Clarke, 2003).

Noise-aware decision support tools are needed so that the decision process for sequencing and scheduling terminal area and en route traffic as a means of increasing overall capacity and efficiency of operation, also includes consideration of noise exposure levels, particularly for the population within the immediate vicinity of the airport (Capozzi *et al.*, 2002).

To our surprise, there is not a large amount of literature referring to the optimization of noise-scheduling. In Figure 3, we present the main studies found in the previous literature referring to the flight stages that can influence runway capacity.

----Figure 3----

Most research found in the literature considering optimization tools refers to flight path optimization (Visser, 2005; Salah & Abdallah, 2012; Salah, 2013). Trajectories optimization considers avoiding built-up areas, topographical details, safety requirements and ATC requirements (Filippone, 2014).

It is possible, however, to find airport noise optimization and aircraft scheduling dating back to 1984. Frair (1984) formulated an optimization mathematical model whose objective is to minimize the measure of annoyance due to arriving and departing aircraft for a given airport, obtaining a 40% reduction in noise impacts.

Temme (2007) defines an interesting method to support the air traffic controller with noise abatement routes during real-time approach planning and guiding. The sound-source aircraft, the propagation medium atmosphere including actual meteorological conditions, a three dimensional model of the earth's surface, and the population distribution around an airport, are all taken into account for the noise propagation calculation.

Hebly & Visser (2007) present a decision support system (DSS) for air traffic controllers for guiding arriving and departing traffic near airports in a safe and efficient manner, making use of the future concept of four-dimensional trajectory-based operations. While doing so, the system minimizes the negative environmental effects of the flight operations and manages their spatial allocation, both for individual movements and cumulative exposure. They formulate the problem as a Mixed Integer Linear Programming (MILP) with Constrained Position Shift (CPS) restrictions.

Prats *et al.* (2010) define a non-linear programing (NLP) problem for departure optimization that is solved by using a lexicographic multi-objective optimization technique. This approach allows the establishment of a hierarchical order among all different noise sensitive locations. However, the major drawback of this approach is the limitation in the number of noise sensitive locations to be considered, due to the exponential growth in computational cost.

The use of optimization tools for real-time aircraft guiding may lead to difficulties, because it requires delivering online results. Unlike Standard Instrument Departure (SID) routes, which follow fixed flight paths, arriving aircraft are guided flexibly by the aircraft controller with radar vectoring. A possible alternative is to reduce the amount of possible arrival trajectories by including the local airspace structure around the airport and taking the trajectory calculation rules of an arrival manager into account (Temme, 2007), then it is possible to reduce the number of possible flight paths significantly and to archive them together with a noise value – depending on population values – in a database. This way, the arrival manager has the possibility to take aircraft noise as well as safety, punctuality, and capacity constraints during the arrival sequencing generation into account.

An interesting and complete study has been undertaken by Zachary *et al. (*2010). They propose an optimization algorithm that explores the best selection of flight possibilities given to minimize noise and/or emissions by selecting available aircraft trajectories, schedules, operational procedures, e.g. time profiles of turbine power levels at take-off and climb, flap settings in take-offs and approaches, altitude variations in climb and approaches, take-off/landing runway displacements, and fleet composition, through a non-linear integer programming (NLIP) minimization problem.

9. RESEARCH OPORTUNITIES

The main approaches addressed today to reduce the impact of noise in the surrounding communities of airports, excluding impacting on land use and/or carrying sound insulation methods, consider operational procedures and regulatory restrictions. Airports must deal with the trade-off between environmental improvement and revenue losses when determining noise charge policies, as well as with the loss of capacity when fixing regulatory restrictions. The largest airports are those that have a greater population near them and also the ones that suffer from more congestion and delays, which results in more environmental impact.

Noise can be significantly reduced if the focus is set on developing optimal scheduling tools that avoid manoeuvres in the approach stage of the flight waiting for authorization to land, and departures are able to arrive at higher altitudes as fast as possible.

Making the most efficient use of the current infrastructure is an important part of the solution. A significant amount of research has been published for optimizing the scheduling of flights in airports. In this sense, Bennel *et al.* (2013) review the techniques and tools of operational research and management science that are used for scheduling aircraft landings and take-offs in order to optimize airport runway scheduling. The main solution techniques include dynamic programming, branch and bound, heuristics and meta-heuristics.

Noise restrictions are almost not present when developing these algorithms. We have found just one interesting perspective to include noise in scheduling optimization. Sölveling *et al.* (2011) studied runway scheduling optimization based on environmental (CO_2 and noise) impacts, finding that it might produce important savings for the stakeholders implied (society, airports and airlines). There is a large field of investigation yet to be developed in terms of optimization algorithms that take into account noise as a constraint or objective of research.

Hence, optimization algorithms that take into account noise constraints avoiding inefficient schedules should be developed and tested. Controllers need these tools to be able to maintain safety and efficiency but also to address noise and environmental issues.

In order to evaluate the optimization algorithms and models developed, it is also necessary to develop standardised calculation methods that use the same data as input in order to be able to compare the results in a consistent way. These calculation methods should consider not only the different noise sources but also be able to match noise predictions with measured data. Hence, validation standards is another topic that needs future research attention in order to develop tools that are really useful in the reduction of noise in airport surroundings.

10. CONCLUSIONS

Minimizing noise disturbance around airports is a task that needs the implications for various stakeholders to be considered: institutions, aircraft manufacturers, airlines and

ATC. There is a real concern by authorities that can be seen in the recent legislations and official restrictions that have been imposed.

There is also a need to improve modelling-simulation-monitoring tools that take into account all the factors implied in the noise problem (weather, population affected, air traffic congestion, airport capacity, etc.). A standardised tool would be necessary, since existing programmes differ greatly in their calculation methods and in data structure, so it is very difficult to compare the results in a consistent way.

There is a large field of research in terms of optimization tools that support air traffic controllers to help them optimize the capacity of airports without breaking the noise abatement procedures established in the vicinity of airports. Designing online scheduling tools that consider noise restrictions has not yet been studied in depth.

Predictions confirm the growth of air traffic transport in the future, thus increasing the noise problem around airports. Operational procedures need to take into account the capacity of the airport in order not to decrease the acceptance ratio of departures and arrivals. Using ICAO standard procedures worldwide for noise mitigation would be an important improvement. There is a large field of research on optimization algorithms that could help controllers schedule airport operations by considering noise restrictions.

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NextGen (USA)	SESAR (EU)
Climate	Global Emissions
Air quality	Local Emissions
Aircraft noise	Noise
Water	
Energy	

Table 1. NextGen (FAA, 2016) vs. SESAR (2016) environmental objectives

ICAO Balanced Approach (2007)	Capozzi *et al.* (2002)
1. Noise reduction at source	-
2. Local measures in the vicinity of the airport	-
3. Noise abatement operational procedures in the air and on the ground	Noise-sensitive ATM approach procedures: - Avoid dive and drive - Base leg extension into noise sensitive areas - Side-step approaches Noise-sensitive ATM departures procedures: Direct climb-to-cruise Route tracking: - Stay in precise route corridor - Follow routes over low population areas - Avoid shortcutting
4. Noise-based operating restrictions	Runway/route selection: - Fan across region - Routing older aircraft to less noise-sensitive runways - Increase the usage of noise-preferred runways Airport interactions within a Terminal Radar Approach Control (TRACON), modifying existing procedures to consider noise Night time operations: - Extend procedures to higher traffic levels - Improve efficiency so that night time operations can be initiated on time

Table 2. Capozzi et al. (2002) vs. ICAO Balanced Approach (2007) noise mitigation approaches

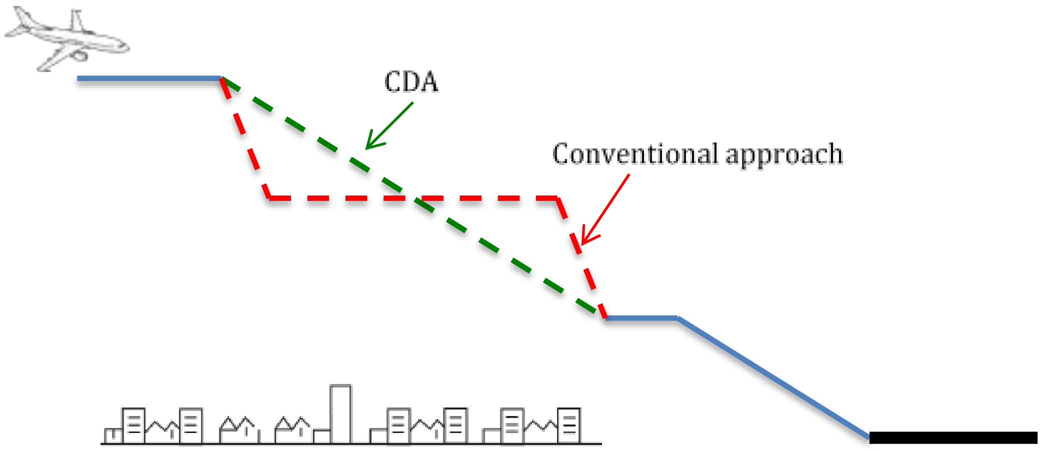

Figure 1. CDA vs. conventional approach

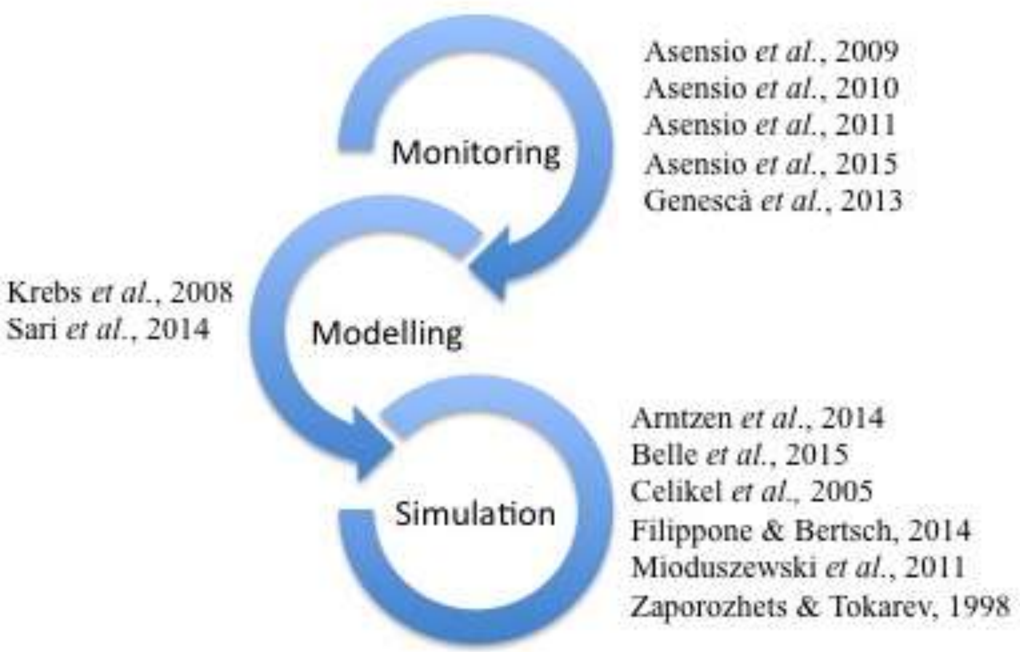

Figure 2. Monitoring - Modelling - Simulation relationship

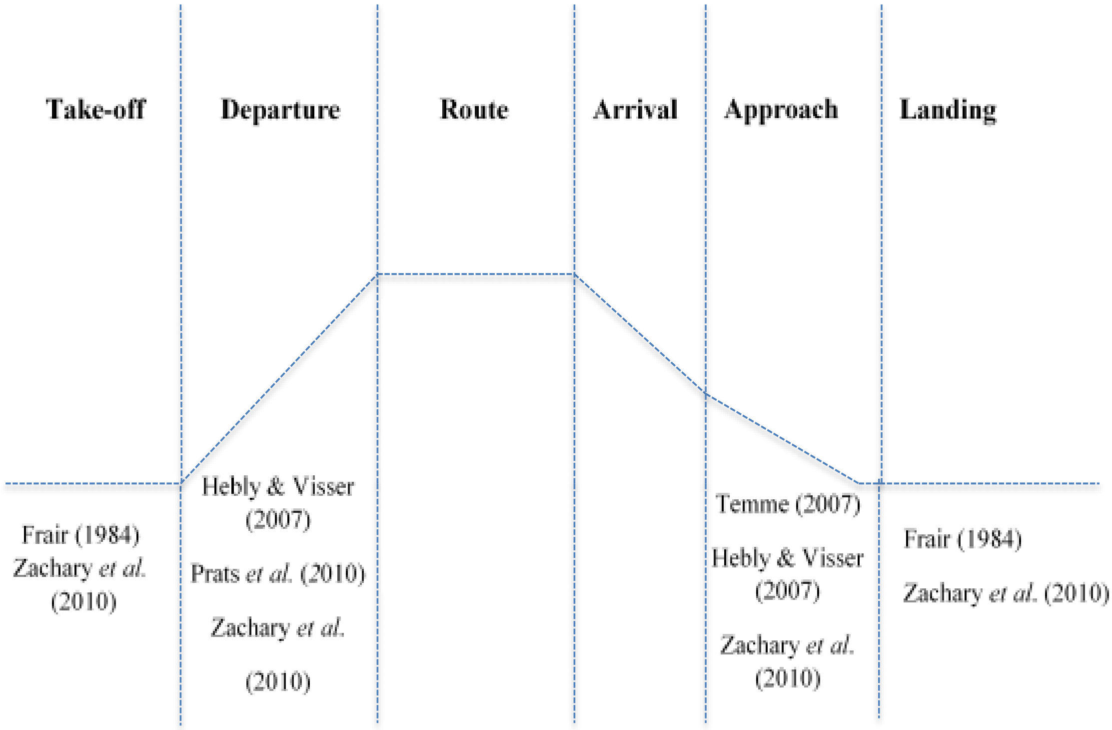

Figure 3. Optimization algorithms depending on the flight stage