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Sound Noise Limits

Options for a uniform noise limiting scheme for EU airports

Report

Delft, January 2005
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Summary

Community-level regulation of noise nuisance at European airports is a contentious issue that has been discussed for over a decade now. Against the backdrop of both 2002 noise Directives[1] this study develops and assesses approaches to setting noise limits at larger[2] EU airports. Harmonisation of noise limit schemes within the Community may contribute to smooth functioning of the internal market. In this study, different degrees of harmonisation are presented, but the pros and cons of the concept of uniformity in noise limiting schemes, though important issues, are not part of this study.

The key question that has been answered is primarily *in what way* could noise limits be defined. Questions like *at what level* such limits should be set and *what mitigation measures* can be applied to reach these levels have not been answered here.

Aim: limitation of noise impacts on people and spatial limitation
The aim of setting noise limits at airports is to limit or reduce noise around them. Limitation of noise can serve the following two goals:
- Limitation of noise impacts on people.
- Spatial limitation of noise impacts[3].

Both aims are addressed in this report.

Components of noise limiting schemes
A noise limiting scheme consists of:
- A noise indicator.
- A method for setting the noise limits (resulting in the levels of the limits).
- A monitoring mechanism.
- Enforcement procedures.

Currently, many different types of noise limitation schemes exist. Many European airports have developed their own system for limiting noise based on different noise indicators, noise limits and monitoring methods.

1 Directive 2002/30/EC of the European Parliament and of the Council, of 26 March 2002 [EC, 2002a], and Directive 2002/49/EC of the European Parliament and of the Council, of 25 June 2002 [EC, 2002b].

2 This report is directed at airports with over 50,000 movements.

3 This goal maybe aimed at the protection of nature but also to the limitation of 'potential nuisance', defined as noise emission over areas which are currently not in use, but which could potentially be used in the absence of noise. This 'potential nuisance' leads to welfare losses since it increases scarcities.

Framework for distinguishing different types of noise limiting schemes
The framework presented in this study is based on six distinctive aspects by which noise limiting schemes can be categorised:

1 Using resulting noise levels or on mitigation measures.
2 Absolute or relative scheme:
   - In an absolute noise limiting scheme there is no direct link between the level of the noise limit and transport or traffic volume, while
   - In a relative noise limiting scheme noise limit is linked to the transport or traffic volume, either through a noise indicator which is relative itself or through the *limit setting method*.
3 Definition of noise indicator.
4 Definition of transport or traffic volume (for relative schemes only).
5 Limit setting procedure, general or airport specific.
6 Monitoring method (e.g. by measurements or calculations).

Different types of schemes based on these distinctive aspects are defined and assessed in this report, which concludes with the recommendation of a combined scheme.

Proposed scheme: combined scheme
The scheme we propose is composed of the following elements:

1 *A locally set limit to the absolute number of exposed people within several L_{den} contour zones*, including a supplementary measure indicating the number of annoyed people.
2 *Locally set limits to night time noise*, based on two indicators:
   a An indicator limiting the number of noisy events to which anyone is exposed during the night (NAx).
   b A Person Events Index (PEI) limiting the total noise load per night.
3 *An internationally set limit based on the ratio of a measure of exposed area and some volume measure*.
4 *Reporting requirements*.

Locally set absolute limits to the number of exposed people within L_{den} contours
The first element of the proposed scheme is directed at limiting the absolute number of exposed people. It is a uniform noise indicator which adheres closely to current Community legislation. Though the indicator is uniform, thus increasing transparency and comparability, the levels of limits are determined locally.
By localising the responsibility for setting limits to the number of exposed people, full account can be taken of the local situation. Local authorities are best equipped to do this, and also to balance the limits levels with land use issues.

We propose a noise indicator based on *exposure* instead of one primarily based on noise *emission* or the *adverse effects* of noise (*annoyance*). Noise *exposure* relates directly to Directive 2002/49/EC and is also in line with environmental legislation in other fields.
Noise exposure limits should be based on *L_{den} contours*, also advocated in the same Directive. Introducing a separate measure with a similar aim in mind would lead to confusion.

The scheme should limit the *total number of exposed people* within L_{den} contours, mainly because this most directly relates to the main problem of aircraft noise and provides a higher flexibility to airports than limiting noise exposure at a number of geographical 'reference' points on the ground.
Special account can be taken of dwellings with noise insulation. A pragmatic approach would be to count these dwellings in a contour with a lower noise level[4].

For monitoring, we suggest making primary use of *calculated airport noise performance*, because airport noise modeling allows a predictive approach and is well advanced, whereas reliable noise measurements are at best very labour intensive. Measurements could be used to validate calculations, to check whether aircraft certificated noise levels are accurate for in-service situations and whether best practice measures are being implemented.

Supplementary measure indicating the number of annoyed people
Using up to five noise level bands makes it hard to assess whether progress is being made. It is not clear how to appraise a reduction in one band and an increase in another. For this reason we strongly recommend using the following supplementary measure: the total number of annoyed people within the 55 dB(A) contour (i.e. the lower boundary of the lowest band for which reporting requirements apply).
Based on established statistical noise-annoyance relationships for aircraft noise, the total number of *annoyed* people within each band can also be estimated. By summing the results for each band, an estimate of the total number of annoyed people is obtained.
This measure is not meant to provide an additional restriction, but might serve as a basis to determine limit levels for each particular band and to get insight into whether the airport is doing a good job or not with respect to noise limitation over the whole of the affected community.

Locally set limits to night time noise
Although the L_{den} measure does have a penalty factor for evening and night flights, this does not fully do justice to the specific problem of night noise. Peak noise levels are a better indicator than the L_{Aeq} based metrics, such as L_{den}.

To have a good indication of the total noise exposure during the night and also provide certainty of protection to individuals, we propose to add two indicators:
- An NAx indicator to limit the number of noisy events to which any individual person is exposed, and
- A Person Event Index (PEI), giving a better indication of total noise exposure during the night than an NAx indicator. The PEI(*x*) sums the total number of instances where an individual is exposed to an aircraft noise event above a specified SEL value of *x* dB(A) for the night time period.

[4] Clearly, agreement between airport and limit setting authority has to be reached on this issue. The specific situation at hand should be a deciding factor. There are many different insulation programmes and costs per dwelling vary widely, not all programmes will be equally successful in reducing indoor noise exposure.

Internationally set limit based on the ratio of exposed area and some volume measure

To provide comparability between airports within the Community and to provide for reflection of the smooth functioning of the internal market, a relative indicator linking noise limits and transport volume should be part of the combined scheme. The indicators proposed above do not directly link the level of the noise limit with the transport volume.

We propose an internationally set limit defined by the exposed area per measure of transport volume. The underlying idea is that any two airports of a similar 'size' should produce broadly similar size noise contours, although they of course to some extent depend on runway layout.

Noise contour size could be based on the total area within a simple 24 hour L_{eq} contour. There may be exceptions where noise contour area is not so important, for example, an airport with contours stretching over the sea or other uninhabitable areas. It could also be appropriate to subtract the area of the airport itself from the airport's contour size. This may help to prevent the airports which cover larger areas being unfairly penalised.

For defining a measure of transport volume some combination of distance and actual payload, such as Maximum Zero Fuel Weight (MZFW)[5] seems the best option.

Further research is necessary for this part of the combined scheme particularly into the robustness of the relationship between noise contour area and airport size in terms of transport volume. This would also identify any deterioration in the achievement of noise limit objectives with traffic growth.

Reporting requirements

The fourth element of the framework we propose consists of extensive requirements on reporting noise policy by the local authorities responsible for setting limits. Reporting should improve transparency and provide a clear picture of what is expected in the future to all stakeholders, airlines and surrounding communities alike. This should provide a firm basis for corporate and personal planning, and that can itself help to limit annoyance.

We propose that airports should publish long term noise policy plans and associated forecasts, clearly stating their objectives and the proposed timescale for their achievement.

Reporting by local authorities should include:

- Why are limits as they are?
- What are the long term noise limit policy objectives?
- How does the airport intend to meet, manage and enforce these limits?

[5] The MZFW is the maximum operational weight without usable fuel.

We also suggest a broadening of possibilities for flanking instruments, so that incentives can be provided to airlines to fly as quietly as possible, by using the quietest aircraft and adhering to best available procedures.

1 Introduction

1.1 Background

Community-level regulation of noise nuisance at European airports is a contentious issue that has been discussed for over a decade now. The issue of subsidiarity has always played a central role in this debate: where does local or national authority stop and does EU co-ordination or even harmonisation become necessary?

From the environmental point of view, it may be argued that noise is in essence a local problem and circumstances around individual airports vary greatly and therefore locally tailored solutions are required. From an economic perspective, it could be argued that all these locally tailored solutions together may have a substantial impact on the smooth functioning of the internal market. An alternative economic point of view is however that a local low sensitivity to noise should be interpreted as a legitimate competitive advantage for an airport.

1.2 Objective

The final objective of this study is to develop and assess a limited number of approaches to setting noise limits at larger[6] EU airports. The key question is primarily *in what way* could noise limits be defined, the question *at what level* should such limits be set is much less object of study. Options on how noise limits can most efficiently be met are beyond the scope of this study. We can but endorse the recommendations of ICAO and the requirements of Directive 2002/30/EC, that it should be done within the framework of the balanced approach.

As noted above, the desirability of a uniform noise limiting scheme is an important issue, relevant to but beyond the scope of this study. Different degrees of harmonisation are analysed, but the pros and cons of different degrees of uniformity are not discussed.

1.3 Approach followed and structure of this report

We first discuss the aims of noise limits and the conditions that they should meet (chapter 2). This is followed by a framework for distinguishing different types of noise limit schemes (chapter 3). In this chapter we and give an overview of schemes and the incentives that they give for different types of mitigation measures.

In chapter 4 and 5 we elaborate two types of schemes: absolute and relative. Finally in chapter 6, we give an overview of the most promising options for a uniform noise limiting scheme.

[6] This report is limited to airports with over 50,000 movements.

In chapter 4 to 6 we use three different cases to illustrate the effects of noise limiting schemes, which are:

- Volume growth.
- New runway.
- Technological improvement of aircraft.

As already stressed, this report focuses on noise *limit schemes* and does not elaborate on *mitigation measures* that can be applied by airports or other authorities (or which can be taken by manufacturers or aircraft operators) in order to meet noise limits. Effective noise limits give incentives for noise *mitigation measures*. We therefore include, as Annex B of this report, an overview of the sort of noise mitigation measures that can be taken as background information.

2 Defining noise limiting schemes

2.1 Introduction

In this chapter we will discuss what we mean by a noise limiting scheme. We address three crucial questions:
1 What elements does a noise limiting scheme contain? – section 2.2.
2 What should it aim for? – section 2.3.
3 What conditions should a good noise limiting scheme meet? – section 2.4.

The answers to these questions will help us to assess various noise limiting schemes.

Related to the aim of a noise limit scheme is the distinction between *absolute* and *relative* noise limiting schemes which is of interest in case the noise indicators take the form of a cumulative measure. This and other distinctions are introduced in the next chapter where present a framework for distinguishing different types of noise limit schemes.

2.2 Definition of a noise limiting scheme

For the purpose of this study, it is crucial to have a clear understanding of what a noise limiting scheme entails. We therefore start off by discussing several important notions.

A noise limit scheme consists of:
- A noise indicator.
- A method for setting the noise limits (resulting in the levels of the limits).
- A monitoring mechanism.
- Enforcement procedures.

These four parts of noise limit scheme are briefly explained below. In this study we will focus on the first two: the definition of a noise indicator and methods for setting limits.

At the end of this section we discuss which of these parts of a noise limit scheme could be made uniform for all EU member States. As stated before, this study does not discuss the desirability of uniform noise limit schemes.

2.2.1 Noise indicator

A *noise indicator* is a statistic. Its value reflects, in some way, the amount of noise. Noise indicators can be based on noise emission (e.g. the certificated noise level or the noise quota count of an aircraft), but also on noise exposure (e.g. the size of a certain noise contour zone, or the number of people exposed to a certain noise level).

Furthermore, noise indicators can be based on the noise by one aircraft movement (e.g. L_{Amax}), but can also be directed at the cumulative noise (e.g. L_{den}). Also note that noise indicators can be determined either by calculation or by measurement.

Noise indicators can serve several purposes:
1 To monitor noise.
2 To limit noise.

In this study the focus will be on the second application of noise indicators, namely the limiting of noise[7]. Depending on the actual design of the noise indicator, noise indicators can, for example, limit:
- Noise level per aircraft movement (e.g. by limiting certificated noise levels, or restricting aircraft with a quota count > 16, say).
- Total number of movements (the noise indicator is then simply the number of movements, which is capped).
- Cumulative noise (by e.g. capping the noise quota, where the indicator is the sum of the noise quota counts for each movement, or by restricting the size of the L_{den} > 65 dB(A) zone).

In any uniform noise limit scheme discussed in this report, we assume that there is a uniform definition of the noise indicator.

2.2.2 Method for setting the noise limits

A noise limiting scheme poses restrictions to the values the noise indicator can take by setting limits. The method for setting noise limits is related to the noise indicator itself.

In a very simple form, a method for setting noise limits could prescribe the limit levels themselves, implying uniform limits, which would make no allowance for local differences in population, airport size or traffic mix. However, it could also be a method prescribing how limit levels should be made dependent on this type of local characteristics. In the latter case, the uniform limit setting method would lead to airport-specific noise limits.

In the absence of a uniform method for setting noise limits, national or local authorities would decide upon the noise indicator as well as upon its value.

2.2.3 Monitoring mechanism and enforcement procedures

A noise indicator, plus a scheme to set the level of the limit of that indicator, together form the core of a noise limiting scheme. There are however two other elements of noise limiting schemes.

[7] However, the noise indicators discussed further on in this report can also be employed for monitoring purposes.

First, the value of the noise indicator will have to be monitored, to know whether implementation of the limit is successful, and its objectives are achieved, or whether it is exceeded. Noise monitoring can either be done by calculations or measurements. Measurements will always be ex post, whereas calculations can be done ex ante and ex post.

Secondly, a penalty system to enforce compliance and to penalize in cases where limits are exceeded, may also be part of a noise limiting scheme, although the management of exceedences to avoid recurrence may be considered more important than the assignment of guilt and punishment.

In this study we will focus on noise indicators and schemes to set limits. Monitoring and enforcement measures are discussed only briefly.

2.2.4 To which extent can schemes made uniform?

An important question is *what* should be *uniform* in a uniform scheme that applies to all larger EU airports. Following the definition of a noise limit scheme as presented in the previous section, we can distinguish the following degrees of uniformity:

- Just a uniform noise indicator definition.
- Uniform indicator definition and uniform method for setting limits.
- Uniform indicator definition, uniform method for setting limits and uniform monitoring mechanism and/or enforcement procedures.

In this study we will focus on the first two options.

2.3 Aims of a noise limiting scheme

Obviously, the aim of setting noise limits at airports is to limit or reduce noise around airports. Limitation of noise can serve the following two goals:

- Limitation of noise impacts on people by population-related noise limits.
- Spatial limitation of noise impacts (over designated areas).

The limitation of noise impacts on people is universally accepted as an important aim of noise limiting schemes and most existing schemes either provide incentives in this direction directly or indirectly. The second possible aim of a noise limiting scheme is limitation of noise impacts over designated areas. Such spatial limitation of noise impacts is, however, less universally accepted. Both aims are elaborated in the next sections.

We recognise that negative trade-offs may occur between noise and other emissions. In this study, however, attention is directed exclusively toward noise limiting schemes and any correlations or connections with any other social or environmental issue are beyond the scope of this study.

2.3.1 Population-related limitation of noise impacts (on people)

The most important aim of noise limits is to limit the impacts of noise on people. Exposure to noise has been widely accepted as a contributory cause of all sorts of physical disorders (see e.g. [HCN, 2004]). This holds even more strongly for exposure to noise during the night. This can cause sleep disturbances which in turn can have detrimental affects on people's wellbeing [Passchier-Vermeer W., et al., 2002].

Article 2 of Directive 2002/49/EC marks a concern with environmental noise to which people are exposed. Built-up areas, public parks and other quiet areas in an agglomeration are specifically mentioned, but also quiet areas in open country, near schools, hospitals and other noise-sensitive buildings and areas are addressed.

Any scheme for noise limits should at least be capable, when appropriate limits are set, of providing certainty of protection against noise impacts. It should also be capable of incorporating different limits for daytime and night-time to accommodate the increased impact of night-time noise on people's wellbeing.

Emissions – exposure - nuisance
In the context of population-related noise limitation, it is important to distinguish:

- Noise emission.
- Noise exposure.
- Noise annoyance.

Noise *emissions* refer to the amount of noise emitted by sources (aircraft). Noise *exposure* is caused by noise emissions and refers to the noise that reaches people living around airports: the noise levels to which people living near airports are exposed (sometimes referred to as noise e*missions*).

Noise *annoyance* is caused by noise exposure, but also includes the subjective valuation of the noise by the receiver. Besides noise exposure, also 'non-acoustic' factors such as type of source and the level of information provided by airport and authorities play a role in this. The relation between noise exposure and noise nuisance depends among others on cultural aspects.

2.3.2 Spatial limitation of noise impacts (over designated areas)

A second aim of noise limits can be to limit noise impacts spatially, over designated areas, irrespective of the presence of people. As well as the costs directly related to the exposure of people to noise, 'potential nuisance', defined as noise emission over areas which are currently not in use, but which could potentially be used in the absence of noise, also causes economic costs. Governments tend to restrict land use in these regions by implementing zoning plans. For example, new house building may be prohibited. This leads to welfare losses since it increases scarcities[8]. This actually happened in the vicinity of Amsterdam Airport Schiphol. The city of Amsterdam needed land to build houses. Due to noise zoning, the land around Schiphol could not be used. As an alternative, polder land had to be reclaimed at high economic cost.

[8] See [CE, 2002a].

Nature reserves present another example of areas in which society might wish to restrict noise exposure, albeit not exposure to people[9].

2.4 Conditions for noise limit schemes

Apart from providing incentives to reach the aims of noise schemes (limitation of noise impacts on people and spatial noise limitation), there are several conditions which schemes need to satisfy as much as possible.

1 Economic impact, flexibility and cost effectiveness

The noise limiting scheme must maximise the freedom of the airport to develop all manner of noise control measures. In this way market forces are permitted to ensure that the framework will minimise the restrictions to airport operations and minimise economic cost, whilst maximising noise control, for optimum results.

Flexibility enables airports to take the most cost effective measures. The noise limit framework should thus reduce the economic impact to a minimum, while guaranteeing effective noise protection.

It remains to be seen how far this principle can be implemented in a practical noise limit scheme. As an alternative we will also discuss in the next chapter a scheme which is primarily based on the application of best practice methods.

2 Functioning of the internal market

It is important that all airports are treated equitably – indeed they should receive equality of treatment without discrimination, so that, for example, smaller airports are not favoured over larger airports. Such might be the case if limits did not take into account the size of the airport. Small airports would then probably have the opportunity to grow without taking any noise restricting measures, whereas large airports might be faced with unachievable limits.

Two exceptions to equal treatment might be made. First, it could be argued to be reasonable to be stricter on newly developed airports (and possibly expanding airports), than on existing infrastructure. Existing infrastructure can only be replaced at enormous cost, while newly developed airports might have a wide range of alternatives to choose from. The same may hold, albeit to a lesser degree, for expansions of existing airports.

The second exception has to do with setting and enforcing limits. In the short run, there might be airports that will find it hard, if not impossible, to meet the new limits, due to historic neighbourhood population growth. This should be taken into account when enforcing limits. However, in the (very) long run, it might be desirable that airports so located, which can not operate without causing noise to an unacceptably high level, are relocated. The scheme should in these cases provide continuing incentives for reducing noise which could eventually lead to relocating the airport.

[9] Although Directive 2002/49/EC does not mention nature reserves, quiet areas in open country are explicitly mentioned.

3 Practicality of target enforcement in the context of global aviation business

We do not expect the (logically) final task of considering practical monitoring and enforcement to be as easy as it may prima facie appear. Real time tracking on the basis of measured noise may reveal breach of a limit defined by predicatively computed contour mapping. Ex post contour mapping might reveal breach of a noise budget limit or failure to limit population numbers affected.

The resultant questions include not only how an airport continues to operate and under what rules when a seasonal noise quota is exhausted for example, but also what sanctions are to be applied, if any, by whom and upon whom will they ultimately bear. These are the sort of problems alluded to in section 3.2.3, where we suggested that solutions, rather than culprits, need to be found in situations where limits are exceeded.

Penalties can be appropriate for violations of specific noise mitigation measures (such as failure to adhere to noise abatement procedures) but it is difficult to see their relevance to, for example, the mix of aircraft types at an airport over a given year causing a noise contour to exceed its planned coverage.

4 Feasibility of monitoring

All the dimensions involved must be readily measurable and accountable without bias. A Community-wide uniform way of defining noise limits requires a uniform, accountable and transparent measurement or calculation scheme.

5 Transparency

Noise limit schemes can be rather complex, which seems to be unavoidable. However, transparency is crucial and it must be possible to explain the scheme to the airports as well as to other stakeholders and third parties. Furthermore, all calculations and measurements in the scheme should be completely transparent.

This principle is also stressed in the ICAO guidance[10] on implementing the balanced approach.

[10] ICAO Doc. 9829: Guidance on the implementation of the balanced approach to aircraft noise [ICAO, 2004].

3 Overview of noise limiting schemes

3.1 Introduction

As defined in chapter 2, noise limiting schemes consist of a noise indicator, a method to set limits, a noise monitoring system and enforcement procedures. This chapter further analyses noise limiting schemes. First we give an overview of distinctive aspects of schemes in section 3.2. Section 3.3 lists different types of schemes and their impacts, and analyses the incentives they provide.

Finally, in section 3.4 the characteristics of the different types of schemes are summarized and a selection of schemes to be elaborated in subsequent chapters is made.

3.2 Distinctive aspects of schemes

Currently, many different types of noise limitation schemes exist. Many European airports have developed their own system for limiting noise based on different noise indicators, noise limits and monitoring methods. One further reason for differences is the large number of noise metrics that have been developed for aircraft noise based on wide ranging social surveys on noise affects over the years.

We distinguish six important distinctive aspects by which noise limiting schemes can be categorised[11]:

1 Based on resulting noise levels or on mitigation measures.
2 Absolute or relative scheme.
3 Definition of noise indicator.
4 Definition of transport volume (for relative schemes only).
5 Limit setting procedure, general or airport specific.
6 Monitoring method (e.g. by measurements or calculations).

These distinctive aspects are explained in the following subsections.

3.2.1 Schemes based on resulting noise levels or on mitigation measures

Noise limiting schemes can either be directed at the noise itself, i.e. the *effects* of flying, or on the *efforts made* to limit noise, the noise mitigation measures themselves. Schemes based on a combination of both are also possible.

Schemes that are set limits based on *noise levels* can for example apply to L_{den} levels on the basis of *ex post* measurement or (generally or *ex ante*) integrated noise model (INM) calculations. Such schemes generally give greater freedom to airports to choose the most appropriate and cost effective noise mitigation measures.

[11] The enforcement procedure can also be a distinctive aspect, but this issue is not elaborated in this report.

Schemes stipulating *mitigation measures* can prescribe best practices for all airports. Therefore, such a scheme could be less complicated and more transparent than schemes based on noise levels. A disadvantage of schemes based on mitigation measures, however, is that they can be over-restrictive by prescribing measures not appropriate for all airports. Moreover such schemes do not provide certainty of protection since no limits are imposed on the actual noise volume.

In this report we will primarily focus on schemes in which the limits are defined in terms of the target resultant noise levels. The following distinctive aspects all apply to these types of scheme.

3.2.2 Absolute versus relative noise limiting schemes

We introduce here the distinction between absolute and relative noise limiting schemes. This distinction is of interest in case the noise indicator takes the form of a cumulative noise measure over time, effectively ginning an airport a 'noise budget' over a season or a year.

Absolute schemes
In an *absolute noise limiting scheme* the level of the noise limit is *not* directly linked to the volume of transportation performed. Thus with an absolute scheme, growth of traffic does not imply an increase in the total noise 'budget' (however defined), and traffic growth during the period for which limits have been set may cause serious practical problems.

An absolute scheme with uniform absolute limits have very serious drawbacks which make its feasibility highly doubtful. For example, large airports would suffer heavily from uniform absolute limits, whilst smaller airports would face no restriction at all until or unless they reached the prescribed threshold of noise impact.

So, absolute schemes seem to be only a feasible option only if the limit setting procedure is not made uniform. Practicable uniform absolute noise limiting schemes prescribe the noise indicator that is to be used, but would leave the limit setting itself to airports and/or local authorities.

Relative schemes
In a *relative noise limiting scheme*, noise limits are directly linked to the volume of transportation performed, generally measured by the throughput of the airport in terms of traffic units[12]. This can either be through a relative noise indicator, based on (average) noise per movement or some other output measure, or through the limit setting procedure, where the level of the noise limit is made dependent on the volume of transportation performed. In each case, the level of the limit depends on the transport volume.

[12] Traffic units are conventionally used to sum up passengers and cargo.

As an example, limits can be posed with respect to the amount of noise per payload.kilometre[13]. Such a scheme could induce airlines to take account of society's noise preferences[14], provided that these preferences are effectively represented by the (relative) noise indicator.

Noise limit schemes that are based on the (average) noise per movement can also be regarded as relative schemes, albeit not based on the ratio of a cumulative[15] noise measure and the transport volume, but based on a noise indicator that is itself relative.

In a relative scheme, traffic growth does not conflict with noise limits, as long as the relative limit of noise (however measured) per traffic unit, is met. In this case, the overall 'noise efficiency' of the airport's activity is maintained.

Relative schemes have the disadvantage that no limit is set on the total noise volume at an airport. Therefore, they provide limited certainty of protection against noise.

3.2.3 Choice of the noise indicator(s)

For all schemes that are based on resulting noise levels, either absolute or relative, a noise indicator (or set of indicators) is needed. Such an indicator (set) could be based on noise *emissions*, noise *exposure* or the adverse effects of noise, often indicated as noise *annoyance*[16] (see also section 2.3.1).

Noise *emissions* relate directly to the noise energy emitted by aircraft. Certificated noise levels and quota counts are examples of indicators based on noise emissions.
Noise *exposure* is related to the noise levels on the ground. It is the amount of noise that a person or area is actually exposed to. An example is the L_{den} metric.
The *adverse effects* of noise (*annoyance*) is related directly to the *impact* of noise on the exposed population. Not only the noise level on the ground determines annoyance, but also 'non-acoustic' factors such as type of source, socio-economic factors and the level of information provided by airport and authorities. An example of a noise indicator based on annoyance would be the number of highly annoyed people.

The advantage of an indicator based on *noise emissions* is that is the value of the indicator can be determined with relative ease. Noise emission data is available from the aircraft's noise certification process. To evaluate the value of an indicator based on *noise exposure*, either calculations or noise measurements on the ground are necessary. An indicator based on *annoyance* would require

[13] CE Delft developed for example a PSI 'performance standard incentive' for its 2002 study 'Economic incentives to mitigate greenhouse gas emissions from air transport in Europe' [CE, 2002b].

[14] E.g. society's preference with respect to carrying a certain load with one large aircraft of two smaller ones could be reflected in the relative noise limit level.

[15] Cumulative over all aircraft movements of an airport.

[16] The adverse effects of noise obviously entail more than just noise annoyance. We will elaborate on this in section 4.2.1.

social surveys to determine the level of annoyance across the population. The main disadvantage of such a scheme is the subjective nature of annoyance and the consequent difficulties of consistent definitions

On the other hand, a noise limiting scheme based on annoyance has a direct relationship with the ultimate aim of many limiting schemes: to limit noise nuisance. A scheme based on noise emission almost entirely lacks that link with the impact of noise on the population.

With respect to noise exposure, note that there is a distinction between instantaneous (or peak) noise levels during an aircraft flyover (L_{Amax}) or sound exposure levels (SEL)[17]. It is also possible to average noise exposure over a period of time, such as L_{den}.

When a new aircraft is certificated, its noise levels are measured at three locations; approach, flyover, and lateral. The aggregate of the three measured levels is a good indication of how noisy that type of aircraft is relative to its size and weight, and is used to determine the noise Chapter, under the ICAO classifications. The three noise levels measured during certification are also used differently by some national authorities to indicate a noise Quota Count for each aircraft type. This can be done individually for arrivals (using the approach level) and departures (using the flyover and lateral level).

The treatment of *day* versus *night* is also an important aspect of noise indicators. L_{den} for example, allows for addition of day, evening and night noise via default conversion factors (5 and 10 dB, respectively), but some schemes contain much more stringent nightly regulations regarding night flights. One of the aspects of the need to distinguish between the effects of noise at night or in the daytime is the use of L_{eq} as an indicator of noise impact at night, discussed in Annex D.

The issue of noise indicators is further elaborated in section 4.2.

3.2.4 Choice of transport volume definition

There are two types of relative noise limiting schemes. A relative scheme could be formed by the combination of a noise indicator and a method for setting limits that takes into account the volume of transportation performed at the airport. Alternatively, a relative scheme could also be based on an indicator that itself takes into account the transport volume. This can either be by done by setting a limit to the noise level per aircraft movement or to a ratio of noise per unit of transport volume. To give ‘noise per unit of traffic’.

[17] Definitions can be found the Glossary at the end of this report.

In case of the latter, the indicator will be a ratio where the *numerator* is the noise indicator described in section 3.2.3. The d*enominator* of such a relative indicator is a measure for the transport or traffic volume of the airport. Possible *volume indicators* to express transport volume are:

- Number of aircraft movements.
- Total MTOW.
- Number of passengers.
- Passenger-kilometres.
- Tonnes of freight.
- Tonne-kilometres of freight.
- Added value[18].
- A combination of these parameters.

An example of an indicator would thus be the number of people exposed to L_{den} > 60 dB(A) per aircraft movement, or the size of a given noise contour per thousand departing passengers.

The issue of volume indicators for relative schemes is further elaborated in section 5.3.

3.2.5 Limit setting procedure: general or airport specific

As already discussed in section 2.2, the method used to set limits is an import element of a noise limiting scheme. A uniform method would prescribe for all larger EU airports how the noise limit levels should be set for all the larger EU airports. Note that this does not automatically imply uniform limit levels at each airport. Of course, in its simplest form, the method could prescribe the limit levels implying uniform limits. However, it could also be a method prescribing that limit levels should be made dependent on local characteristics such as for example population density[19]. In this case, the uniform limit setting method would lead to airport-specific noise limits.

Both absolute and relative schemes can theoretically be defined with general limits, prescribing identical restrictions for all airports. An example of a general limit for an absolute scheme would be limiting the number of people in a certain noise zone, a simple general limit for a relative scheme might limit the amount of noise per tonne transported. As we have seen, one problem of absolute schemes with uniform limits is that large airports can be faced with enormous practical restrictions, whereas small airports may face none.

One way to correct for this in an absolute scheme is by defining a method for setting limits which takes into account the local and possibly historical situation. However, by setting noise limits based on historical performance, additional complicating factors are introduced. For example, how to reward airports which

[18] This is value added to the economy, which would have to be defined more precisely when used in a scheme.

[19] Note that if the method for setting limits depends on some measure of the volume of the airport, we will speak of a relative scheme, irrespective of whether the indicator itself is formed by the division of a noise indicator by a volume indicator or not.

have implemented noise mitigating measures in the past is not a straightforward question. Basically, it is very difficult to account for the specific local situation in a uniform limit setting procedure. Therefore, as was already concluded before (section 3.2.2), absolute schemes seem to be a feasible option only if the limit setting procedure is not imposed uniformly. So uniform absolute schemes prescribe the noise indicator that is to be used, but will always leave the limit setting itself to airports and/or local authorities, implying airport specific limits.

For relative schemes, general limits do seem a feasible option. There is no reason why two airports with similar volume characteristics would expose areas of widely differing sizes. However, even the relative noise performance of different airports can vary considerably when the noise exposure is defined in terms of the number of people affected. Alternatively, local characteristics could in principle also be taken into account in a uniform method for setting limits.

If only the indicator of the noise limiting scheme is made uniform, the control over noise limit levels is effectively left to the national (or local/regional) authorities. This would imply airport specific limits and would not solve any of the major problems with the smooth functioning of the internal market. Clearly, prescribing a uniform noise indicator would increase comparability between airports enormously.

Noise limit setting in the UK
Currently, noise limits are commonly set by local or regional governments and in some cases by the central government. In the UK, noise policy for London's Heathrow, Gatwick and Stansted airports is set by the central government, as these are officially 'designated'. No other UK airports are designated, but there is provision in legislation to designate other airports if noise management is found to be sufficiently poor. All manner of local conditions are taken into account in setting noise limits so the resultant limiting values vary.

One possibility related to the limit setting procedure is that existing and new airports could be evaluated differently. Standards for new airports could possibly be set more strictly than those for existing airports. It could be argued that new airport site choice, design and construction should reflect current knowledge of noise and its mitigation, whereas existing airports have to try to ameliorate situations which have developed because of historic site choices and of land use decisions, allied to unforeseen growth and/or technological developments. For instance, the boundaries of some of Europe's busiest airports were set before civil jet aircraft existed.

3.2.6 Monitoring method: measurements or calculations

As well as the noise indicator and limit setting procedure, a monitoring method is also part of a noise limiting scheme (see section 2.2). The noise indicator needs to be monitored to be able to evaluate whether the limits are being respected. Monitoring for an indicator based on implementation of noise mitigation measures or on noise emission levels is relatively straightforward, but it is more complicated with respect to indicators based on noise exposure and noise annoyance.

The noise exposure level may be *measured directly* (such as through sophisticated Noise and Track Keeping systems) or *calculated* (e.g. from aircraft certification data and number of aircraft, or from a noise model). Although in some cases measured noise could be more accurate and adequate than calculated noise, calculated noise is internationally mostly favourable as a limitation method[20]. Consensus on noise calculation is increasing with the forthcoming revision of the ECAC Document #29 on noise calculation.

3.3 Types of schemes

Based on the first three distinctive aspects of the previous section (summarised in the first paragraph of section 3.2), we distinguish ten different schemes. The other distinctive aspects, e.g. incorporating weighting with respect to time of day/night, can be used to define more subtypes of the ten basic types of schemes identified below:

1 Prescription of best practice measures.
2 Quota.
3 Noise per aircraft.
4 Absolute scheme for population-related noise limits.
5 Absolute scheme for spatial noise limits.
6 Absolute scheme for population-related and spatial noise limits.
7 Relative scheme for population-related noise limits.
8 Relative scheme for spatial noise limits.
9 Relative scheme for population-related and spatial noise limits.
10 Noise permit trading system.

3.3.1 Prescription of best practice measures

One possibility is the implementation of schemes that simply prescribe to airports which best practice measures should be implemented. As long as these best practice measures do not incorporate noise levels, no certainty of protection is being offered by this scheme. At best it ensures that, given the specific aircraft employed[21], and the noise they emit, noise exposure is kept to a minimum through take off and landing procedures, reverse thrust procedures, flight patterns, insulation programmes, landing charges etc. No limit is set on the total volume of noise.

A second drawback is that prescription of best practice measures is inflexible and leaves no space for airports to opt for the optimum solution in terms of cost effectiveness according to local conditions.

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[20] In accordance with ICAO's balanced approach recommendations, Article 4 of Directive 2002/30/EC stipulates that any noise-related operating restrictions must be based upon certificated aircraft noise performance, but that refers to the implementation of noise management measures rather than monitoring. The Dutch Parliament has expressed its strong preference for noise measurement instead of calculation. An advantage of noise measurement is that it is linked to everyday operational practice whereas calculation is based on assumed operational practice. Background noise is an important disadvantage, however.

[21] The fleet may be influenced by best practice phasing out procedures.

Since local situations can differ widely, prescribing a universal set of best practice measures could be overly restrictive for some airports. Prescribing airport specific sets of best practice measures would from this point of reasoning be preferable.

3.3.2 Quota

Quota schemes can come in a wide variety of forms[22]. Strictly speaking, curfews form a special case of quota schemes, where the maximum number of operations for a certain time period is limited to zero. In a less severe form quota schemes simply limit the number of aircraft operations during a certain time period. This time period can either be one hour, one night, or even one season or one year. Separate quota counts for day and night may exist, or they can be incorporated in one scheme (often by penalising night flights by weighting).

More sophisticated quota schemes take into account the certificated noise levels of each aircraft operation. This leads to differential treatment of landings and take-offs. These more sophisticated schemes offer greater flexibility to the airports and more certainty of protection. Incentives are being offered for a wide variety of noise mitigating measures, including measures to reduce noise at source by using quieter aircraft. Land use measures and insulation programmes are however not stimulated.

If the definition of the quota counts is closely related to the noise caused by aircraft, the limit will be more effective than in a case of only three categories of aircraft, implying a weak relation between quota counts and actual noise emission levels of aircraft.

Quotas are based on an absolute noise indicator. Limits could be based on local characteristics but could also be determined non-uniformly by the national or regional authorities. In any case, airport specific limits are best suited to ensure that no large distortions are being introduced into the market. Airport specificity would allow for different limits for large and small airports and ensure that no overly restrictive limits are set at airports located in relatively unpopulated areas. However, quota can have large impacts for carriers, particularly for the home-based carriers of an airport (because in the short to medium term, short of re-equipment, they have less flexibility in choosing an optimal fleet-mix[23] for movements at their home airport).

3.3.3 Noise limits per aircraft

Noise limits can be set per aircraft, possibly depending on MTOW. These limits could relate to the certified noise level or to quota counts. Different limits could apply during the day and night. A noise limit scheme that sets noise limits per aircraft is by definition a relative scheme.

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[22] Schemes in which the quota count per aircraft is limited, are relative and are treated in section 3.3.3.

[23] Like selecting the quietest airplanes for an airport with a restrictive quota system.

Such a scheme does not provide great flexibility and only provides an incentive to limit noise at source for non-compliant aircraft. There is no incentive for compliant aircraft to reduce noise at source. Furthermore, it does not provide any certainty of protection, since no limits are set on the size of the fleet or total fleet noise emission.

Limits can only be tightened gradually over time, since substantial amounts of capital will have been invested in aircraft. To account for the local situations around airports, actual limits could be made airport specific. However, in practice this will often come down to aircraft having to meet the strictest limit, since aircraft typically service a variety of routes. Airport specific limits of this type might therefore be of limited use.

3.3.4 Absolute scheme for population-related noise limits

Absolute limits can be set to the number of affected people within one or more noise contours. Gradually consensus is being reached on basing noise contours on some time-average of calculated noise. Separate noise zones for day and night could be implemented.

Schemes based on absolute noise limits can provide certainty of protection (if adequately enforced) for the number of people affected. Ideally, a series of noise contours would be employed, the higher the noise limit, the less people to be affected. This could also provide a reasonable limit of maximum noise level exposure. These schemes could be related to noise insulation programmes and land use planning. Furthermore, such schemes would provide great flexibility for airports to decrease noise exposure. Incentives for adaptation of flight patterns are given. There are however no direct incentives to limit the area affected.

The certainty of protection to individual people depends on the structure of the scheme. If only the number of people exposed is limited, the flexibility of the airport to reduce the number of people exposed, by adjusting flight patterns, will increase the uncertainty of protection for the people living in places that are only exposed under certain flight patterns (see also chapter 6).

As already stated, actual limits will always be airport specific, accounting for the population density around the airport and size of the airport through historic performance. Uniform absolute schemes prescribe the noise indicator that is to be used, but will always leave the limit setting itself to airports and/or local authorities.

3.3.5 Absolute scheme for spatial noise limits

An alternative to schemes setting absolute limits to the number of affected people are schemes relating noise contours to the area affected. Again, separate noise zones for day and night could be implemented.

Such schemes do provide adequate certainty of protection for the area affected, but do not provide incentives to adjust flight patterns so as to minimise noise impacts on people. They do provide flexibility, allowing the airport to implement the most cost effective measures.

These schemes could be related to noise insulation programmes, and to land use planning policies. They also can be used to protect outdoor recreational areas or nature reserves, where that is felt necessary.

Limits for airports could be universally set, independent of population density, or could be based on historic achievements and gradually converge. The latter would have the advantage of not disproportionately favouring smaller airports.

3.3.6 Absolute scheme for population-related and spatial noise limits

A scheme based on both the number of people affected and the affected area could combine the best features of both of the two schemes discussed directly above. Such a scheme could provide both incentives to limit the number of people affected and the area affected.

In its simplest form, such a scheme would pose separate limits on noise exposure for people and affected area. Alternatively, in a more complex form it could be a scheme with absolute limits to the affected area, in which different areas would be treated differently. For example, noise near hospitals would receive a high weight, followed by residential areas and then nature reserves. Industrial areas, arable land and uninhabited areas like mountains or sea would receive relatively low weights. Special weights could apply to areas where insulation has taken place.

This scheme would provide a maximum of incentives, leaving airports which ample room to select the most cost effective measures thus reducing economic impact to a minimum.

There would still be a high degree of certainty of protection, though flying over residential areas can be weighted against flying over industrial areas, but this kind of weighting will also occur within noise zones in more simple schemes.

A clear drawback of the scheme is getting the weight right. How strongly should flying over residential areas be penalised compared to flying over nature reserves, for instance?

A characteristic typical of all absolute schemes is that only the noise indicator that is to be used will be uniform, while, the limit setting itself will be left to airports and/or local authorities.

3.3.7 Relative scheme for population-related noise limits

As discussed in section 3.2, relative schemes, in contrast to absolute schemes, do not require airport specific limits to be set to ensure equal treatment of small and large airports. Limits do not only relate to (some measure of) total noise, but also take account of transport or traffic volumes. Consequently in such a scheme, the limit to the noise that an airport is allowed to produce, depends on the transport or traffic volume of the airport.

An advantage of relative schemes is that equal treatment of large and small airports can be ensured without the need to set limits airport specific limits. This comes at the cost of not providing certainty of protection. Noise limits are volume based, but no limits are set on the total transport of traffic volume thus not capping total noise.

These schemes do have another important characteristic (which might be regarded a drawback), which is related to the measurement of transport or traffic volume. Possible candidates are payload, MTOW, passenger seats offered, passengers transported, volume of freight transported etc. Since in this scheme, limits are relative to transport or traffic volume, typically higher volume would lead to a higher noise allowance[24].

In such a scheme, no direct incentives are given to limit the area affected. In general, however, these schemes do provide flexibility to airports, and separate limits could be set for day and night.

3.3.8 Relative scheme for spatial noise limits

Like schemes with relative limits to people exposed, spatially oriented limitation schemes also score well on flexibility and equal treatment of large and small airports. The above discussion on the uncertainty of protection and the difficulties of selecting a transport or traffic volume metric also holds for this scheme, however.

Such schemes do provide incentives to limit the area affected, but not to limit the number of people affected.

3.3.9 Relative scheme for population-related and spatial noise limits

The previously discussed advantages of an absolute scheme combining both affected people and affected area, as compared with absolute schemes that do only one of these, also hold for relative schemes.

This sort of scheme would be flexible, provide the right incentives, could deal with separate restrictions for day and night and allow for differences in size between airports.

[24] Care should be taken to prevent perverse incentives. Airlines might be tempted to fly aircraft with higher MTOW, more passenger seats, sell tickets cheaply etc. to have less stringent noise limits.

However, it would not provide certainty of protection, since total noise would not be capped. Two other problems to overcome would be the definition of a volume indicator, which should not lead to perverse incentives, and the relative weight to be given to numbers of people affected as against area affected.

3.3.10 Noise permit trading system

Several forms of noise permit trading can be distinguished of which the following are summary examples:

1 Noise permits can be traded between airports within the European Community, with an overall cap on the number of noise permits for the European Community as a whole. The underlying idea would be that at airports with a high added value to society, parties are willing to pay more for noise permits. This would also provide the greatest flexibility and minimise economic impact. Not only can airports select the most cost effective measure, by deciding on the 'value' of a permit and how many permits to issue, but a trading system would also ensure that overall the most cost effective measures are taken. Noise reducing measures will be implemented there where they are cheapest. Dependent on how the initial distribution of noise permits would take place, this scheme could also ensure equal treatment of large and small airports.

   One very important drawback of such a system, however, is that no certainty of protection at a given airport can be guaranteed. For this reason it is unlikely that Member States will support this option.

2 Airlines can trade noise permits related to a specific airport. A noise cap would have to be defined separately for each airport, and hence this option should not be seen as a uniform noise limiting scheme, but could be used to allocate noise permits between airlines serving that airport, given an overall cap.

   This option becomes more interesting if citizens are also allowed to hold permits. In this case the actual volume is not only determined by the initial cap, but also by the willingness of those exposed to noise to buy permits and thus further reduce the total noise volume. The practicability of this suggestion might be questioned, however, since a permit (say to land a full long-haul 747 at 05:00) would be equivalent to the value of the slot; which may be tens of thousands of Euro per flight per day. The population could effectively be trying to buy the multimillion annual profits of a global business.

The permits themselves could however be related to noise contours, either referring to exposed area or the number of people exposed to a certain noise level. A scheme could also require airports to hold permits of both types. Depending on the permit, such a scheme could provide certainty of protection with respect to the affected area or number of people for all airports involved. If permits relate to a particular airport, this system will provide certainty of protection at that airport.

Of course, all the issues of emission rights allocation schemes would also play a role in the initial allocation[25] of noise permits:

- How are newcomers treated?
- At what level should the cap be set?
- Grandfathering or auctioning?
- How to account for airports that have already taken noise limitation measures (early action)?
- How to account for future changes in volume?

3.4 Summary and selection of schemes for further elaboration

In this section the different types of schemes are summarily discussed and a choice is made of which schemes are to be elaborated in the subsequent chapters.

The table below gives an overview of the incentives given by the various types of schemes presented in the previous section. In general, schemes based on either noise calculation or measurement outdoors will offer no incentive for insulation programs, unless indicator values are somehow corrected for the number of houses that are insulated, or account is taken of 'equivalent' indoor values.

Table 1 Overview of incentives per type of noise limiting scheme

	Type of noise limiting scheme	**Incentives for noise mitigation measures**
1	*Prescription of best practice measures*	Only for prescribed measures
2	*Noise quota*	Depends on quota definition
3	*Noise limit per aircraft*	Only noise limitation at source
4	*Absolute scheme for population-related noise limits*	All measures except insulation programs, but no incentive to limit noise in uninhabited areas
5	*Absolute scheme for spatial noise limits*	All measures except insulation programs, but no incentive to limit number of people affected
6	*Absolute scheme for population-related and spatial noise limits*	All measures except insulation programs
7	*Relative scheme for population-related noise limits*	All measures except traffic volume limitation* and insulation programs, but no incentive to limit noise in uninhabited areas
8	*Relative scheme for spatial noise limits*	All measures except traffic volume limitation* and insulation programs, but no incentive to limit number of people affected
9	*Relative scheme for population-related and spatial noise limits*	All measures except traffic volume limitation* and insulation programs
10	*Noise permit trading system*	Depends on definition of noise permits and the party that holds them (airports, airlines or people exposed to noise)

* Volume limitation: limitation of number of aircraft movements; total MTOW; number of passengers; tonnes of freight, depending on the definition of relative scheme.

[25] See e.g. Directive 2003/87/EC [EC, 2003a].

On the next page we present a table giving an overview of the degree to which the different aims and conditions are met for each of the ten types of scheme identified.

In consultation with the client, it was decided to develop two variants of noise limiting schemes in greater detail. These are:

1 Absolute scheme for population-related and spatial noise limits.
2 Relative scheme for population-related and spatial noise limits.

The emphasis will be on in reducing population exposure to noise. In add to these two variants discussed in chapter 0 and 5 respectively, Annex C further elaborates on noise permit trading systems.

Table 2 Overview of schemes and their main characteristics

		Certainty of protection		*Provides incentive for*					*Conditions*				
		Limitation of noise impacts on people	**Spatial limitation (over designated areas)**	**Limitation of noise at source**	**Land use planning and management (without insulation)**	**Insulation**	**Noise abatement operational procedures**	**Operating restrictions**	**Economic impact, flexibility and cost effectiveness**	**Functioning of the internal market**	**Feasibility of monitoring**	**Practicality of target enforcement in the context of global aviation business**	**Transparency**
1	Prescription of best practice measures	-	-	P	P	P	P	P	-	-	P	P	P
2	Noise quota	-	-	P	-	-	-	+	-	-	P	P	P
3	Noise limit per aircraft	-	-	+	-	-	-	-	-	+	P	P	P
											P	P	P
4	Absolute scheme for population-related noise limits	+	-	+	+	-	P	P	+	-	P	P	P
5	Absolute scheme for spatial noise limits	-	+	+	+	-	P	P	+	-	P	P	P
6	Absolute scheme for population-related and spatial noise limits	+	+	+	+	-	P	P	+	-	P	P	P
											P	P	P
7	Relative scheme for population-related noise limits	-	-	+	+	-	P	P	+	+	P	P	P
8	Relative scheme for spatial noise limits	-	-	+	+	-	P	P	+	+	P	P	P
9	Relative scheme for population-related and spatial noise limits	-	-	+	+	-	P	P	+	+	P	P	P
											P	P	P
10	Noise permit trading system	P	P	P	P	-	P	P	+	P	P	P	-

+: yes, the scheme does provide certainty / incentive or meets condition; -: no, it does not; P: possibly, depending on actual lay out of scheme

4 Absolute scheme for population-related and spatial noise limits

4.1 Introduction

In this chapter we elaborate on different aspects of absolute noise limiting schemes. We do the same for relative schemes in chapter 5. In chapter 6 we propose a scheme for noise limiting at Community airports, which is actually a combination of both types.

As already defined , in an absolute noise limiting scheme the level of a noise limit is not directly linked to the volume of transportation performed. The core of an absolute scheme is the definition of an indicator for population-related noise. This is described in section 4.2. We will elaborate on the choice for a scheme directed at noise exposure instead of noise emissions or the adverse effects of noise. The possibilities for also including spatial limits are briefly discussed in section 4.3. The desirability of and possibilities for a separate limit on night time noise are discussed in section 4.4.

4.2 Indicator for population-related noise

4.2.1 Limiting noise emissions, noise exposure or the adverse effects of noise?

As addressed in section 3.2, an indicator for population-related noise can be based on:

- Noise emissions.
- Noise exposure, or
- The adverse effects of noise such as annoyance.

Here we will go deeper into the distinctions between these three clearly related metrics and will elaborate on the advantages and disadvantages of each.

Link with the aim of a noise limiting scheme
An advantage of a noise limiting scheme based on adverse effects is that it has a very direct relation with the underlying aim of many noise limiting schemes: to limit the impact of noise on the population. This holds to a slightly lesser extent for a scheme based on exposure. Schemes based on noise emission lack the direct link with the impact of noise on the population.

Economic impact, flexibility and cost effectiveness
As we have argued earlier, noise limiting schemes should allow for as many noise mitigation measures as possible. The main principles for noise mitigation are to consider noise control at source, along the transmission path and at the receiver.

If we only consider limiting noise emission at source, then we are reducing our options for noise control. Ways to limit the actual noise exposure to people include adjusting flight tracks, insulation programmes and possibly buying up and demolishing nearby houses. These measures can decrease noise exposure at the receiver but are not considered if we are only looking at expressing noise limits in terms of noise at the source. Therefore, schemes that are based only on the total noise emissions from aircraft allow for less noise mitigation measures to be evaluated than schemes based on the number of exposed people at the receiver location.

Transparency and feasibility of monitoring
The advantage of an indicator based on *noise emissions* is that is the value of the indicator can be determined with relative ease. Noise emission data is available from the certificated noise levels for example.

To evaluate the value of an indicator based on *noise exposure*, either calculations or noise measurements on the ground are necessary. These could be combined with data on the location of dwellings to determine the number of people[26] exposed to a certain noise level.

An indicator based on *adverse effects (annoyance)* would require social surveys to determine the level of annoyance across the population. An alternative would be to combine data on noise exposure with information on the dose-effect relationship between noise exposure and the adverse effects of noise. There are a number of different noise exposure-annoyance relationships that have been derived from field studies over many years. Based on noise exposure, an estimate of the effects can thus be derived. However, it is important to bear in mind that these relationships are not simple, and many factors in addition to the noise exposure level are responsible for determining the extent of the adverse response.

Annoyance remains, however, an essentially subjective measure on whish consensus definition may be difficult to achieve, despite authoritative statistical evidence[27], of relationships between measured noise and declared annoyance. Annoyance may well vary not only between different parts of Europe reflecting different social and cultural attitudes, but also across regions or social strata, for a variety of reasons.

Current EU legislation
Directive 2002/49/EC provides guidance for Member States on the assessment and management of environmental noise. As a noise *indicator* to assess potential annoyance L_{den} is put forward and L_{night} is selected to assess potential sleep disturbance. Member States can use supplementary indicators in order to monitor or control special noise situations and for acoustic planning and noise zoning. As examples of special, additional noise indicators for night period

[26] In this section, where we say ‘people’, we will mean ‘people or dwellings’. In the next section we elaborate on which of the two is to be preferred.

[27] [Miedema, 1992].

protection L_{Amax} and SEL (sound exposure level) are put forward. It seems to suggest that L_{den} is related to annoyance. Adaptations to noise assessment methods can be made in the future if further technical and scientific progress is made. One aspect that will probably be subject to future adjustment concerns the use of dose-effect relations to assess the harmful effects of noise on populations.

Conclusion
Summarizing, a choice needs to be made between an indicator based on noise emission, noise exposure or the adverse effects of noise. Noise emission can be more easily determined, but adverse effects have a more direct relationship with the underlying aim of noise limiting schemes. Countries are obliged to inform the Commission on the number of exposed people to certain noise levels. A noise indicator based on the number of exposed people relates directly to the recently introduced Directive 2002/49/EC. This is also in line with environmental legislation in other fields, where the same level of protection is guaranteed, irrespective of possible geographical differences in dose-effect relationships.

Furthermore, we can be more certain about noise exposure levels than about adverse effects, because there is still some uncertainty about the exact dose-effect relation and this relation may differ over country and time. Therefore, an indicator based on noise exposure seems the best option.

4.2.2 Which noise metric to use?

Having argued for a scheme based on noise exposure, we now discuss the most meaningful way to express the exposure level, i.e. what noise metric should be used. The question of how to determine the level of the noise indicator (measurement versus calculation) will be addressed in the next section.

L_{den} is advocated by the EU[28] as an indicator for the assessment of environmental noise. It is measured in decibels (dB) and makes use of A-weighted average sound levels. Evening noise is penalized by 5 dB and nightly noise by 10 dB[29].
In addition to the discussion on the relationship between annoyance and sound exposure, Miedema[30] (2000) did find that the strongest correlation of L_{den} with annoyance is indeed obtained with a night time penalty of circa 10 dB.

L_{den} is a measure based on L_{eq}. L_{eq} is a measure of energy equivalent noise level, averaged over time.[31]. It should be noted that L_{eq} contours do have shortcomings. They have been criticised for not giving clear information to the lay person about the actual number of aircraft overflying an area or the noise level of individual events. L_{eq} contours do not show the main flight tracks and can therefore be confusing to interpret. L_{eq} values are also dependent on the averaging time

[28] Directive 2002/30/EC.
[29] This means that the contribution to the L_{den} value of one noise event during evening and night time is equal to respectively 3.16 and 10 similar noise events during daytime.
[30] [Miedema, 2000].
[31] Cumulatively, there can be a mix of several aircraft all of different types passing over a given point in a given time period - L_{eq} expresses that as a single number.

period, and long averaging time periods can make the L_{eq} value insensitive to infrequent peak noise events.

To overcome some of these drawbacks, we propose[32] to connect to the L_{den} measure advocated by the EU in directive 2002/49/EC. Introducing a separate measure with a similar aim in mind would lead to confusion.

However, that is not to say that the L_{den} could not be supplemented by some more transparent indicators. Supplementary metrics have both been mooted and tested in Australia[33]. Their primary aim was to provide information that was transparent, easy to interpret and meaningful to all including the layperson.

As well as the number of people inside L_{den} contours, additional or alternative measures could include:

- Number of dwellings inside specific aircraft noise SEL footprints.
- Number of dwelling over-flown by x average daily number of movements.
- Number of dwellings exposed to SEL events over an L_{max} of say 70 dB(A).
- Number of dwellings with x respite hours or minutes (i.e. not exposed during a certain time period).
- Any of the above, but during different times of day or night or week.

These supplementary metrics are discussed in Annex E.

4.2.3 How to monitor noise indicators: calculation versus measurement?

The levels of the noise indicator can either be determined by calculation or by measurement. Calculations make use of assumptions on (among other things) weather conditions, runway use, flight tracks and noise emissions. These assumptions may differ from the actual operational conditions. In measuring noise levels, we are observing what actually happens under operational conditions, and thus have a more precise indication of noise exposure on site.

Using calculated noise levels has the advantage over measurement that it can be done ex ante. This means that if it is anticipated that the noise limit (or 'budget', hoever expressed) will be exceeded, aircraft operations can be limited or altered. In the calculation of noise ex ante, actual weather conditions and other unpredictable circumstances do not play a role. This options is usually cheaper, faster and more useful in planning or in making strategic decisions.

Noise measurement can only be done ex post. Actual (historic) noise exposure cannot be influenced , although more stringent limits can be set for future periods. Noise measurement reflects the actual noise levels to which the population has been exposed. The advantage is that if aircraft deviate from anticipated flight tracks this will be reflected in the noise indicator. However this option can be very expensive and time consuming. It can, however, provide more accurate data on what really happens, can give information on specific events,

[32] At least for noise exposure during day time. For a discussion on night time noise limits, see paragraph 4.4.

[33] See http://www.dotars.gov.au/avnapt/sepb/and/downloads.htm.

and can help to provide data on trends. Measurement will also more closely adhere to the perception of the community.

Conclusion
Based on the consultations with stakeholders from the sector, we suggest the use of calculations, primarily. Although measurement techniques are rapidly becoming more sophisticated, there is still a cloud of uncertainty with respect to the outcome of noise measurements. Calculations also have the advantage of serving land use planning procedures.

Measurements could be used to validate calculations. Moreover, measurements could be used to check whether aircraft certificated noise levels are accurate and whether best practice measures are being implemented. Comparing outcomes of different measurement methods, one should be aware that they may not be directly comparable due to assumptions made in the measurement process with respect to background noise.

4.2.4 How to deal with the impact of weather conditions?

Another point of interest is that the actual weather has a large impact on runway use, flight tracks and exposure[34]. This raises the question whether limits should refer to actual noise exposure based on actual flight tracks and operational procedures (either by measurement or ex post calculations), or whether limits should refer to forecast noise exposure, based on average weather patterns.

The former has the advantage that the actual noise exposure is taken into account. The latter method provides more clarity for the airport and allows the opportunity to set stricter limits. However, additional regulations need to be imposed to guarantee that, 'on average', actual noise exposure does not exceed limits. Validation of average weather patterns and of flight procedures used in the calculations are required.

For the average weather patterns, 30 year weather records could be used, working within statistical confidence limits as is common practice in evaluating aircraft performance (e.g. route headwind components).

Conclusion
We believe that the ability to set strict limits which can be met on average outweighs the benefits of relating to actual noise exposure at the cost of requiring limits to incorporate a weather margin of say 20%. The latter would imply that with average weather, more noise emissions are allowed.

[34] At Amsterdam Airport Schiphol noise forecasts are based on optimal flight paths and average weather conditions. Limits include a twenty percent margin for deviations from average weather.

4.2.5 Noise exposure levels, number of exposed people or exposed dwellings?

We have argued for a noise limiting scheme based on noise exposure, expressed in L_{den}. We have not yet addressed whether the noise indicator should be directly addressing:

- Noise exposure levels at different geographical points.
- The total number of exposed people in a contour, or
- The total number of exposed dwellings in a contour.

Geographical points versus numbers in a contour
Limiting noise exposure at a number of geographical 'reference' points on the ground can provide certainty of protection for people living close to the reference points. Given sufficient reference points, every member of the community will know exactly what noise level he/she can expect.

Limiting noise exposure levels at reference points comes at the cost of flexibility for the airport. Binding restrictions might potentially leave very limited room for adjusting choice of runways, flight tracks and so on. The airport will not be specifically induced to expose as few people as possible, whereas this is normally a major aim of noise limiting schemes.

A second option would be to limit the number of people or dwellings exposed at a given L_{den} level. This leaves more room for the airport to adjust so that a minimum of persons / dwellings is exposed. It would also provide certainty of protection at community level, but not at the individual level. This is a serious disadvantage for a scheme aiming at limiting the number of exposed people / dwellings. Implicitly, one exposed person is taken to be exchangeable for another. In practice, it does not work like this. People used to noise exposure tend to complain less than people previously not exposed.

The main question is whether, from a social point of view, it is better to maintain the status quo, with a relatively large number of people exposed to what they are used to, or to reduce the overall exposure by making a relatively small number of people worse off. In our opinion, in the long run, one should strive to have as few people as possible exposed to noise, given the airport capacity. At the same time, people have the right to know what to expect.

People versus dwellings
Assuming a system based on the number of exposed people or dwellings, a choice has to be made between these two options. The primary aim of noise limiting schemes is normally to limit or reduce people's exposure to noise, which is an argument to use the number of *people as the indicator*.
It is hard for airports and local authorities to actually achieve this, however, due to the variability and availability of data on population at any given time. Population data is more variable over the short term than the number of dwellings or households. However, Directive 2002/49/EC requires Member States to report the estimated number of people living in noise-exposed dwellings, so in practice reasonable approximations should be available.

As an alternative, to overcome short term fluctuations, the number of exposed dwellings (i.e. households) rather than estimated population could be used.

The number of people within a contour are often derived from the number of dwellings and an assumed average number of people per dwelling. From this perspective, the difference between the two options is not very fundamental.
However, because a scheme based on the number of people gives the possibility for adjusting for differences in the average number of people per dwelling, this option should be preferred.

One argument against methods that pose limits to the number of exposed people or of dwellings within given noise contours is that airports cannot be held solely responsible for meeting limits. Spatial planning is often the responsibility of the local and / or regional authorities and can have a major impact on the number of exposed people.
As long as the authority responsible for setting the actual limit level takes spatial planning developments into account, meeting the limits remains the full responsibility of the airport. It is vital that local authorities and the airport work in close cooperation over spatial planning and potential future airport expansion plans.

Conclusion
The total number of exposed people in a contour seems the best option. The L_{den}-contours can be calculated by making use of the widely applied integrated noise model (INM) of the FAA or by the methodology recommended in the Directive 2002/49/EC. These calculations require very specific input information, from flight procedures and runway use to aircraft noise certification data.

4.2.6 Which contours to use and how to account for insulation?

Two more questions now arise:
- Which contours to use in the setting of limits?
- How to account for insulation programs?

Which contours?
We propose to adhere closely to the information Member States are required to report to the Commission under Directive 2002/49/EC. Member States are required to inform the Commission on (among other things) the number of people living in dwellings exposed to aircraft noise of L_{den} 55-59, 60-64, 65-69, 70-74 and >75 dB.

Correction for insulated properties
As in the Directive, special account can be taken of dwellings with quiet façades and insulation programs. To pose limits on these categories separately would be overly complicated. A more pragmatic approach would be to count these dwellings in a contour with a lower noise level[35].

4.2.7 Overview of the preferred indicator definition of absolute schemes

To summarise, absolute schemes should be based on:

- Calculated L_{den} values (supplementary indicators being considered where appropriate).
- Estimates of the number of people exposed to specific L_{den} values.
- Population-related limits (number of people exposed to specific noise levels).
- Correction for insulated properties (e.g. counting people living there in a contour with a lower noise level).

4.2.8 A further refinement: defining a composite indicator for different noise zones

The scheme discussed in the previous section regulates the number of exposed people within one or more particular noise contours. Such a scheme leaves open many possibilities to reduce or limit the number of exposed people, but might be overly restrictive in one aspect. That is, it does not allow for the balancing of (for instance) a reduction in the number of people within noise contour L_{den} 70-74 and an increase in the number of people within noise contour L_{den} 55-59. It imposes separate limits for the number of people within each noise contour, whereas one overall limit leaves more flexibility, at the cost of less certainty of protection.

To derive a scheme which uses one composite indicator as an overall limit, dwellings in different noise contours must be weighted. We see two possibilities for deriving weighting factors. Either noise exposure-annoyance relationships, or the economic valuation of noise exposure, can be used.

Composite limits using exposure effect relationships
One way in which noise exposures across different noise bands can be summed is to make use of an established dose-response relationship, such as that for annoyance. The noise level - annoyance relationship can be applied within each noise exposure band by considering the population exposed and their average noise exposure level, to give an estimate of the number of people annoyed, or highly annoyed by noise. This process can then be repeated in each band, and by summing all bands, an estimate of the total number of people annoyed is made. This technique is used in the UK to compare noise impacts across transport planning options[36]. This is a powerful technique that give intuitive results in terms of number of people that the public can relate to.

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[35] Clearly, agreement between airport and limit setting authority has to be reached on this issue. The specific situation at hand should be a deciding factor. There are many different insulation programmes and costs per dwelling vary widely, not all programmes will be equally successful in reducing indoor noise exposure.

[36] Guidance on Methodologies of Multi-Modal Studies (GOMMMS), UK Department of Environment, Transport and Regions, 2000 [UK-DETR, 2000].

Composite limits using the economic valuation of noise exposure
This alternative is based on an assumption often made in studies on the external costs of noise around airports. These studies[37] either assume a fixed level of costs per household per dB noise exposure above some cut off value or relate housing prices with noise exposure. Houses exposed to high noise levels will generally be valued lower than comparable houses not exposed to noise. By econometric methods percentage values for the average depreciation per dB are derived, the so-called noise sensitivity depreciation index (NSDI). Implicitly, population preferences for noise are thus derived.

These studies do not provide indications that the average depreciation per dB varies with noise level, but assume a constant relationship. Thus, reducing noise exposure from 75 to 74 dB is valued no differently than a reduction from 64 to 63 dB. If the NSDI is indeed constant (for the relevant bandwidth of noise levels), an overall indicator of noise exposed people could be calculated by multiplying the average noise exposure level in each noise contour by the number of exposed people and summing the results for each noise contour. A measure in exposed person.dB is thus derived.

An example: Assume that 200 people in the L_{den} 70-74 contour are exposed to noise levels exceeding the cut-off value of 55 dB. The average exceedence is 72.50 - 55 = 17.5 dB, accounting for 200 x 17.5 = 3,500 person-decibels (person.dB). These can be added to say 1,000 exposed people in the L_{den} 65 - 69 contour accounting for 12,500 person.dB, to get a total exposure of 16,000 person.dB in these two contour zones.

Unfortunately, this approach may have a negative influence of the transparency of the system.

4.3 Spatial noise indicator

4.3.1 Introduction

In this section we will describe how the area affected by noise can be taken into account in an absolute noise limiting scheme. Exposing a certain area to noise effectively lays a claim on the area, which cannot then be used for purposes such as housing, schools or hospitals. The social costs associated with the claim on land should be minimised, and therefore one might also want to take account of the size of the exposed area in a noise limiting scheme.

This scheme will be based on the assumption that a separate population-related scheme is in place for the protection of people against noise. Any indicator that will take into account of both the number of exposed dwellings and the affected area will be subject to great debate, because balancing dwellings and area is

[37] Examples include [Pearce and Pearce, 2000], [Van Praag and Baarsma, forthcoming]. The same assumption lies at the basis of the proposed methodology in [EC, 2002b].

difficult to do objectively. Therefore we describe a spatial limit scheme separately from a population-related scheme, as described in the previous section.

4.3.2 A noise limiting scheme for affected area

The treatment of affected area is very similar to the treatment of exposed people. Limiting the area of each noise contour can obviously limit the area of the noise zones between them.

There are several questions to be addressed in this regard:
- Is L_{den} the best noise indicator for affected area as well?
- Do we want to balance the areas in different noise contours?
- If so, how can this be done?
- Should we treat all areas (and noise zones) equally, irrespective of their purpose (and the contour values)?

The answers to these questions depend on the rationale for setting spatial limits at all.

We distinguish two main reasons:
- To account for the economic costs of reducing the possibilities for land-use by noise exposure.
- Protection of nature reserves and habitats.

If the exposed area is to be noise-limited because of the first reason, we propose to adhere as closely as possible to the noise limiting scheme developed for population exposure, thus not complicating the scheme more than necessary. Moreover, there is no reason to assume that the L_{den} measure would not be the appropriate metric.

On the other hand, if protection of nature reserves were to be the primary aim of a noise limit scheme, L_{den} might not be the best indicator for noise exposure. Night time protection may be appropriate for animals that are awake during day time, but day time protection may be more appropriate for nocturnal animals. Furthermore, animals may be more sensitive to individual events, so the supplementary L_{max} figures may be required.
Although noise limitations over nature reserves might seem unlikely to be a high priority for most large airports, it might actually prove more complicated to devise an appropriate scheme.

We will therefore confine ourselves to the elaboration of a noise limiting scheme based on L_{den}. We propose a scheme in which limits are set to the total area within noise contours. Directive 2002/49/EC requires data to be sent to the Commission on the total area exposed to values of L_{den} higher than 55, 65 and 75 dB. We propose to extend this to the areas exposed to values of L_{den} of 55-59, 60-64, 65-69, 70-74 and over 75 dB, in line with the reporting requirements for the number of exposed people.

As in the case of the number of exposed people, one might wish to add indicator values over different contour zones. This can be done by the same method used for noise exposure to people. The area in km^2 is multiplied by the average L_{den} value for the noise contour and these values can subsequently be added up to one noise exposure indicator, measured in km^2.dB.

Weighting might also be possible. For example, one could distinguish between sea-areas, nature reserves, industrial regions and residential areas. Less noise sensitive areas could be counted in a contour with a lower average L_{den} value (i.e. the area would be multiplied by a lower noise exposure value).

4.4 Night regime

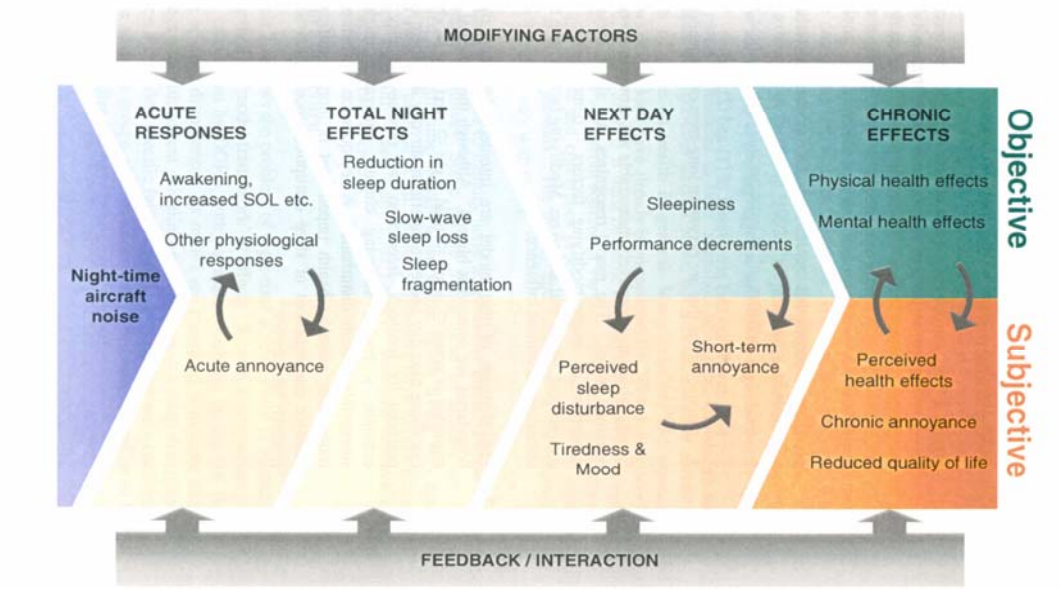
There is a growing number of complaints against night flights in the EU. Banning night flights from airports where they do not cause any nuisance seems overly restrictive. Furthermore, a total ban of night flights would restrict the operations of several sectors of the industry and their customers/passengers, including intercontinental scheduled services, leisure flights, express and mail. The European Commission has commissioned a study on the economic benefits of night flights as further input for the discussion.

For this reason we pay special attention in this section to the subject of night time noise and discuss how this could be included in the definition of an absolute scheme.

4.4.1 The effects of night time noise

Much research has been completed on the effects of aircraft noise during the night-time period. There are a number of *potential* effects during the night, a model for which was developed in [Porter et al., 2000]. These included sleep disturbance, annoyance, performance decrements and some chronic effects. The model from this work is reproduced in Figure 1.

Figure 1 Potential impact of night-time aircraft noise: Model framework



Studies on sleep disturbance have shown that in general, the extent of a response is related to the individual events.
In 1992, [Ollerhead et. al., 1992] reported that for the UK average sleep disturbance rates were unlikely to be affected by outdoor noise events below 90 dB(A) SEL[38], and, at higher noise event levels (mostly in the range 90-100 dB(A) SEL), the chance of the average person being wakened by an aircraft noise event was about 1 in 75. It was acknowledged that this key finding related to awakenings once asleep. It gave little information about the effects on sleep onset latency (time taken to fall asleep) and premature awakenings in the early morning referred to as the 'shoulder hours'.
Similar data was found in the US although awakenings were measured slightly differently using press buttons rather than limb movements.

4.4.2 Dealing with night time noise in an absolute scheme

There are several reasons why a separate night time regime might be desirable. First, the L_{den} measure does not capture the specific nuisance problems of flights at night. Although a penalty factor for evening and night flights applies, this does not fully do justice to the specific problem of night noise. Peak noise levels may be a better indicator of the probability of awakening than the A-weighted sound level conventionally used.

In order to assess night-time noise we have to determine the metric which best indicates the effect. There are arguments about the main source of impact, be it sleep disturbance or annoyance[39].
Night time noise is already included in the indicator based on the number of exposed people in L_{den} contours discussed in section 4.2. This includes a 10 dB

[38] This corresponds with L_{max} noise levels of approximately 80 dB(A).
[39] See [Porter, 1997].

penalty for noise occurring during the night period. However, we feel this offers little certainty of protection against night time noise. Because L_{den} offers the opportunity to balance day, evening and night time flights, people do not know what to expect during the night. Both for this reason and for transparency, an indicator directly relating to the number of noisy events to which people are exposed to during the night, should be added.
We discuss the following options:

- Number of noisy events (NAx indicator).
- Person Event Index (PEI).

Number of noisy events (NAx indicator)
NA*x* is the number of noisy events with a SEL value of over *x* dB(A). So, for example, a N90 limit of 25 would imply that nobody around the airport is ever exposed to more than 25 noise events with a SEL value above 90 dB(A) within one night. This provides absolute certainty of protection (up to the locally set limit) for anyone living in the vicinity of the airport.

Person Event Index (PEI)
A second option is to include a supplementary measure for information purposes based on the Person Event Index (PEI). The PEI(*x*) sums the total number of instances where an individual is exposed to an aircraft noise event above a specified SEL value of *x* dB(A) for the night time period.

Compared to the NAx indicator which is based on the maximum number of events any individual may be exposed to, the PEI indicator gives a better indication of total noise exposure during the night. It cannot provide certainty of protection at the individual level, however, because a PEI(90) value of 70,000 may mean that only one person has been exposed to (70,000) noise events with a SEL value of over 90 dB(A), but may also mean that 7,000 people were exposed to on average 10 events during the night.

Conclusion
To have a good indication of the total noise exposure during the night and to provide certainty of protection to individuals as well, a combination of an NAx indicator and a PEI seems the best option for an additional measure for noise during the night.

Again, for both measures, it would have to be decided how to take insulation into account. If noise insulation provides for the possibility of ventilation without opening the windows, it could be argued that exposed population counts should ignore any person living in a noise insulated house completely, thus incentivising the use of noise insulation.

There is one further point to take into consideration. We recommend the use of a separate indicator for limiting and possibly reducing night time noise, because the L_{den} measure is not designed to do this, but to offer a weighted 24-hour indicator[40]. To avoid the possibility of two separate (day and night) schemes

[40] The shortcomings of L_{eq} as an indicator of noise impacts at night are considered in more detail in Annex D.

giving possibly inconsistent incentives, one could decide not to include night noise in the 'standard' day noise indicator. Instead of using L_{den} one could argue that using L_{de} for day and evening noise would be more appropriate.

However, as we have argued before, the L_{den} measure fits closely to recently introduced EU legislation. Introducing a different measure could therefore have some negative side-effects with respect to transparency.

Illustrative cases for absolute scheme

Volume growth
Once current noise limits at a given airport have been reached, in an absolute scheme based on population exposure, further traffic growth is only possible if no more people are exposed to noise.
There will thus be an incentive to use more quiet aircraft (reduce noise at source), so that additional flights become possible while not breaching the current limits. There will also be an incentive to optimize flight tracks, runway use and other noise mitigation procedures further. Some traffic growth might be absorbed in other ways, such as increasing the load factor. Once the ultimate ability of these measures to effectively increase the airport's 'noise capacity' have come to an end, further volume growth is severely constrained.
In the long run, if limits are set locally, the local authority might decide that the economic benefits of increased traffic volume offset the environmental disbenefits of additional noise exposure, and stretch the limits.

New runway
Airport expansion with a new runway will always be the result of a long process of Environmental Impact Assessments and consultations with the local authorities responsible for land use planning and noise limit setting. The introduction of a new runway will have a large impact on the number of exposed people and on exposure levels. The purpose will normally be an increase in physical capacity, and not necessarily an increase in environmental capacity.

In an absolute scheme, the local authority can only allow for an increased physical capacity by stretching limits which will lead to increased noise exposure, effectively increasing the airport's environmental capacity.

Technological improvement of aircraft
If noise at source can be reduced by technological improvements, additional environmental capacity becomes available, and more aircraft movements can be allowed. On the other hand the local authorities might decide to adjust the limits such that the total number of movements remains the same, but noise exposure is reduced.

5 Relative scheme for population-related and spatial noise limits

An absolute noise limiting scheme, as discussed in the previous chapter, does not relate the noise of an airport to its transport volume. An absolute scheme does only prescribe a uniform noise indicator, but cannot prescribe a uniform method of setting the levels of the limits.

In this chapter we focus on relative schemes. In a relative noise limiting scheme, noise limits are directly linked to the volume of transportation performed. So, in a relative scheme, the overall 'noise efficiency' of the airport's activity is maintained.

As explained in section 3.2.4, there are two types of relative noise limiting schemes:
1 The combination of a noise indicator and a method for setting limits that takes into account the volume of transportation performed at the airport.
2 An indicator that itself takes into account the transport volume.

The difference between these approaches does not determine the effect of the limit scheme and is therefore not very fundamental. In this chapter we will only discuss a relative scheme that is based on an indicator that itself takes into account the transport volume. This option seems us more transparent than a scheme where the relativity of the scheme is built into the way in which the noise limit is set.

An indicator that takes into account the transport volume of an airport can either be:
- Noise per aircraft movement, or
- A ratio of a cumulative noise indicator and a transport volume indicator.

As argued in section 3.3, an indicator that limits the noise emission per aircraft is less favourable than a relative indicator based on a cumulative noise indicator. Therefore we only elaborate the latter.

The transport or traffic volume of an airport can be defined in several ways, which will be discussed in this chapter.

5.1 Transport volume as a proxy for economic value

In a relative scheme, traffic growth does not conflict with noise limits, as long as the relative limit is met. Not the *absolute* noise but the overall *'noise efficiency'* of the airport's activity is maintained. Therefore there is no absolute limit of protection in a purely relative scheme.

An important question to be answered in this context is what type of 'noise efficiency' we are looking for. The answer to this question directly touches the definition of the transport volume indicator.

The idea behind a relative scheme is to relate the noise of an airport to its size and economic value. However, the economic value of an airport is hard to quantify. It depends on many parameters (like country, transport volumes, type of goods or passengers). Ideally, the best option would be to base a relative scheme on the contribution of all movements to the GDP. However, this would require very detailed information about the types of passengers or cargo of each flight. This is practically not feasible in practice and will not contribute to the transparency of the scheme. Therefore, other proxies for the economic value are needed.

A good proxy is to take the total amount of the 'product' of an airport: the transport volume to and from the airport. This is much easier to define in a uniform way. Therefore, we have taken the transport volume as a basis for volume part of a relative scheme.

5.2 Basic structure of a relative scheme

Basically, a relative scheme consists of two parts:

1 Indicator for the absolute population-related or spatial exposure to noise (numerator).
2 Indicator for the absolute transport or traffic volume of the airport (denominator).

This may be expressed as:

$$\textit{Relative noise indicator} = \frac{\textit{Noise indicator}}{\textit{Transport volume indicator}}$$

In case of a scheme based on both population and spatial limits, there will be two different limits (and two formulae) with the same denominator.

The numerator of a relative scheme can be chosen in the same way as the indicator for population-related and/or spatial limits in an absolute scheme (see the extensive discussion on this issue in the previous chapter), i.e. the population (or area) within each noise contour or contour zone exposed to given levels of L_{den}. As in an absolute scheme there are two options:

- *A set of limits*: a limit for each noise zone. In a relative scheme this will be (for each zone) a limit to the number of people per unit of transport volume, and a limit to the number of square kilometres per unit of transport volume.
- *A composite population-related and spatial limits* In a relative scheme this will be one aggregated limit to population per unit of transport volume and one aggregated limit to the exposed area per unit of transport volume.

The definition of the denominator is less straightforward and will be discussed in the next section.

5.3 Definition of the denominator (transport or traffic volume)

A relative scheme relates the noise of an airport to its transport or traffic volume. The advantages and drawbacks of the following options are discussed below:

- Number of movements.
- Actual payload.
- Potential payload (load capacity).
- Flight distance.
- Combination of flight distance and actual/potential payload.

A disadvantage of all relative schemes is that they give incentives not only for reducing noise, but also for increasing the traffic volume. These perverse incentives depend on the definition of the transport volume.

5.3.1 Number of movements

The number of movements is readily available for each airport. However, it is a rather rough way to approximate the economic value of an airport, because it does not take into account either the productive capacity of different aircraft or variations in commercial efficiency of operation such as load factor. The economic value of a full 747 will be of an other magnitude than of small aircraft such as a Fokker 50. Therefore, the number of movements is not a good proxy for the economic value. Furthermore, such a scheme would give a perverse incentive for increasing the number of flights.

5.3.2 Actual payload

Actual payload is an important indicator for the economic value of a flight. A denominator that is related to the actual payload could be the actual payload in tonnes or cubic meters or the actual number of passengers. The number of passengers is no good option, because we are looking for a single definition that covers both passenger and freight transport, as well as belly cargo. For transport in general, but especially for air transport, the mass of the actual payload is more important and more commonly used as measure for the transport volume than the spatial volume. Therefore, we focus on the actual payload in tonnes.

An important issue related to this variant is development of a methodology to combine passengers and freight into a single payload indicator, such as Revenue Tonne Kilometres (RTK) which also includes a distance factor, thus reflecting the increase in the environmental and economic efficiency of air transport as length of haul increases. The usual definition of Revenue Tonne Kilometres (RTKs), hereby passengers including luggage are taken as 100 kilograms, is unsatisfactory. Passenger transport requires seats, galleys, toilets and service items such as in-flight meals and newspapers, whereas freight does not. Some airlines, including Lufthansa and Air France, have developed methodologies to

correct for this in their environmental reporting. Lufthansa concluded that on short-haul flights one passenger accounts for about 140 kg on average, on medium hauls 155 kg and on long hauls 173 kg. Air France arrived at figures of between 140 and 200 kg, depending on type of aircraft and load factor. For the definition of an uniform noise limiting scheme, we recommend to use an average (of about 160 kg per pax) as a base estimate, which is in line with values used in [CE, 2002b].

The actual payload as denominator has the advantage that it gives incentives both to limit the noise per aircraft and to improve load factors, as both responses limit the noise per payload.

Using actual payload to calculate the volume would mean operators having to report full details of the payload transported on every flight. This is not an unusual practice; for example, in the UK and the US airlines already face such obligations. However, in a noise limit scheme, limits need to be set in advance, which implies the use of forecast payloads. An option could be to base the limit for a certain year on the actual payloads of the previous year, but this will give a bad estimate when the mix of flights (share of charters, freight, large/small aircraft etc.) changes significantly. Therefore the load capacity could be an alternative.

Another disadvantage of using the actual payload as volume indicator is that it gives a theoretical perverse incentive to sell additional seats or tones cargo at predatory prices, although in practice existing commercial pressures probably militate against this.

5.3.3 Load capacity

If the previous option using actual payload kilometres is not deemed feasible, an alternative option that is a good proxy for the *potential* payload comes into play. There are several options for a denominator that is related to the load capacity of aircraft:

- MTOW (Maximum Take Off Weight).
- MZFW (Maximum Zero Fuel Weight)[41].
- MZFW minus MEW (Manufacturer's Empty Weight).

Prima facie, the best definition of potential payload might be MZFW minus MEW. However, MEW is not a consistent officially certified value for a generic aircraft type.

MZFW is a better metric than MTOW, as the trade-off between payload and range is better reflected in MZFW than in MTOW. Fuel capacity can be highly variable across different aircraft types of similar MTOW, depending on the design range of the aircraft.
On the other hand, use of MTOW as a proxy for potential payload has the practical advantage that this value is already incorporated in, for example, the Eurocontrol charging and billing system.

[41] The MZFW is the maximum operational weight without usable fuel.

The main disadvantage compared with the previous option (actual payload) is that no account is taken of improvements to productivity (and thus to environmental efficiency) achieved by increasing the load factor.

Another disadvantage of using MZFW as a volume indicator is that it gives a theoretical perverse incentive to use larger aircraft than necessary for a flight, although in practice existing commercial pressures militate against this.

As already noted, MZFW has the advantage over the actual payload that is easier to apply in an *ex ante* scheme.

5.3.4 Flight distance

In this case, the definition of the volume would be the total number of kilometres by all aircraft movements to and from the airport. This definition of the denominator gives an incentive to limit the noise per flight-kilometre. Consequently, long-haul flights are put at an advantage over short-haul flights per unit of noise, owing to the much lower proportion of the flight profile comprising the noise relevant take-off and landing phase.

Generally short-haul flights give more noise *per flight kilometre* than long-haul flights. Therefore a noise limiting scheme with a distance-based denominator gives an advantage to long haul flights in terms of 'noise efficiency'.

5.3.5 Combination of flight distance and actual/potential payload

Another option for the denominator is a combination of the payload and the flight distance. In this case the denominator could be the *total transport volume* to and from the airport, defined as the sum of the transport volume of all flights. The transport volume per flight is the product of payload per flight and flight distance per flight (alternatively the MZFW times the flight distance).

The product aircraft produce is transportation of *load* over *distances*. Therefore, a definition that combines payload and distance is the most accurate indicator for the transport volume.

This could be the actual payload.kilometres performed or alternatively the number of MZFW.kilometres performed. However, it may be questioned whether distance and payload should be weighted equally. A product of both values implies that carrying 10 tonnes over 500 kilometres would have the same economic value as carrying 1 tonne over 5,000 kilometres. If this is not true, other combinations (e.g. actual payload times the square root of the flight distance) might be better proxy for the economic value of a flight. This issue in our view both requires and deserves further research, although it is beyond our scope here.

5.3.6 Discussion

All the options discussed above work identically in encouraging noise mitigation measures like quieter aircraft, flight procedures, etc. However, each of the four candidates for use as a denominator discussed above provides different incentives with regard to aircraft size, load factor and flight distance. They thus have different environmental and economic impacts.

The most appropriate indicator for the volume part of a relative scheme is some kind of a combination of the actual payload (or otherwise MZFW) and the flight distance, RTK being the most readily available and universally recognised. This option will give the most direct incentives to reduce noise per 'amount of product' produced at an airport.

It is important to note once more that a relative scheme does give an airport the freedom to attract as much traffic as possible as long as the 'noise efficiency' does not decrease. This implies more noise for more people unless noise per traffic unit decreases faster than traffic increases. Thus for all their attractiveness, relative schemes *alone* give neither population-related nor spatial protection from noise exposure.

Illustrative cases for a relative scheme

Volume growth
In a relative scheme, volume growth can be absorbed more easily than in an absolute scheme. If the additional flights meet the relative limit, there is no restriction on growth. However, more people will be exposed to noise, because the limits are only directed at the relative noise performance.

New runway
A new runway will normally increase capacity at the airport unless its use is constrained on environmental grounds. Even if the new runway were located relatively unfavourably with respect to housing, quiet aircraft might be able to use it without breaching the relative limits. Thus an increase in the overall number of exposed people would be likely.

Technological improvement of aircraft
In case of a technological improvement such that noise at source is reduced, the average noise level per volume measure of the current fleet will decrease. If the limits are not adjusted, more – perhaps even some noisier - aircraft than before will be able to use the airport, as long as the overall average relative limits are still met. The environmental capacity of the airport will increase substantially. It is therefore essential that limits will follow (or precede) technological progress.

6 Proposal for a noise limiting scheme at larger EU airports

In the previous two chapters we discussed how an absolute or relative scheme could be used to limit noise around airports. There are arguments in favour and against either type of scheme. It is important to keep in mind that the 'optimal' uniform noise limiting scheme does not exist. The introduction of a new scheme will always produce winners and losers, both in terms of airports and in terms of people, of which some might be exposed to more noise, and some to less.

In this chapter, we describe what in our opinion is the best compromise scheme. Note that several objections can still be launched at this proposed scheme. It is a mix of a relative and absolute scheme and tries to combine the best of both worlds by providing the opportunity to take the specific local situation fully into account, while also enabling incentives to be given for limiting noise around Community airports where appropriate.

6.1 Outline of proposal

The scheme we propose is composed of the following complementary elements:

1 *A locally set limit to the absolute number of exposed people within several L_{den} contour zones*, including a supplementary measure indicating the number of annoyed people.
2 *Locally set limits to night time noise*, based on two indicators:
   a An indicator limiting the number of noisy events to which anyone is exposed during the night (NAx).
   b A Person Events Index (PEI) limiting the total noise load per night.
3 *An internationally set limit based on the ratio of a measure of exposed area and some volume measure*.
4 *Reporting requirements*.

Apart from that, we also advise a broadening of possibilities for flanking instruments, such that a continuous incentive can be provided to airlines to fly as quietly as possible, by using the most quiet aircraft and adhering to best available procedures.

The proposal is based on the analysis from the previous chapters. We have also consulted several stakeholders (listed at Annex A) and asked for their opinion on the design of a uniform noise limiting scheme. Many of them stressed that it is very important to take the local situation fully into account. Indeed, the very desirability of a uniform scheme was often questioned. As previously stated that is an issue beyond our terms of reference for this study.

We did take notice of all opinions in constructing the proposed scheme described in this Chapter, but were not able to reflect each and everyone of them in our recommendations, particularly where opinions conflicted. Nonetheless we would

like to record our thanks to the stakeholders interviewed for their co-operation, which was of real value to us in developing out ideas. The responsibility for the conclusions we drew from the interview program of course remain our own.

6.2 Locally set absolute population-related limits

The first element of the proposed scheme is directed at limiting the absolute number of exposed people. It is a uniform noise indicator which adheres closely to current Community legislation in Directive 2002/49/EC. Though the indicator is uniform, limits are determined locally. A uniform noise indicator at Community airports would increase the transparency and comparability of noise limits, and thus help to ensure a level playing field in competition terms.

We will discuss our proposal below and also address how to account for insulated properties, whether the indicator should be assessed by calculation or measurement and how to account for weather conditions in setting limits.

6.2.1 Population-related limits: indicator and limit setting

The noise indicator is the number of exposed people within L_{den} bands. The L_{den} measure is described in directive 2002/49/EC. It requires Member States to report on the (estimated) number of people living in dwellings in the following L_{den} bands:

- 55-59 dB(A).
- 60-64 dB(A).
- 65-69 dB(A).
- 70-74 dB(A).
- >75 dB(A).

We acknowledge that it will be difficult to set limits on the number of people within each band. Furthermore, using five different bands might cloud the appraisal of a reduction in the, say, >75 band at the cost of an increase in the 55-59 band. However, we feel that it is important to use more than one band or contour, to reflect decisions to be made as described in the previous sentence. These considerations are not uncommon in the assessment of noise mitigation measures. Therefore, reducing the number of bands for which limits are set, from five to three, might provide a solution.

In section 6.2.4 a supplementary measure is discussed further, enabling comparability between exposed people in different noise bands.

We think it is imperative that limits are set locally. This is the only way in which full account can be taken of the particular situation at the airport, such as the population density around the airport and the runway layout.

As directive 2002/49/EC specifically mentions the estimated number of people living in dwellings, we propose to adhere to this. The Commission will have to decide whether it wants to regulate or recommend how to deal with hospitals,

hotels and schools, or whether it leaves these issues to the discretion of the local authorities.

6.2.2 Taking into account the effects of insulation programs

Another point is how to account for *insulation programs*. Any good insulation program should reduce the noise exposure inside substantially, but it does not reduce noise exposure outside and has only a small effect if windows are open. However, there are obviously differences between the extent to which different insulation schemes provide noise reductions inside. For this reason it will be hard to find consensus on a uniform method to take insulation into account.

Our proposal is to transfer the people living in insulated houses to a lower band. So, assuming the effective difference made by insulation to be 5 dB(A), suppose the number of people in band 55-59 is 40,000 and in band 60-64 20,000 of which 2,000 live in insulated houses, the adjusted noise exposure levels will be: 55-59 42,000 and in the 60-64 band 18,000.

Depending on the particular insulation scheme, the local community and the local body responsible for noise limits will have to agree on how much insulation is provided, and the number of bands houses can be transferred over. This process should of course take into account that insulation only provides a noise reduction inside houses, not their gardens or nearby open spaces used by the inhabitants.

6.2.3 Monitoring method and the impact of weather conditions

We propose that the assessment of the level of the indicator should use noise *calculations* based on *average weather patterns*.

Most of the consulted people preferred calculations over noise measurement, because of the context of the balanced approach and because measurements are still clouded with too many uncertainties. Using measurements for validation of calculated noise is a possibility, but care must be taken because there is usually a difference between calculated noise and measured noise due to the measurement techniques used. Inputs into the model must of course be validated and agreed upon by different stakeholders.

6.2.4 Supplementary indicator for limiting absolute number of annoyed people

As discussed earlier, using up to five noise level bands makes it hard to assess whether progress is being made. Clearly, if numbers in each band go down over time, there is progress. However, it is not clear how to appraise a reduction in one band and an increase in another. For this we propose a supplementary indicator.

The indicator refers to the total number of annoyed people within the 55 dB(A) contour (i.e. the lower bound of the lower band for which reporting requirements hold). Based on surveys[42] of noise-annoyance relationships for aircraft noise, the total number of annoyed people within each band can be estimated[43]. By summing the results for each band, an estimate of the total number of annoyed people is obtained. By assessing this number, insight is obtained as to whether the airport is doing a good job or not, if numbers in some bands go up and numbers in others go down.

We strongly recommend using this supplementary measure. It is not meant to provide an additional restriction, but might serve as a basis to determine limit levels for each particular band.

6.3 Locally set limits to night time noise

As discussed in section 4.2, an absolute scheme based on L_{den} contours should be supplemented with an additional indicator for noise at night. We propose to add two indicators: both an NAx indicator to limit the number of noisy events to which any individual person is exposed and a Person Event Index (PEI).

As explained in Chapter 5, NA_x is the number of noisy events with a SEL value of over *x* dB(A). The limit should be set locally, and be valid for every night. So, for example, a N90 limit of 25 would imply that nobody around the airport is ever exposed to more than 25 noise events with a SEL value above 90 dB(A) within one night.
The value for x should be agreed, if not set, at the European level, so limits can be compared. It can be seen as a statement on the level of infringement on night rest that is allowed for by local noise regulators to accommodate night flights[44].

Secondly, we propose to include a supplementary measure for informational purposes based on the PEI, giving a better indication of total noise exposure during the night than an NAx indicator. The PEI(*x*) sums the total number of instances where an individual is exposed to an aircraft noise event above a specified SEL value of *x* dB(A) for the night time period.

Again, for both measures, it would have to be decided how to take insulation into account. If noise insulation provides for the possibility of ventilation without opening the windows, it could be argued that any person living in a noise insulated house should be completely ignored in counting population exposure, thus giving an incentive for the use of noise insulation.

In case of unexpected flight delays (e.g. because of extreme weather conditions, bomb alarms, etc.), this type of night schemes might not be met for some days of

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[42] See [Miedema, 1992].

[43] Note that while 'annoyance' is inevitably a subjective emotion, we use the term in the statistically significant sense of the proportion of people likely to react to a given level of noise by finding it annoying.

[44] Limits are set locally, but it is conceivable that the Commission might make a guidance statement on acceptable NAx values. However, it should be kept in mind that the NAx value is for a large part determined by historical land use planning, runway layout and the number of aircraft movements.

the year. The scheme should include an incentive to limit this type of exceptions to a reasonable number. This can be done either by putting a maximum to the number of days the night limits are not met, or by giving the authority for accepting a break of night limits without consequences, in case of *force majeure*.

6.4 Internationally set limits based on the ratio of a exposed area and some volume measure

The above discussed indicators are all locally set limits. They all address the exposure of people due to the air traffic movements at the airport. These are absolute, in the sense that there is no direct relation between the transport volume and the level of the limit. However, as discussed in Chapter 5, there are also good reasons for introducing international restrictions on the 'average' environmental performance. The most important reasons for adding a relative part to the combined scheme as we propose it in this chapter are:

- To provide for smooth functioning of the internal market.
- To make airports more comparable.

In this section we suggest a uniform system, based on some sort of (EU) performance standard. Unlike the first two elements of the combined scheme, it will provide a like for like comparison between airports within the Community in terms of how well they manage their aircraft noise. A limit is set on how noisy (measured in noise contour area size) the airport may be, given the level of transport volume. Consistent implementation may require Community-wide action, but as frequently noted throughout this report, legislative recommendations are beyond our terms of reference. It should be noted that this is not yet a fully worked out system and further research is required.

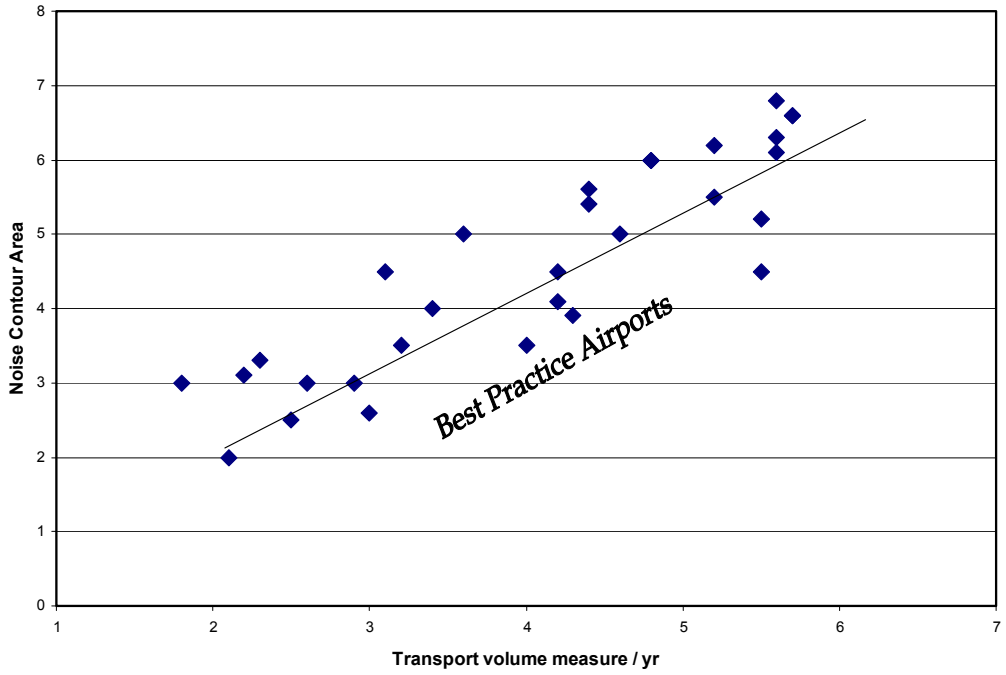
The system we propose sets a spatial limit on the exposed area per measure of transport volume. The underlying idea is that any two airports of a similar 'size' (which broadly tends to reflect their character) should produce similar size noise contours. The size of the noise contour of course to some extent depends on runway layout, which itself may depend on the land use planning and housing zones around the airport. However, for most existing runways, the reverse is more likely to be true.

We do not propose to base this system on the number of exposed people for two reasons:

1 There is a wide variation in the population densities around European airports. Some are in relatively unpopulated areas at one extreme, whereas other are surrounded by vast conurbations. Two airports of similar size can therefore affect hugely differing numbers of people. This will have come about for historical reasons that are probably out of the airport's control.
2 The number of exposed people is sufficiently addressed by the indicators proposed above.

This system is based on the broad relationship between noise contour size and airport size, as depicted in Figure 2.

Figure 2 Airport Noise Contour/Airport Size Relationship



Airports plotted towards the bottom right of this diagram should, other things being equal, be those practising the best noise control measures. Bad performers can be easily be identified as tending toward the top left, with a large contour area relative to transport volume or traffic. However, before discussing how this form of plot might be used for setting relative noise limits, it is important to consider how airport size can be fairly defined, and also what noise contours should be used.

Some options for defining an airport's size have been discussed in chapter 5. Some combination of distance and actual payload or Maximum Zero Fuel Weight (MZFW) was proposed.

Noise contour size could be based on the total area within a simple 24 hour L_{eq} contour, (i.e. the L_{den} contour without evening or night weighting) to avoid bias against airports with a large proportion of evening or night flights. There may be exceptions where noise contour area is not so important, for example, an airport with contours stretching over the sea or other uninhabitable areas. It could also be appropriate to subtract the area of the airport itself from the airport's contour size. This may help to prevent the airports which cover larger areas, perhaps having been deliberately designed in this way for security and/or environmental control reasons, from being unfairly penalised.

The issue whether such a system should be based on one contour or some composite integration of different contours needs to be further researched.

The contour area/airport size relationship could perhaps also be used to condition allowable growth in airport size. One would certainly not wish the airport's average performance to deteriorate after expansion. Drawing a line from the origin through its current position in the graph (as has been done for illustrative purposes in Figure 2), one could restrict the expansion plans by requiring the airport to end up at the lower right side of the line after expansions plans have been carried out. This may be a way of allowing growth whilst conditioning for a good standard of noise control.

The power of such a system of plotting noise contour area against airport size may lie in the way it reveals how comparatively well noise is being managed. Poorly performing airports would be revealed, and just by having their performance reported in this way may be encouraged to take action to improve. Another useful feature of this type of noise limit is that it is under the sole effective control of the airport stakeholders (the airport operator and the airlines it manages). The local land use planning authority, although important stakeholders, are not involved, and could be set performance targets through alternative limits, such as those involving population counts. So a limiting system of this kind would have clear accountability.

A relative noise limit could also be used for Community benchmarking of the environmental noise performance of airports, provided that agreements can be reached on an appropriate indicator for airport size.

6.5 Reporting requirements

The fourth element of the scheme we propose consists of extensive requirements on reporting current and future noise policy by the authorities responsible for setting local limits. There are basically three reasons for including this:

1 People need to know what to expect in the future.
2 Transparency is important to keep annoyance limited.
3 To allow for comparison of airport performances.

Before summing up the reporting requirements we foresee, we first elaborate on these three points.

People need to know what to expect in the future

The adverse effects of noise, such as annoyance, are substantially determined by so-called non-acoustic effects. One of these non-acoustic factors is uncertainty. Uncertainty of what to expect in the long run is detrimental to the well being of people. This helps to explain why most noise complaints come from areas which have seen an increase in noise exposure, and not necessarily from the areas exposed to the highest noise levels. Note that we would accept that numbers of complaints (but perhaps not of complainants) are in any case a poor indicator of annoyance.

Most measures that can be taken to reduce the absolute number of exposed people (in one contour band, or cumulated by using a fixed noise-annoyance relationship), will probably also result in some people being worse of than before.

Particularly when this is unexpected, actual annoyance can be expected to increase substantially.

There is anecdotal evidence of people who moved to escape from noise exposure and were again confronted with the same noise exposure a few years later in their new house. If people know what to expect and where to expect it, they can adapt their behaviour to optimize welfare.

Clearly, comprehensive information is essential. In a system dependent upon population-related limits, rather than limiting noise at a large number of reference points, this argument becomes even more important.

Economic aspects (depreciation of housing prices) also clearly play an important role for owners of houses exposed to noise.

The very serious effects which too many unexpected changes of noise exposure can have cannot be ignored. It is therefore essential that we also propose that airports should put in place long term policy plans with respect to noise describing exactly what their plans are for the future – an element missing from Directive 2002/49/EC, perhaps on grounds of subsidiarity.

Transparency is important to keep annoyance limited
Given a critical exposure level, non-acoustic factors can influence annoyance to a considerable degree. Lack of transparency is one of the more important non-acoustic factors. We strongly feel that transparency can be increased by having clear reporting standards.

Value of comparison of airport performance
Universal reporting requirements also make it easier to compare airports. Although local situations can differ substantially, it is still of interest to see how well airports manage noise in relation to other airports. Bad performers can be identified. This can provide an extra incentive for airports to increase efforts to reduce noise.

What should be reported?
Local authorities should make a clear public statement on noise policy. Included should be:

- Why are limits as they are?
- What are the long term noise limit policy objectives?
- How does the airport intend to meet, manage and enforce these limits?

6.6 Conclusion and additional recommendations

The scheme we propose is composed of the following elements:

1 *A locally set limit to the absolute number of exposed people within several L_{den} contour zones*, including a supplementary measure indicating the number of annoyed people.
2 *Locally set limits to night time noise*, based on two indicators:
   a An indicator limiting the number of noisy events to which anyone is exposed during the night (NAx).
   b A Person Events Index (PEI) limiting the total noise load per night.
3 *An internationally set limit based on the ratio of a measure of exposed area and some volume measure*.
4 *Reporting requirements*.

We also suggest a broadening of possibilities for flanking instruments, such that a continuous incentive can be provided to airlines to fly as quietly as possible, by using the most quiet aircraft and adhering to best available procedures.

We believe that the scheme proposed above offers a good balance between:

1 Allowing for local situations at different airports;
2 Ensuring worst performers can be identified, and appropriate action taken;
3 Providing transparency so that :
   – Stakeholders have a firm basis for planning.
   – Annoyance due to uncertainty is minimized.
4 Providing certainty of protection.
5 Allowing for flexibility for the airport.

We elaborate on each of these issues below.

Allowing for the local situation at different airports
By leaving the responsibility of setting limits to the number of exposed people to the local authorities, full account can be taken of local circumstances. The local authorities are best equipped to do this, and also to balance the limit levels with local land use characteristics.

Ensuring worst performers can be identified, and action taken
By prescribing the noise indicators to be used, transparency increases and comparisons between airports are possible.
Anticipating the results of further research, the relative measure relating exposed area to a measure of traffic volume will further enhance the identification of airports that expose a relatively large spatial area to noise. We feel it offers a necessary addition to the absolute scheme, by making it easier to identify worst performers, thus providing opportunities for benchmarking at Community level to help ensure a level competitive playing field in internal market terms, and to incentivise quieter air traffic. This relative element in our recommended scheme does not guarantee an absolute limit to noise exposure, but it should ensure that disproportionate exposure to noise is highlighted.

Providing transparency so that stakeholders have a firm basis for planning and annoyance about uncertainty is minimised
One important element of the scheme we propose is the reporting requirements and supplementary measures directed at increasing transparency and reducing uncertainty at the individual level. As discussed previously, schemes reliant upon population-related indicators allow flexibility for the airport, but at the cost of uncertainty about noise exposure at the individual level. This can be partly rectified by requiring extensive reporting on future noise policy and flight plans. The supplementary indicators we have proposed are aimed at increasing transparency and increasing the information level, rather than to impose additional restrictions.

Providing certainty of protection
The absolute elements of this scheme provide certainty of protection at the population level and at the individual level at night time. Allowing for flexibility for the airport, and aiming to have the minimum number of people exposed in the long term, may lead to conflicts with certainty of protection at the individual level. This can be partly remedied by setting extensive reporting requirements.

Allowing for flexibility for the airport
The scheme does not limit noise exposure levels at reference points on the ground. Doing this would substantially reduce the flexibility of the airport to expose as few people as possible in the long term. By focusing on the number of exposed people, all noise mitigation measures can be brought into action, leaving the choice for the most cost effective measures to the airport.

Of course, with so many different indicators, care should be taken to ensure that no airports and/or airlines do receive conflicting incentives. We feel that, despite night time noise being covered both by separate indicators and the L_{den} indicator, this will not be a problem in practice.

Additional recommendations
Further to the scheme as discussed in the previous sections, we have the following additional recommendations:
1 Increase opportunities for airport to give incentives for quiet aircraft.
2 Publicise – and manage - breaches of limits.
3 Nominate and safeguard quiet areas.
4 Coordinate land use planning with noise limit setting.

If limits are set tightly at local level, the forecast autonomous growth of the airline industry will provide a continuous incentive to fly as quietly as possible. However, we feel that airports should perhaps have more instruments available to give incentives to airlines to fly as quietly as possible using the latest technology.

To improve transparency, breaches of limits should be dealt with in the public domain (as breaches of noise abatement procedures by airlines already are). It is of even greater importance, however, that plans to manage breaches of planned limits are in place. For example, if the number of people in a given contour is

found through monitoring or calculation to have been exceeded in a given year, it is important to find out how and why that happened (number and mix of movements, population growth, etc), not so much for 'disciplinary' purposes but to avoid recurrence while simultaneously ensuring acceptable continued operations.

A further recommendation is to study the possibilities of safeguarding quiet areas from aircraft noise. Apart from controlling noise in the vicinity of airports, quiet areas in open country further away from the airport, as mentioned in 2002/49/EC, may be protected from aircraft noise at low cost. If such areas or nature reserves are designated, they should be acknowledged and respected in planning and authorising flight tracks, as well as incorporating them in the airport's noise management strategy.

Finally, we must re-emphasise the importance of sound long-term land use planning as a vital element of airport noise management and the achievement of noise limit objectives, particularly when such aims are expressed .in terms of the number of people exposed to noise. It is essential that the authorities responsible for setting limits to the number of people exposed work in close cooperation with the authorities responsible for land use planning.

Illustrative cases for the scheme proposed in this chapter

Volume growth
In the scheme we have proposed in this chapter of this report, volume growth during day time is restricted, just as in any absolute scheme. The restrictions provide an incentive for more quiet aircraft and any other measures that might increase volume capacity, while adhering to the noise exposure limits. In the long run insulation programs and other land use planning measures are also incentivised.

New runway
Plans for a new runway would have had to be made public long before introduction under existing environmental legislation.
With respect to the overall number of exposed people, if local authorities decide to increase limits, additional capacity is created and more people are exposed.
However, the relative element of the proposed scheme also plays an important role. From this relative element, restrictions will be placed on the additional noise exposed area. The airport may not do worse on average, than is was doing before, in terms of 'noise efficiency'.

Technological improvement of aircraft
In case of technological improvement, environmental capacity will increase if limits are not adjusted. The number of exposed people will however remain stable. Night capacity might also increase.

The internationally set relative limits might have to be adjusted to take into account the improved fleet performance.

Glossary

A-weighted

A filter that is applied to the output of the microphone within a sound level meter to simulate the way the sensitivity of the human ear varies with sound frequency, broadly being more sensitive to high frequencies than low. With this filter, the meter output is A-weighted sound level.

Absolute scheme

Noise limiting scheme; without any direct link between the level of the noise limit and traffic or transport volume.

CAEP

ICAO Committee on Aviation Environmental Protection.

Certificated noise levels

The ICAO aircraft noise certification procedure for subsonic aircraft over 5,700 kg requires three separate noise measurements to be made at Approach, Sideline and Flyover locations. The three certificated noise levels (measured in EPNdB, Effective Perceived Noise Level) are determined within tight tolerances and normalised to standard atmospheric conditions.

Dose-effect relation

The relationship between a noise level and a known effect.

dB

Noise levels are measured using the decibel scale. This is not an additive system of units (as for example, metres or kilograms are) but a proportional system (a logarithmic progression). A change of 10 dB corresponds to a doubling of loudness; changes of less than 3 dB are not normally regarded as noticeable.

dB(A)

Units of sound level on the A-weighted scale. Environmental noise measurements and levels are usually expressed using a variation of the decibel scale, which gives less weight to low frequencies and very high frequencies. This system was derived to correspond to the reduced sensitivity of the hearing mechanism to these frequencies when noise levels are low (ie relatively quite). It is now used regardless of the intensity of the noise.

EPNdB

Units for effective perceived noise levels. A complex frequency ad temporal weighting unit, now used only in aircraft certification.

ICAO

International Civil Aviation Organization.

$L_{A, eq, T}$

A-weighted equivalent continuous sound level. Energy average noise level integrated over some specified time period, T.

$L_{A, max}$

Maximum A-weighted sound level.

L_{den}

A measure of 24-hour noise level, based on the equivalent continuous level in dB(A), but with a 5 dB weighting is added to evening period, and a 10 dB weighting added to night time period.

$$L_{den} = 10 * \log \frac{1}{24}\left(12 * 10^{\frac{L_{day}}{10}} + 4 * 10^{\frac{L_{evening}+5}{10}} + 8 * 10^{\frac{L_{night}+10}{10}}\right)$$

In which:

- L_{day} is the A-weighted long-term average sound level as defined in ISO 1996-2:1987, determined over all the day periods of a year.
- $L_{evening}$ is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the evening periods of a year.
- L_{night} is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night periods of a year.

In which:

- The day is 12 hours, the evening four hours and the night eight hours. The Member States may shorten the evening period by one or two hours and lengthen the day and/or night period accordingly, provided that this choice is the same for all the sources and that they provide the Commission with information on any systematic difference from the default option.
- The start of the day (and consequently the start of the evening and the start of the night) shall be chosen by the Member State (that choice shall be the same for noise for all sources); the default values are 07.00 to 19.00, 19.00 to 23.00 and 23.00 to 07.00 local time.
- A year is a relevant year as regards the emission of sound and an average year as regards the meteorological circumstances.

MAGENTA

Model for Assessing Global Exposure to the Noise of Transport Aircraft.

Manufacturer's Empty Weight (MEW)

The weight of structure, power plant, systems, furnishings and other items of equipment that are an integral part of particular aircraft configuration, including the fluids contained in closed systems. The weights of all operator's items are excluded.

Maximum Take Off Weight (MTOW)

The maximum weight at the start of take-off-run.

Maximum Zero Fuel Weight (MZFW)

The total maximum of operational empty weight (OEW) and payload; it is also the maximum operational weight without usable fuel.

Noise

Unwanted sound.

NAx

Number Above X dB. A form of noise contour used to depict the number of noise events above a given noise levels X.

Noise contour

A line on a map depicting level of equal noise.

Noise band

An area on a map between two noise contours.

Noise emission

The noise level emitted by an aircraft.

Noise exposure

Noise levels on the ground, as related to particular noise-sensitive receptors, generally dwellings.

Noise zone

An area within which noise levels fall within a given range. See also noise band.

Noise indicator

A physical scale for the description of environmental noise which has a relationship with a harmful effect.

Noise limit

The level of a noise indicator above which an enforcing authority would consider enforcement action such as implementation of mitigation measures.

Noise limiting scheme

Scheme to set limits to noise from airports consisting of:

- A noise indicator.
- A method for setting the noise limits (resulting in the levels of the limits).
- A monitoring mechanism.
- Enforcement procedures.

Relative scheme

Noise limiting scheme in which the noise limit is linked to transport or traffic volume, either through a noise indicator which is relative itself or through the limit setting method.

SEL

Sound Exposure Level. The sound dose generated by a single aircraft at a particular point. It is a measure of the effect of duration and magnitude for a single event, measured in A-weighted sound level which is within 10 dB below the maximum value.

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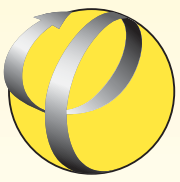

A Consultations

During the study, we consulted the parties listed below on an informal and non-attributable basis, for feedback on the development of our thinking.

We would like to extend our sincere thanks to the individuals and organisations concerned. While we found this consultation process to be of great value, the responsibility for the interpretation of the opinions expressed and the conclusions we drew from them of course remains our own.

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B Noise mitigation measures

Noise limits aim at limitation of noise nuisance of airports by giving incentives to implement noise mitigation measures.

To be able to assess the effectiveness and flexibility of different noise limit schemes, we need to have an overview of the different mitigation measures that can be taken at airports.

Therefore, this chapter provides an overview of the current noise mitigation measures in place at airports across Europe, with comments on the best practice methods to be employed within each.

B.1 Overview of existing noise mitigation at European airports

The overview in this chapter has been reported under headings corresponding to the elements of the 'Balanced Approach' to reflect current EC policy.

It will show that the current situation is rather fragmented with a wide range of practices being adopted at airports across Europe. Careful consideration may be required in attempting to harmonise both noise mitigation measures and noise limits because the environmental noise burden placed on the communities around airports varies hugely. There may be numerous factors to consider, but the amount of noise (quantified by a metric that is indicative of its effect), and the size of population affected should be included.

We present current schemes at European airports, categorized by means of the four elements put forward in the 'balanced approach'. Agreement was reached on the balanced approach in ICAO Resolution A33-7[45] and was reconfirmed in the most recent resolution A35-5. It recognises the need for individual airport noise management measures and setting out a framework of principles and practices for their implementation. Appendix C of the resolution sets out the elements or (implicit) 'phases' of the balanced approach, Appendix E homes in on the fourth 'phase', local noise-related operating restrictions at airports.

The elements of the balanced approach are listed (broadly from 'upstream' to 'downstream', or from general to particular) implicitly in order of desirability and thus applicability:

- Reducing noise at source through research and development.
- Land-use planning to keep the people away from the noise.
- Noise abatement procedures (as developed in CAEP WG2).
- Operating restrictions (supported by cost/benefit analysis) as a last resort.

[45] ICAO 33rd Assembly Resolution A33-7 'Consolidated statement of continuing ICAO policies and practices related to environmental protection', including Appendix C 'Policies and programmes based on a 'balanced approach' to aircraft noise management' and Appendix E 'Local noise-related operating restrictions at airports'.

B.2 Limitation of noise at source

One of the most effective methods of mitigation is the limitation of noise generation at source. This is particularly relevant to airborne aircraft, where the opportunity to screen the noise transmission path is not available. Noise control at source is currently applied to aircraft noise mitigation in the following way.

B.2.1 Chapter II Phase Out

The gradual removal of the noisier aircraft types from service has historically been implemented under an EC managed Chapter Phasing program reflecting stringency limitations agreed at ICAO. Each aircraft type is assigned to a given chapter depending upon its noise output and weight. The weight affects the chapter compliance of an aircraft by allowing those with a larger weight handling capacity to generate more noise within a given chapter. Restriction on the registration of non-Chapter 2 compliant aircraft came into force across Europe in 1988. The gradual removal of Chapter 2 aircraft commenced in 1994 and was completed across all EU Member States on 1st April 2002, with some exemptions, including Accession Member States.

Whilst the noise emitted by aircraft has been subjected to continuously tightening emissions limits for a number of years, the physical volume of air traffic has continuously increased, as have aircraft sizes, thus eroding the overall community noise benefits, in some cases almost entirely. No further chapter phasing out related to noise limitation issues is currently agreed. Unless action is taken the predicted growth in aircraft movements is likely to continue to erode any benefits of the Chapter 2 phase out and cause a worsening in the noise climate at many airports in Europe. Some airports are already seeing noise contours growing year on year. ICAO's own analysis highlights that, without any further action, the number of people affected by aircraft noise in Europe will have increased 42% by the year 2020. Currently, the only restriction adopted by ICAO is that Chapter 3 stringency be increased by a cumulative margin of 10dB with applicability from Jan 1st 2006 to form Chapter 4, but without an associated phase-out of noisier aircraft. This Chapter 4 has been established for certification of new aircraft and not for as a basis for the introduction of operating restrictions.

Directive 2002/30/EC also gives the possibility to ban marginal compliant aircraft (5dB or less below the Chapter 3 restriction).

B.2.2 Hush Kits

Hush kits are sometimes employed, which modify the aircraft engine to reduce its acoustic output. These have found use in bringing aircraft into more or less marginal compliance with Chapter Phasing programmes.

The use of hush kits can produce useful noise reduction at source, but substantial reductions require new engine designs. Over the years, since the original 'pure jet' engines of the 1950s and 1960s, this has generally been

achieved through increasing the by-pass ratio, allowing a smoother mixing of the propelling air stream. Substantial noise reductions of 10-20dB have been achieved in this way, but future reductions are likely to be smaller. There may be limits as to how high by-pass ratios can be for various reasons, some of which may conflict with the other environmental issues of pollutants affecting air quality; higher by-pass engines are larger, and of increased mass, so can increase (absolute) aircraft fuel consumption, although they tend to be more efficient in terms of specific fuel consumption. By-pass ratio also affects fuel burn conditions, which can in turn affect NO_x and other pollutant emission rates.

B.2.3 Best Practice

A best practice approach is difficult to identify within noise at source mitigation measures and procedures. Many of the benefits available have already been achieved through improved aircraft and engine design over the last 40 years and a step change in noise emission levels would require new technologies and many years to implement. It is however noted that some military aircraft (e.g. stealth types) have very low noise emission levels.

It is perhaps fair to state that tightening the continual program of phasing out of the worst offending aircraft within the current Chapter would ensure a continual commitment to noise at source mitigation, and this will help to drive the development of new technologies that achieve noise reduction at source.

B.3 Land use planning and management

B.3.1 Land use Planning

Generally, noise generated from airport activities needs good land use planning, providing adequate spatial separation of noise sources and noise-sensitive areas. However, suitable land for the construction of new airports is scarce and is usually found only at some distance from the cities they serve. Montreal Mirabel airport, at a distance of 80km from the city centre, was one of the first examples of the sitting of a new airport where the total area of land purchased included the area to be impacted by noise, in this case 300 km^2.

Where noise problems occur around an existing airport or where spatial separation cannot be used to affect a satisfactory solution, other land use management options can be employed. These include the following:

- Negotiated and compulsory purchase of land and property by the airport authority. This permits the proprietor to develop the land with a more noise compatible use.
- Financial compensation, whereby the property owner receives payment in return for permitting the over-flight of aircraft.

The last option listed cannot be viewed as a noise limitation method per se as the noise and the effects still remain.

B.3.2 Land Use Zoning

As a refinement, land use planning can be based on zoning of the land surrounding an airport. In Germany, for example, certain airports use two fixed protection zones, which are allocated such that zone 1 has a noise level of 75dB or below, and zone 2, 67dB or below.

Land use within these zones is restricted. In zone 1, no housing is allowed and in zone 2, this is only allowed if the buildings are insulated. Amenities such as schools and hospitals are not allowed in either zone. France and the UK follow a similar policy, using a varying number of zone categories.

B.3.3 Insulation to Properties

Around many of the larger EU airports, domestic dwellings that are seriously affected by noise are eligible for a grant for improving sound insulation to limit internal noise. The methods of sound insulation involve improvements to the sound insulation of windows and doors along with roof insulation and the attenuation of roof ventilation and blocking of chimney flues. The provision of fixed or multiple windows will often require additional ventilation by fans. Some airports may also have noise insulation schemes for Schools.

B.3.4 Landing Charges

For some years noise charges have been applied to civil aircraft operations by incorporating a charge that depends on the aircraft's noise level into the landing fee. The aim is to provide an incentive to encourage operators to reduce operational costs by lowering noise emissions, normally in the form of the choice of aircraft. The charges collected are sometimes used to help fund alternative noise mitigation measures such as sound insulation of buildings. Several European countries adopt this method, whereby the fee is divided into categories according to the noise emission of the aircraft type. The overall aim of noise-related aircraft charges can be summarised as follows:

1 To encourage airlines to retrofit or replace their noisiest aircraft and to assign their noisiest aircraft to long haul journeys (therefore minimising the landings giving a rise to a noise charge), or to locations where no noise charges are collected.
2 To encourage aircraft manufacturers to develop and produce quieter aircraft.
3 To assist with the funding of sound insulation, re-housing and various measures aimed at protecting airport neighbours from noise.

[CE, 2000] argued that noise charges are generally neither efficient nor effective. They are not efficient because charge levels do generally not correspond closely to the noise level of the aircraft. Furthermore, noise charges are generally not effective because charge levels are not derived from the environmental goals.

B.3.5 Best Practice

Best practice in terms of Land Use control should preferably be in the consideration given during the design stage of new airports, to ensure a suitable location is found for construction. Existing airports are often restricted by the surrounding land use for properties and commercial purposes and in this instance land use controls are quite limited in what they can achieve. Appropriate importance must also be placed on the other mitigation options, such as ground operations and flight paths, to minimise the impacts on the surrounding land users.

Insulation and landing charges do not really have best practice approaches, as the other measures do. Insulation is a direct mitigation to the noise problem, whereas landing charges do not really mitigate anything unless the money collected goes on to fund insulation schemes, which is not always the case.

B.4 Noise abatement operational procedures

There are several ways of limiting aircraft noise by adjusting the way in which they are flown. These are called operational procedures or operational means.

Note the distinction we make in this report between operational procedures and operating restrictions (see also section B.5). Operational procedures are to mean changes in the way a specific aircraft is flown during a specific trip. Operating restrictions are directed at the type and timing of operations permitted.

B.4.1 Take off and landing procedures

Aircraft produce their loudest emissions during takeoff when close to full power is used. If residential or other sensitive areas are situated close to the airport, the aircraft will not have climbed to a sufficient height when crossing them and noise limitation measures are needed.

There are several best practice methods that can be applied to these procedures. For example, engine power can be reduced once a safe height has been reached and the climb is continued more gradually. At most major airports this ‘climb-out’ technique is controlled using noise-monitoring stations under the departure routes, which indicate whether the prescribed climb profile and engine power settings are followed.

The ICAO Noise Abatement Take-Off Climb Procedures allow operators a choice of when to reduce engine power and make changes to flap settings after take-off. This process is usually referred to as ‘Cutting Back’ and is divided into two procedures, namely A and B.

Procedure A allows for cutback at a height of 1,500 ft and Procedure B at a height of 1,000 ft. These are known as ‘distant’ (A) and ‘close-in’ (B) abatement options. Because thrust determines noise emission levels, the comparative

benefits of these options depend on the distribution of populated areas around the airport.

The application of procedure A, increases noise in inner contours, but shrinks the outer noise contours of the airport as a whole; this is of benefit when the majority of the surrounding communities are located in the outer noise contour bands and not situated in close to the airport. Applying procedure B extends the outer noise contour, but lowers the inner noise contour impacts. This is of benefit when the majority of surrounding communities live close in to the airport boundaries.

For arrivals, there are recognised low noise procedures, involving Continuous Descent Approach and low noise low drag techniques. Compliance with these is a complex matter as several parties are involved, including airlines, pilots and air traffic control. Pilot preferences vary, and the quietest techniques can potentially conflict with safety requirements. One approach currently used, is to publish a best practice guide and seek general compliance with it within operational and safety constraints. This can be seen in practice in the regular meetings of representatives of airlines, manufacturers and pilots' associations to explore new operational procedures and techniques in international fora, at the technical / professional level.

B.4.2 Reverse thrust

At some airports reverse thrust is used upon landing to rapidly reduce aircraft speed. However, this produces a large noise event at ground level and, at airports with noise sensitive areas nearby, this can give rise to problems.
Some airports apply thrust reversal controls as part of their abatement plan and several restrict reverse thrust procedures, particularly at night.

B.4.3 Flight Patterns

Controls on flight paths are sometimes applied where certain departures and arrivals occur over densely populated areas. Noise Preferential Routes are often prescribed to avoid populated areas. For noise abatement purposes, the flight tracks are most useful for departures where there is more flexibility on routing. Airports monitor compliance with these preferred routes with sophisticated noise and track keeping (NTK) systems.

At some airports a rotation of operating runways may be used, with flight tracks distributed in a more or less equal pattern, in an attempt to spread the noise geographically evenly across the surrounding communities. In other cases, runways can sometimes be alternated preferentially to reduce operations over more populated areas. Runway rotation is of course limited by the wind speed and direction on a day-to-day basis.

B.4.4 Best Practice

Best practice in terms of operational means depends very much on the given situation. For instance, flight Procedure A or B should be selected based upon the location of the local population. If the runway length allows the avoidance of reverse thrust use, then this should be applied. Choice of runways should be used to best achieve the most limited (or perhaps evenly distributed) noise disturbance to the local population wherever possible. Noise preferential routes often provide benefits and reduce complaints. A good understanding of the local population spread is essential to allow the best adoption of take-off climb procedures and flight path headings.

B.5 Operating restrictions

Operating restrictions usually take the form of some kind of time-related limit that is applied to aircraft flight operations.

B.5.1 Curfews

Application of curfews relating to the restriction of operating hours is common across Europe especially during the night-time period. These range from partial curfews, such as found at Birmingham in the UK, where a maximum number of 4,200 movements a year are allowed between 23:00 till 06:00, to complete and total curfews such as found at Berne in Switzerland where no flights are permitted between 23:00 and 06:00 every day. Total curfews may be a more feasible option in a region with more than one major airport.

A partial curfew is often applied where the airport permits certain operations at night, based upon the type or class of aircraft. For example, scheduled departures of noisy aircraft may be prohibited whilst quieter aircraft are permitted. Some airports place a restriction on the total number of operations over a selected time period, such as during the summer season.

Restrictions in many countries are not limited to civil aircraft only. In rare instances complete curfews are in operation restricting any aircraft movements, usually at night.

Suggestions were recently made by some members of the European Parliament to ban all air transport movements during the night (23:00-06:00). Disadvantages arising from such action would include the difficulties arising in the scheduling of long-haul flights crossing multiple time zones, and the financial and logistical affects on the ‘Next Day’ and ‘Just in Time’ express delivery service industry, as well as mail, all of which are heavily active during the night.

B.5.2 Ground Operations

Airport ground operations can also create a noise disturbance to the surrounding community. The sources of ground noise include engine testing and run up prior to taxiing, and aircraft noise on apron and terminal stands.

Methods of controlling the noise from these operations include the re-orientation of aircraft for run up procedures, relocating the aircraft away from noise-sensitive areas, or the use of suppressors and barriers. There are also time based restrictions in place at some airports, such as at Cardiff in the UK, where restrictions are imposed on the ground running of engines between 2230-0700 unless permission is given by the airport manager.

Other ground operations are controlled using space to separate noisy operations from noise sensitive areas, and the use of buildings and screens to shield the noise.

B.5.3 Best Practice

The most appropriate approach to best practice applied under the heading of Operating Restrictions, is to consider local situations as suggested for Operational Procedures to assess the use of the methods available to obtain the most effective results to a given situation. However, operating restrictions will directly affect the level of service the airport can provide and so may need careful balancing against the disadvantages this may create for the local or wider economy, as well as to the airport company.

C Noise emissions permit trading

C.1 Introduction

In this Annex we briefly discuss noise permit trading. Lately, more and more emphasis is being put on market-based options and efficient allocations. Emissions trading is sometimes seen as the all-resolving cure. For this reason, it is certainly of interest to see if emissions trading could be helpful in the context of noise around airports.

There are basically two types of noise permit trading schemes. First, there is an *intra-airport* trading scheme, in which airlines can trade noise emission permits related to their movements at that airport. These permits reflect the right to emit noise at a certain airport. Such a scheme would provide an efficient allocation of noise emission permits at a certain airport, *given* a total cap of noise emission permits at the airport. Hence, it is not really a noise limiting scheme, but it could be an instrument to ensure an efficient allocation of noise permits, given a limit on total noise.
There is however one exception in which an intra-airport trading scheme could be interpreted as a noise limiting system. If, besides airlines, other parties such as the community are also allowed to hold permits, then by buying permits the community can reduce the total noise allowed at the airport. This may not be very practicable, as once noise permits ('environmental slots') become associated with operational slots to give them validity, their value equates, and the community might effectively be trying to 'buy' the airlines' profits from their prime slots. We discuss this option briefly in section C.2.

The second type of scheme, an inter-airport trading scheme, would allow airports (or possibly airlines) to trade permits to emit noise at *any* airport. This could lead to an efficient allocation of noise around European airports, but would not ensure certainty of protection at any given airport. An inter-airport trading scheme would thus take away any influence of local governments on the noise burden for its citizens and is hence a very unlike option from a political perspective. For this reason we do not elaborate on this option.

Note that neither of the above options contribute significantly to further the study and design of a uniform noise limiting scheme for Community airports. An intra-airport trading scheme could be of use once the noise limits at an airport are set, to induce an efficient allocation. The second option, an inter-airport trading scheme, might give undesirable results because no certainty of protection can be given at a particular location.

C.2 Intra-airport noise emission permit trading

Intra-airport trading of noise permits would allow trading of noise permits between airlines. After the initial allocation of permits over airlines, given the total noise cap at the airport, airlines can trade permits. Airlines that fly with relatively quiet aircraft might increase the number of flights, or might sell permits to airlines that fly with relatively noisy aircraft.

Such a scheme would therefore provide airlines with an incentive to fly with relatively quiet aircraft. Airlines are thereby encouraged to make the most use of the possibilities to increase their services without breaking the total noise cap at the airport.

The primary goal of this study was however to sketch options for noise limiting schemes at airports. Options on how these noise limits can most efficiently be met are beyond the scope of this study.
However, intra-airport noise permit trading is briefly discussed because setting noise limits is always a trade-off between benefits for airlines, airports and 'flight-consumers' on the one hand, and environmental disbenefits for the surrounding population. If people exposed to noise are allowed to enter the trading scheme and buy permits, this trade-off is made explicit. The community can theoretically buy and remove permits from the market, thus reducing total noise around the airport.

Irrespective of the initial distribution of rights, this would lead to an efficient allocation of rights[46] (or noise emission permits in this case). In this manner, noise permit trading could lead to an optimal allocation of noise and thus be a very efficient way of setting noise limits.

C.3 Conclusions

That emissions trading is not the all-resolving cure in the case of noise around airports may well be because it essentially fails to address the basic problem. This problem is not the efficient allocation of noise emissions between airlines, but the exposure of population (and/or areas) to noise. Thus an inter-airport emissions trading scheme can be dismissed in this context, and the limitations of an intra-airport scheme recognised. Some sort of absolute cap is always required to give certainty of protection.

[46] Of course, the initial allocation of rights does influence the outcome for the level of welfare of the parties.

D Shortcomings of L_{eq} as an Indicator of Noise Impact at Night

L_{night} is the 8-hour A-weighted Equivalent Noise level ($L_{Aeq,\ 8\ hour}$), and under directive EC2002/49 the 8-hour period is 2300-0700 hours by default, but can be shifted by up to 2 hours forwards or backwards. The directive requires Member States to report population exposure to various ambient noise sources using L_{night}, as well as L_{den}. Whilst the $L_{eq,\ period}$ family of noise metrics have been shown to be good indicator of community noise effects (particularly annoyance) for some types of noise, there are reservations about how well it indicates aircraft noise effects at night. Annex 1(3) of Directive 2002/49/EC states:

'In some cases, in addition to L_{den} and L_{night} and where appropriate L_{day} and $L_{evening}$ it may be advantageous to use special noise indicators and related limit values'

Aircraft noise, particularly at night, is unlike other types of ambient noise such as road traffic because it comprises a series of relatively infrequent noise events. L_{Aeq} (and therefore L_{night}) is a sound energy-based metric, in fact a logarithmic average. Being logarithmic it gives a heavy bias to peaks, but if there are few peaks in an 8-hour period (as is often the case for aircraft noise near an airport at night) then the resultant $L_{Aeq\ 8\ hour}$ bears little resemblance to the peak levels because of the disproportionately long averaging period. The major community effect of noise at night is sleep disturbance (eg. changes of sleep state, sometimes termed 'awakenings'). If a person is asleep other effects, such as speech interference, loss of concentration etc, cannot occur. It is because sleep disturbance depends on the peak noise level, that L_{Aeq} based metrics such as L_{night} may not be the best indicator of night noise impacts for aircraft noise near airports.

Directive 2002/49/EC goes on to state that metrics such as SEL and L_{Amax} should be used:
'*for night period protection in the case of noise peaks.'*

UK research has shown that around airports there is little sleep disturbance below L_{Amax} (ie 'peak') levels of around 80 dB (strictly speaking SEL, Sound Exposure Levels, 90 dB). At levels above this, roughly 1 in 75 aircraft noise events creates an awakening (ie a disturbance in sleep state). Let us consider two cases:

Airport 1 – has 2 movements of 747-200 aircraft per night, each producing levels of L_{Amax} 80 dB in a particular residential area.

Airport 2- has 20 movements of much quieter BAe 146s at night, each producing only L_{Amax} 70 dB in a similar residential area.

Considering sleep disturbance in terms of L_{Amax} it is clear that in the Airport 1 case there is likely to be some sleep disturbance (the rough number of awakenings would be 2 x 1/75 x population effected), whilst at Airport 2 the aircraft are not noisy enough to make people up. The L_{night} levels for the two cases are in fact the same, 48 dB, and do not identify the large differences in their sleep disturbance potential.

Clearly, if two airports have similar numbers and fleets of aircraft then this shortcoming of L_{night} as an indicator of sleep disturbance would be less severe. Equally, L_{night} might be a reasonable indicator of some effect such as annoyance, which tends to accumulate through the exposure period. However, given that communities sleep at night, the key night noise effect for aircraft noise should be sleep disturbance, and since airport night operations can vary considerably in terms of aircraft types and numbers, L_{night} as a metric is not considered to be an ideal indicator for airport noise effects at night. Indicators aimed at numbers of awakenings might be preferable.

The UK research on noise levels that cause sleep disturbance has been criticised for not considering the late evening and early morning (so called 'shoulder hours') fully. There is evidence that sleep disturbance can be more acute in these periods, and perhaps occurs at lower levels. So any indicator aimed at estimating numbers of awakenings may need to be sensitive to the time of night variations in sleep disturbance sensitivity too. Reliance on L_{night} as a single metric indication does not support these findings as L_{night} is not sensitive to the time of night.

It is clear that a multi metric approach needs to be used in the assessment of night noise impacts arising from aircraft movements, in order to fully quantify its effects on the surrounding airport populations.

E Overview of supplementary metrics for transparency of noise policy

Supplementary Metrics

In the main part of our work, we have suggested that the main measure of noise should be L_{den}. L_{den} is a measure based on L_{eq}. L_{eq} has been found to be no worse than any other noise measure and has been adopted in many of the Member States. However, it should be noted that L_{eq} contours do have shortcomings. They have been criticised for not giving clear information to the lay person about the actual number of aircraft overflying an area or the level of individual events. L_{eq} contours do not show the main flight tracks and can therefore be confusing to interpret. L_{eq} values are also dependent on the averaging time period, and long averaging time periods can make the L_{eq} value insensitive to infrequent high noise events.

Supplementary metrics have both been mooted and tested by a group in Australia. Their primary aim being to provide information that was transparent, easy to interpret and meaningful to the all including the layperson. They are intended to add information to the L_{eq} contours. Here we give brief details and examples of the some of useful metrics recommended in the Australian guidance, and suggest that those authorities providing information on the absolute limits, may which to consider additional metrics when disseminating information to the public or when setting limits. These have been tried and tested both in the Australia, some areas of the US and at some EU airports. The metrics could prove useful in monitoring trends, or pinpointing local problems or specific improvements at locations or at different times of day – this aims cannot be fulfilled by using Leq contours alone. Full information, including a discussion of the pros and cons of using these metrics and guidance to users, can be found at http://www.dotars.gov.au/avnapt/sepb/and/downloads.htm.

F Non-noise specific information - Flight path movement charts

Essentially these charts provide simple information on where the aircraft fly and how many overflights there are. These can be calculated for an average day or for specific sensitive times. Examples of the range of information are given in the following charts below.

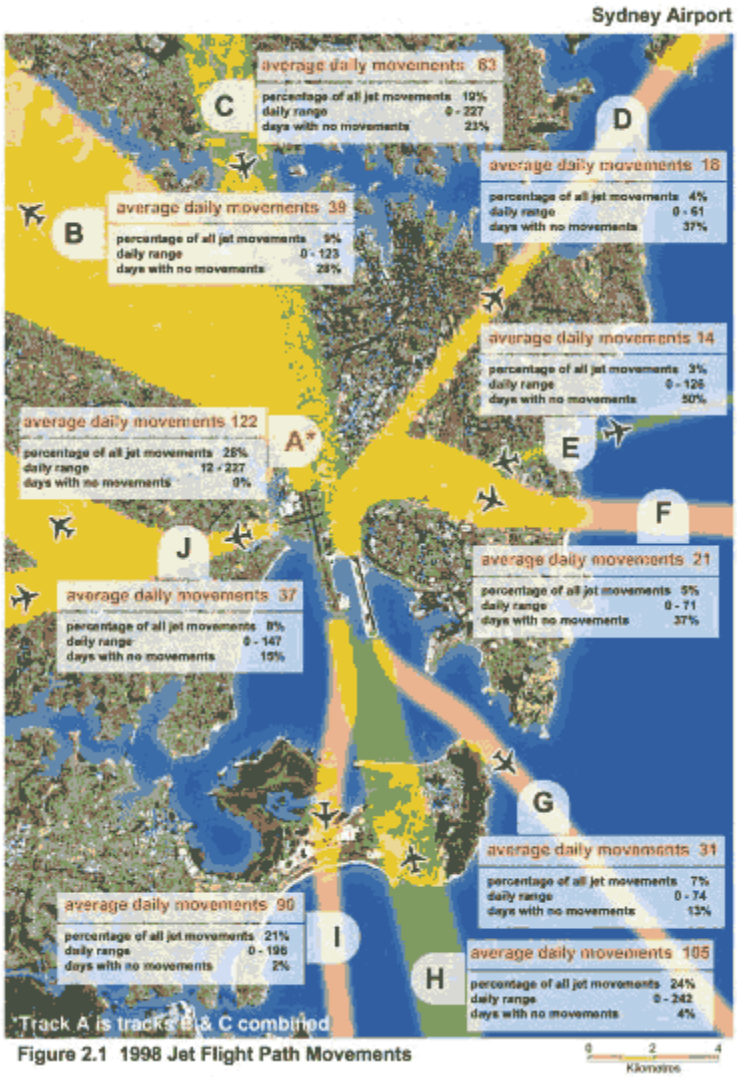

Figure 2.1 1998 Jet Flight Path Movements

This next example is for sensitive times' (defined for this example as 6am-7am & 8pm-11pm on weekdays and 6am to 11pm on weekends).

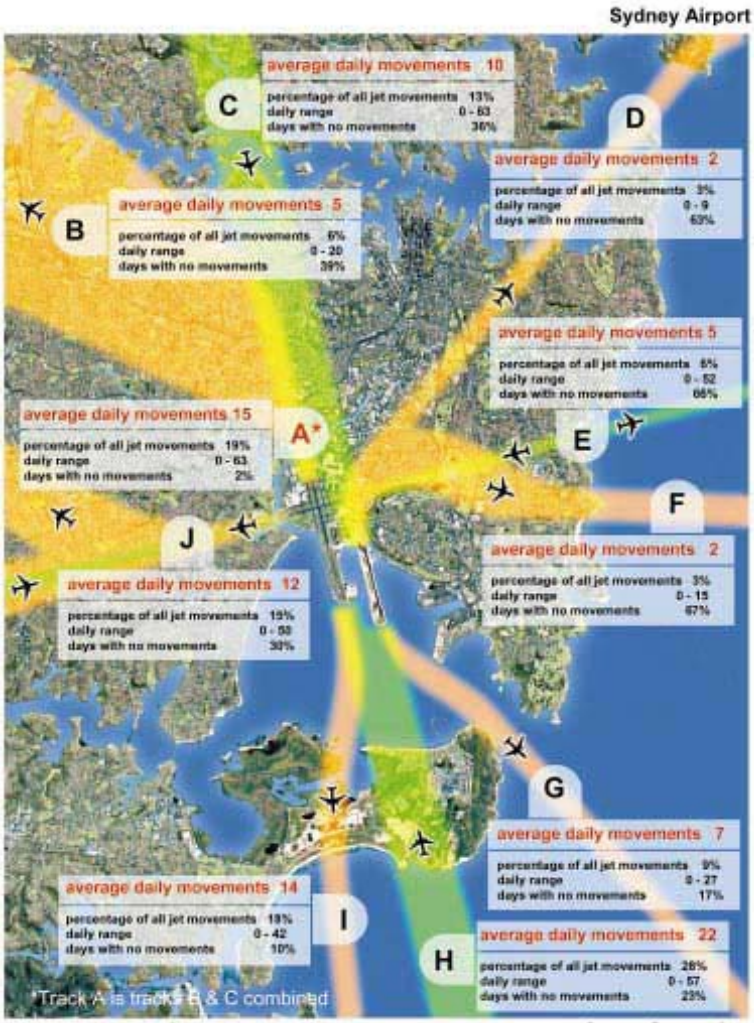

Figure 2.6 1998 Sensitive Hours Jet Flight Path Movements

F.1 Comparison information showing Movement Charts with Noise Contours

The next example shows how the movement charts can be added to the noise contours to give additional information outside the contour areas.

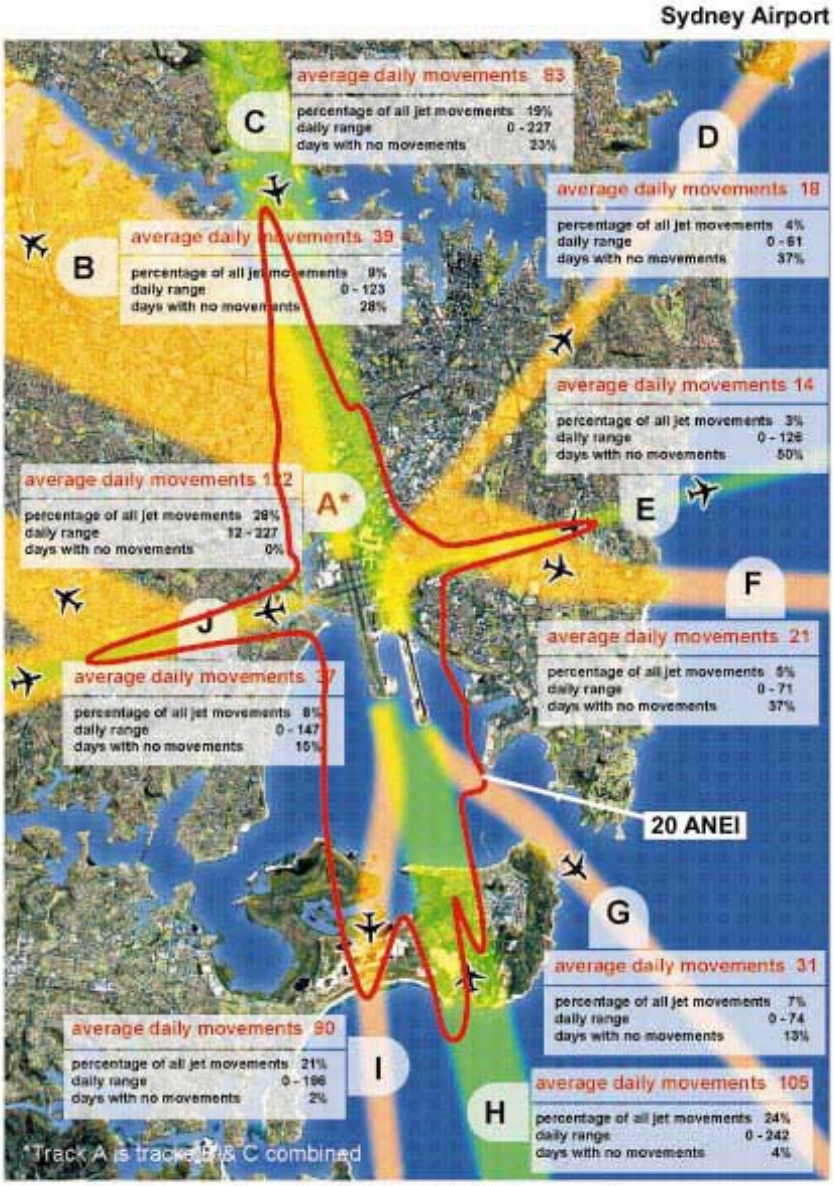

Figure 2.7 Comparison of 1998 Flight Path Movements and 1998 ANEI 20 Contour

F.2 Respite Hours

This measure is intended to give an indication of the 'rest' from exposure to aircraft noise - again a measure not shown up with an Leq descriptor. The Australian approach is to compute the number of whole clock hours (eg 7am to 8am) when there are no movements on the particular flight paths and reporting these as a percentage of the sum of all the clock hours in the period in question. For example, if there were no movements on a particular flight path during 50 clock hours in a 100 clock hour period then it would be reported as 'Respite Hours 50%'. Alternative computations could be adopted. An example chart for respite is given below.

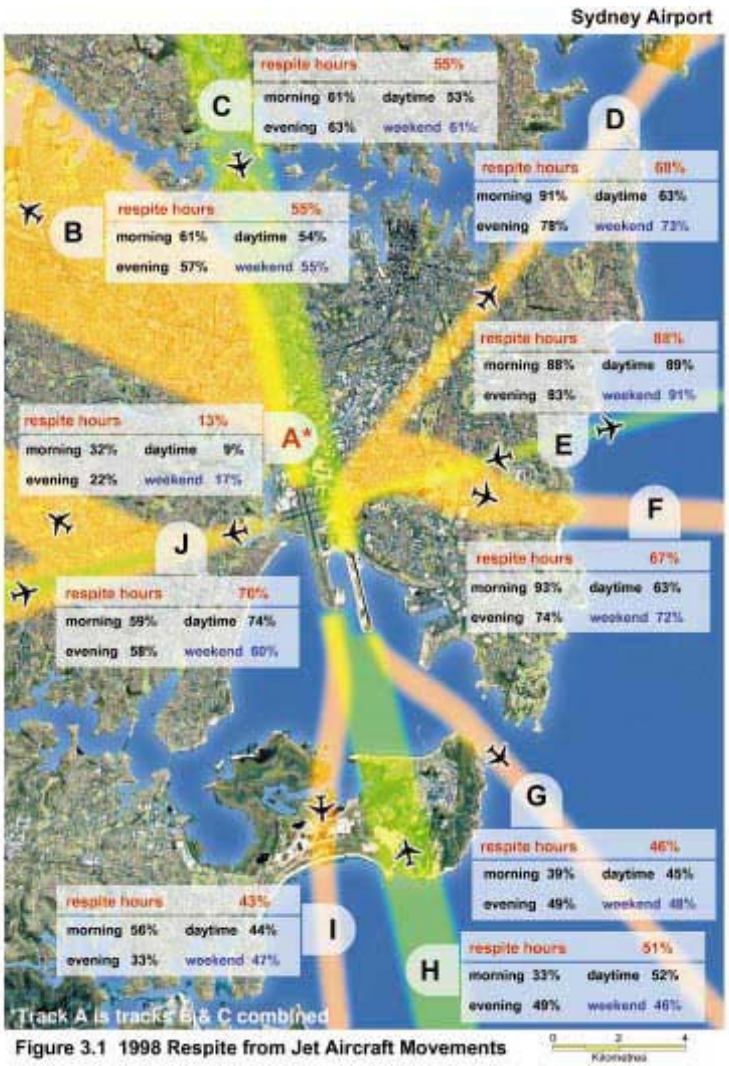

Figure 3.1 1998 Respite from Jet Aircraft Movements

F.3 The N70 - Combining Movement Numbers and Noise Levels

L_{eq} contours do not give information about single event levels, and therefore the impact of one individual noise event is 'lost' within the averaged L_{eq}. The Sound Event Level (SEL) for a single event can be shown as a 'footprint' over the geographical area. An example is given below of departing A320 at Vancouver airport.

However a noise footprint does not give any indication of how often such events occur. In order to overcome these problems 'Number Above' contours can be used. These contour maps in effect combine information on single event noise levels with aircraft movement numbers. In the Australian approach contour maps showing the number of events louder than 70 dB(A) have been adopted as the normal presentation i.e. lines showing the number of events above 70 dB(A). Other noise levels can be used, with different combination of times of day as required. Intuitively it is very easy to conceptualise noise impact using an N70 because it reports aircraft noise in the way that a person perceives it - as a series of noise events some of which are perceptibly intrusive. The N70 is particularly attractive to the layperson in that it is an arithmetic indicator. All other being equal things, if the number of movements over an area doubles the N70 doubles - a very different outcome to logarithmic indicators such as L_{eq}. An example for Sydney airport is shown below.

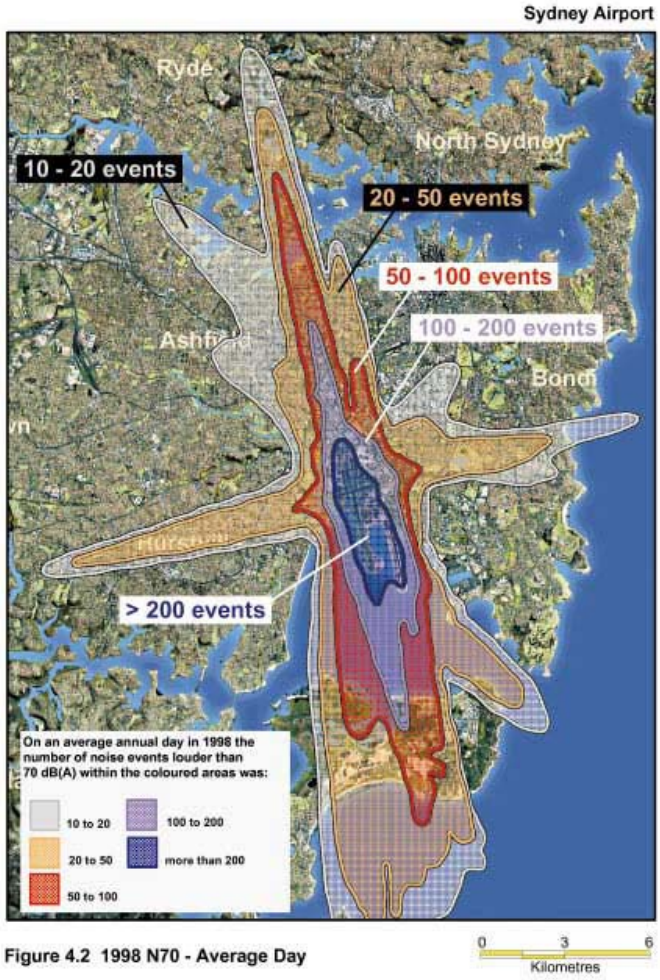

Figure 4.2 1998 N70 - Average Day

F.4 The Person-Events Index - Assessing the Total Noise Load of Airports

This PEI index is introduced in the Australian work and takes the N70 concept further by allowing the total noise load generated by an airport to be computed by summing, over the exposed population, the total number of instances where an individual is exposed to an aircraft noise event above a specified noise level over a given time period. For example, if a departure off a specific runway at an airport by a particular aircraft type leads to 20,000 persons being exposed to a single event noise level greater than 70 dB(A) then the PEI(70) for that event would be 20,000. If there were a further similar event the PEI(70) would double to 40,000 since there would have been that number of instances where a person was exposed to a noise level louder than 70 dB(A). The PEI is therefore expressed by the following formula:

$$PEI(x) = \sum P_N N$$

where

x = the single event threshold noise level expressed in dB(A)
P_N = the number of persons exposed to N events > x dB(A)

The PEI is summed over the range between N min (a defined cut-off level) and N max (the highest number of noise events louder than x dB(A) persons are exposed to during the period of interest).
By summing all the single events at an airport, say for an average day or any time period (say the night), a total PEI(70) (or PEI(80), etc) can be developed. This is referred to further in our recommendations on night-time noise.

The PEI in itself does not indicate the extent to which the noise has been distributed over the exposed population. For example, a PEI(70) of 2 million for an airport could mean that one person has been exposed to two million events in excess of 70 dB(A) (assuming this were possible), or that two million people have each received one event or it could be arrived at by any other combination of the two factors. A summary of the noise distribution is provided by the Average Individual Exposure (AIE) which is given by the formula:

AIE = PEI/total exposed population

The AIE therefore gives the average individual noise exposure in the number of events greater than the specified noise level over the specified time. Again refer to the website report more details.