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Environmental Noise

Main Focus: Aircraft Noise

by

Jorge Guerra González (Ed.)

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Foreword

Following the recent general EU-directive 2002/49/EC on Assessment and Management of Environmental Noise, and thus focusing on noise produced by human activity, the Europäische Akademie zur Erforschung von Folgen wissenschaftlich-technischer Entwicklungen Bad Neuenahr-Ahrweiler GmbH has organised on 12th and 13th December 2002 in Bad Neuenahr-Ahrweiler (Germany) an international and interdisciplinary expert meeting on environmental noise. Special interest was paid to aircraft noise, since it works as a paradigm and paradoxical case: air-travel is a growing noise source and people are nevertheless increasingly intolerant with regard to noise; simultaneously air-travel is to be seen as a core element of a progressively accepted modern mobility, thus endowed with a high economic potential.

At the first session, noise was considered in general and its problematic was lightened from the philosophical (Professor Dr. Klaus Kornwachs, BTU Cottbus, Germany) and medical (Professor Dr. Barbara Griefahn, University of Dortmund, Germany) point of view. The second session went into more detail and focused on aircraft noise. Its technical, economical and juridical aspects were respectively clarified by Dr. Dietmar Wurzel (DLR, Germany), Professor Dr. Rainer Friedrich (University of Stuttgart, Germany) and Carlos San Martín Castaño (Aena, Spain). Last but not least, the meeting counted additionally with the guest expertise of Professor Dr. Helmut Strasser (University of Giessen, Germany).

On the basis of the results of this expert meeting, the Europäische Akademie has founded a two-year transdisciplinary research project on environmental noise, focusing on aircraft noise.

Bad Neuenahr-Ahrweiler, March 2004

Jorge Guerra González

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Introduction

„What a peaceful life the one's who escapes away from the worldly noise" Fray Luis de León (1527-1591)

If noise may be defined as unwanted and/or harmful sound, we may understand with the EU directive 2002/49/EC of the European Parliament and of the Council of 25th June that environmental noise is that unwanted or harmful outdoor sound created by human activities, including noise emitted by transport (i.e. mainly road, rail and air traffic) and from sites of industrial activity.

Noise is potentially dangerous to human beings, for despite its *subjective* valuation, it *objectively* affects physical and psychical human health, since the human brain perceives and the body reacts to noise even if the person does not feel annoyed by it. Sleep disturbance – and its consequences –, cardiovascular problems or hearing loss are some of the adverse effects connected with noise. Furthermore, given that the auditory channel is undoubtedly even more important and essential than vision for the social and mental development of people, noise constitutes an obstacle to social life, e.g. by obstructing communication or impairing performance.

Over a relatively long period of time already, public awareness and concern with regard to these facts has been steadily growing and the 'noise discourse' has become more and more important. As a consequence thereof, national and international policies have changed and a considerable number of legal instruments have been applied in order to reduce noise emission and exposure to noise for the purpose of health protection. These measures have been undertaken in conjunction with others in dealing with the protection of the natural environment and improving the quality of life which also indirectly act on the noise problem. Though great strides have been made, more progress is still needed, for despite those legal measures public unease concerning noise has not decreased.

The Europäische Akademie is aware of the relevance of this issue and therefore willing to contribute to its comprehension and solution. This volume of the "Graue Reihe", as a result of the expert meeting on environmental noise held in Bad Neuenahr-Ahrweiler on 12th and 13th December 2002, aims at bringing closer to the general public an overview of the main issues concerning noise: its philosophical, medical, psychological, technical, economical and legal aspects.

The expert meeting was opened by Professor Dr. Klaus Kornwachs' philosophical reflections on the noise problem. He underlines first of all the difference between what is subjectively and objectively considered noise. Anthropology – and thus all factors that may influence culture and cultures – may play a significant role if the goal is to find out when and how different individuals perceive noise. Nevertheless, even if it is indubitable that noise may objectively damage human health, no clear correlation is to be observed between noise acceptance and health damage. Not even the "objective" factors are entirely unambiguous, since noise measurement, or the consideration of threshold values are valid only relatively or they may even hide unwanted facts – e.g. by not considering the accumulative effects of noise sources on health. Professor Kornwachs concludes his observations with some ethical aspects to be taken into account in the noise normative discourse.

Professor Dr. Barbara Griefahn shows in her paper on the medical aspects of noise the enormous problem complexity from the human health point of view. The effects of noise can be aural (noise-induced-hearing loss) and extra-aural (e.g. communication or sleep disturbances, performance decrease or development of chronic (cardiovascular) diseases. The problem is often that these effects are non specific – they might also have other causes – and this will make it more difficult to take any effective measures. This is of paramount importance, because the measurement of dose-effect results will only be partially objective if those results depend on different environmental noise stressors. Moreover, it is difficult to measure dose-effect relationships caused by irregular noise sources or to report on the consequences on health of in principle tolerable but permanent noise sources. Finally, it is clear that the subjective annoyance level varies from individual to individual.

Taking all this into account, Professor Griefahn makes concrete proposals on noise limits to be observed in various circumstances. Three roughly defined noise level values, – from intolerable for human health until tolerable in any case – critical loads, protection guidelines and threshold values are suggested.

Going into more concrete terms, Dr. Dietmar Wurzel focuses on technical developments in the field of aircraft noise reduction. The conflict between the goal to increase human mobility and an increasing concern and intolerance towards noise exposure is the background against which technical – or, more generally, scientific – developments aiming at aircraft noise abatement are needed. With this target in view, the only achievable goal in the long term would be to design such quiet planes that they do not pollute acoustically the environment, irrespective of their number. In this connection, it should be mentioned that modern jet aircraft more than four times quieter than those of the first generation.

What still has to be done on the way to noise abatement in the field of air traffic concerns the engines (turbines, combustion process and jet flow from the exhaust jet), the airframe (or aerodynamic noise which nowadays may be louder than engine noise) and the operational procedures during takeoff and landing.

Professor Dr. Rainer Dietrich explains in his paper the external costs of aircraft noise. External costs are those that are not reflected in the price of goods. It seems certain that most of the external costs of noise on human health and economy (e.g. resource costs, opportunity costs, disutility) are not taken into consideration when talking about noise costs – at least, not by those who produce the noise or benefit from the noise sources. But they probably should be. In view of their large extent and wide diversity, external costs are difficult to calculate; one of the main difficulties being to assess such costs in monetary terms, since some impacts on damage categories do not have a market price. With the help of an impact pathway approach, this paper tries to offer a method to calculate external costs.

Once those costs are calculated, the last important question to answer is how to determine the best way to establish liability and effect compensation.

Carlos San Martín Castaño deals with the juridical aspects of noise, especially aircraft noise, citing the example of the Barajas-Airport in Madrid.

On the one hand, the author stresses, on the one hand, the unavoidability of the risks involved in any action taken, and, on the other hand, the role of Law to limit such risks. Paramount in his reflection is the precautionary principle – established by the EU in 2000 as the essential basis and guiding principle for decision making. In this sense, the judiciary (or the State) should assess carefully when legal action is permissible. Accordingly, preventive action should be taken as a first step to eliminate negative effects on the environment. Legal action should only be taken in the event that such measures prove ineffective.

With regard to (aircraft) noise, the aims are to protect human health and to ensure and maintain a high standard of life quality. For this purpose, several norms and recommendations at international, national, regional and local level constitute the legal framework to be observed. This framework is commented on by the author in his contribution.

This issue concludes with the paper of Professor Dr. Helmut Strasser and Professor Dr. Hartmut Irle. The authors are critical of two assumptions that are often taken for granted but that present several important problems when confronted with reality. First of all, the authors show that although the measurement of sound pressure or intensity in decibels may simplify the representation and calculation of figures by using a logarithmic scale, the results do not correspond to people's noise perception and sensation. Thus using this scale of measurement is not appropriate. Moreover, decibels are based on a physical law that is proven false. In view of this, the authors propose a scale of loudness measurement with linear units based on sensation.

Secondly, and as a consequence of this thesis, the authors are critical about simplifying average measurements and prescriptive threshold limits concerning noise. Above all, in the sense that even when sound intensity and duration of sound exposure may be equivalent, this ignores the human side of the problem, since some theoretical, physical equivalencies may be unbearable for human health.

Some Philosophical Aspects of Noise

Klaus Kornwachs

Abstract:
1. Introduction, 2. The Basic Situation with Noise, 3. Some Remarks on Threshold Values, 4. Ethical Aspects

Reach of sounds

… Again
One need not wonder how it comes about
That through those places (through which eyes cannot
View objects manifest) sounds yet may pass
And assail the ears. For often we observe
People conversing, though the door(s) be closed;
No marvel either, since all voice unharmed
Can wind through bended apertures of things,
While idol-films decline to- for they're rent,
Unless along straight apertures they swim,
Like those in glass, through which all images
Do fly across. And yet this voice itself,
In passing through shut chambers of a house,
Is dulled, and in a jumble enters ears,
And sound we seem to hear far more than words.

Lucretius: On the Nature of Things; Book IV (50 B.C.)
Translated by William Ellery Leonard

1 Introduction

A philosopher, if he is confronted, what can he tell about noise? Within the context of this workshop about environmental noise with particular respect to aircraft noise he must be aware not to "philosophise against" the technological state of the art. The first thing he can do is to investigate the scientific and everyday meaning of the term noise. This is not done in order to find out something about physical or technical facts – this may remain the business of science and technology – but to extract something new in relation to our attitude toward noise and sound influences disturbing and annoying us.

The respective section from Lucretius´ poem "On the Nature of Things"[1] reported above already shows some interesting issues: Noise is distributed around the corner, is diffusing in all directions, dividing itself and filling the space. But sound can be dampened and attenuated – the first step to protection from noise.

The term noise is frequently used in literature as a description for talking unnecessarily (making a noise about something), it is a sound without any utility and very often one may find in poems, as in story telling, that somebody may be horrified by a sudden noise. But noise itself does not seem to be a topic for philosophical reflection besides a more metaphoric use of the term, referring to the "noise of world". A short glimpse into the contemporary use of the word shows a lot of concurrent and side meanings. Noise as a nuisance influence from the mostly man-made environment is also expressed by the terms din or fuss. Noise as it comes from etymology has the same root as nausea in Latin which can be translated in seasickness or nausea.[2] Synonyms with similar meaning are din and fuss, *bruit* (French), ψόφος (Greek)[3], *strepitus, tumultus* (Latin). Shakespeare "Much ado about nothing" may serve as a further illustration for the semantic field of this kind of nuisance. Whereas the use of the term "noise" tends to have negative notations and connotations it may be interesting to look at the field of tension between silence and noise.

Not only philosophers but also everybody knows silence as a necessary condition for reflection and meditation. Not only when temporarily retracting from a noisy world, silence is necessary for work, concentration and good performance. On the other hand, too much silence causes anxiety and the feeling of getting lost. It can be easily tested by spending only a short time within a noise-protected box as used in acoustic research labs or in broadcast studios for special effects. This effect can be massively experienced not only in soundless chambers (increasing of heart rate and blood

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1 Titus Lucretius Carus (97-55 B.C.): *De rerum natura,* lib. IV.

2 *Noise* middle English from Old French "noise", = *nausa* (Provençal), *nausea* (Latin). Cf. The Concise Oxford Dictionary (1975), p. 818.

3 Also θόρυβος (Greek) as noise and unrest.

pressure beside physical and psychical discomfort) but also life in monasteries by those that are not used to be in silence for a long time.

Too much noise obviously impairs our physical and mental existence and therefore it is reasonable to pursue Technology Assessment concerning noisy technologies. The two directions of research are: How to avoid the generation of noise or how to protect ourselves from too much noise already generated? These two questions may again be divided into two classes: How to avoid the generation of noise by avoiding the generating process itself or by attenuating its deliverance? How to prevent already produced noise from reaching our ears or how can we protect our ears if the sound has already arrived?

It has been maintained by the German Umweltbundesamt that the relation between nuisance experienced by aircraft noise, and further impacts with respect to health, which may be supposed within the context of modelling stress, still remains unclear to a wide extent.[4] It is known that in most cases dealing with any emitting technology there is a field of potential conflict between safety and economic viability. The acceptance and attractiveness of a technology will depend strongly on the position within the portfolio, shown in Fig. 1. For short-term considerations, a certain risk or harm may be accepted when set against high economical benefits. In long-term consideration everybody knows that seemingly economical but harmful technology is not cheaper but more expensive than anything else, if one is counting and including the externalised costs.[5] But in noise producing technologies like aircraft the rule holds also for short term estimation: A noisy machine is running without high effectiveness, silence sells better.[6] Thus the aim of Technology Assessment and any programme for shaping better technologies should be to shift the attractiveness line (the dotted line in Fig. 1) to a safe or harmless *and* economical technology.

On the first glimpse this may be rather trivial, but there are some obstacles in doing so, particularly in the field of environmental noise.

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[4] Cf. Ortscheid, Wende (2000), p. 6.
[5] Cf. Lindakers (1995).
[6] Cf. the presentation of D. Wurzel on the Workshop, see also within this volume (2004).

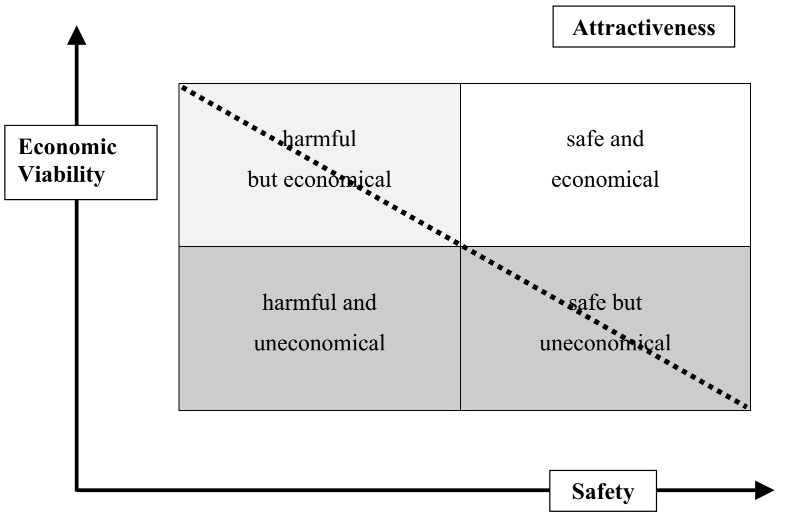

Fig. 1: *Portfolio for attractiveness of a technology (Kuhlmann, 1977)*

2 The Basic Situation with Noise

2.1 Difficulties with the Risk Formula

In order to prepare the arguments, it is necessary to look again at the well known risk formula as it is used meaningfully and predominantly in the field of Insurance Mathematics:

Risk = Amount of Damage x Probability of Occurrence

The amount of damage is generally expressed in terms of losses of life or health, goods, lowered quality of life, harm of personal and/or public welfare, loss of options and potentialities etc. The probability of the occurrence of a damaging event is in the particular case of noise very simple: We have noise, that is for sure. It is rather the question as to what a level a ubiquitous noise is probably inducing a damage. Therefore a consequence of the risk formula is trivial: Risk becomes here a question of the intensity of the cause.[7]

[7] For a review of the risk concepts cf. Banse (1993, 1996). It has been proposed to substitute the term risk by regarding the time dependent variable reliability. It is known that the reliability of each process controlled by man has a time decline dynamics. A damaging event stemming from such a decreasing unreliable process always induces an effect on the reliability of the affected systems. In the case of a group of inhabitants or individuals a disturbance of wellness may be an expression for this decreased reliability. Cf. also Kornwachs 1994, 1996.

The level of damage to be compensated *(kompensierbarer Schaden)* is represented by an estimated amount of money in order to compensate damage (like repair, therapy, health care, money for public installations like bathes or sport grounds etc.). This should be clearly distinguished from the level of damage not able to be compensated *(nichtkompensierbarer Schaden):* This is irreversible damage like the loss of the sense of hearing, body damage, health, capabilities, psychological distortions etc. In this case we consider a payment of damages as money for pain and suffering caused *(Schmerzensgeld),* that is often confounded with "compensation" conventionally (see insurance tables, in case of death say 50 thousand €). In Germany we have a word game: *Eine* ***Ver****sicherung ist keine* ***Ab****sicherung****!*** (An insurance is not a safe maker).

The anticipated damage categories and the mechanisms are known: Reduction or loss of hearing, sleep disturbances, cardiovascular problems, psychological and mental problems, loss of quality of life, long term effects etc.[8] Difficulties to concentrate and to keep attention during teaching and lectures are reported.[9] Any unexpected damage, that cannot be anticipated, should be investigated as far as one has an idea about possible mechanism involved, like low frequency noise in air and solids (infra sonic), high frequency parts (ultra sonic). Extreme cases of damage are not known.

Here, it is not very meaningful to apply the risk formula, since the damage or harm generating process is well known in the case of aircraft noise: The processes within the engines and aircraft in operation are generating waste material and energy (in the form of emissions, heat and noise). They are establishing the technological structures to which they belong, they are man made, i.e. technology driven and the effects produced by them are, for the most part, proximity-dependent.

Because of this strong proximity-dependence, one has a kind of optimising task to balance the interests of the residents to be located near the airport or

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8 Cf. the presentation of B. Griefahn in this volume (2003).

9 According to a non dated dpa – message from January 2003, reported in Süddeutsche Zeitung, München. It refers to a study with pupils, comparing long term memory and reading capabilities of those residing near the new Munich airport since 1992 and those remaining at the old airport location. The latter gained an increasing capacity in these skills after the relocation of the airport.

other economically interesting but noisy centres, on the one hand (whereby a short distance saves time and money) and the nuisance of noise causing stress and harm to health, on the other hand.

2.2 Control of "Risk" and Damage

In Fig. 2 a schematic classification of risk and damage control is given. The two sides of measures are the control of (noise) levels and causing factors on the one hand and the mentioned compensation of the damage on the other hand.

On the left side we are asking: What are the causes for the generating process *(ante factum)?* In the case of aircraft noise, we have lots of factors that can be ordered in a chain of causes, such as: Basic needs (and rights?) of mobility, economical pressure for cheap transport and traffic (with respect to time, amount and distance), technology of jet propulsion, too close proximity to airports in crowded areas.

Can these factors be reduced by reasonable measures? Apart from an unthinkable short-cut change of causes in the field of mobility needs and conditions of economy, a lot of measures have been discussed and already taken. These are for instance regulations for flight times (day – night), new technologies in jet propulsion (whisper jets), noise protection by shields and absorption technologies, increasing the distances.[10] Well-known measures are earmuff, shielding, and sound insulation.

Thus, limitation, reduction and elimination can be distinguished. Whereas limitation introduces a limit value in the form of a maximum allowed value, reduction would lead to a possible minimum (distance) value as a limit or threshold value. Elimination means to suppress the factor below any detectable effect or to stop the process completely.

All these different approaches are using the term of a limit value. As it can be seen already from these distinctions above, the concept of limit value has a manifold meaning and one should carefully make clear the differ-

[10] Cf. Wurzel in his presentation on the workshop. See also this volume (2003).

ences between the particular meanings. Whereas one may put the emphasis on the question, how to limit, reduce or eliminate the restriction of quality of life, of the nuisance in actual situations, of the damage to the ears, damage to mental stability, even the ruin of lives, most of the actual cases show that the damage has already taken place.

Thus on the right of Fig. 2 we are asking for the possibilities to compensate the damage that has already happened *(post factum):* Are there goods in financial or material terms that are able to compensate the damage, such as financial support, prosthetic measures, psychological therapy and, last but not least, resettlement.

All this gives rise to the question of “thresholds” or “limit values.”[11]

[11] Since each limit value can be expressed as a threshold value and vice versa we will use the two term synonymously.

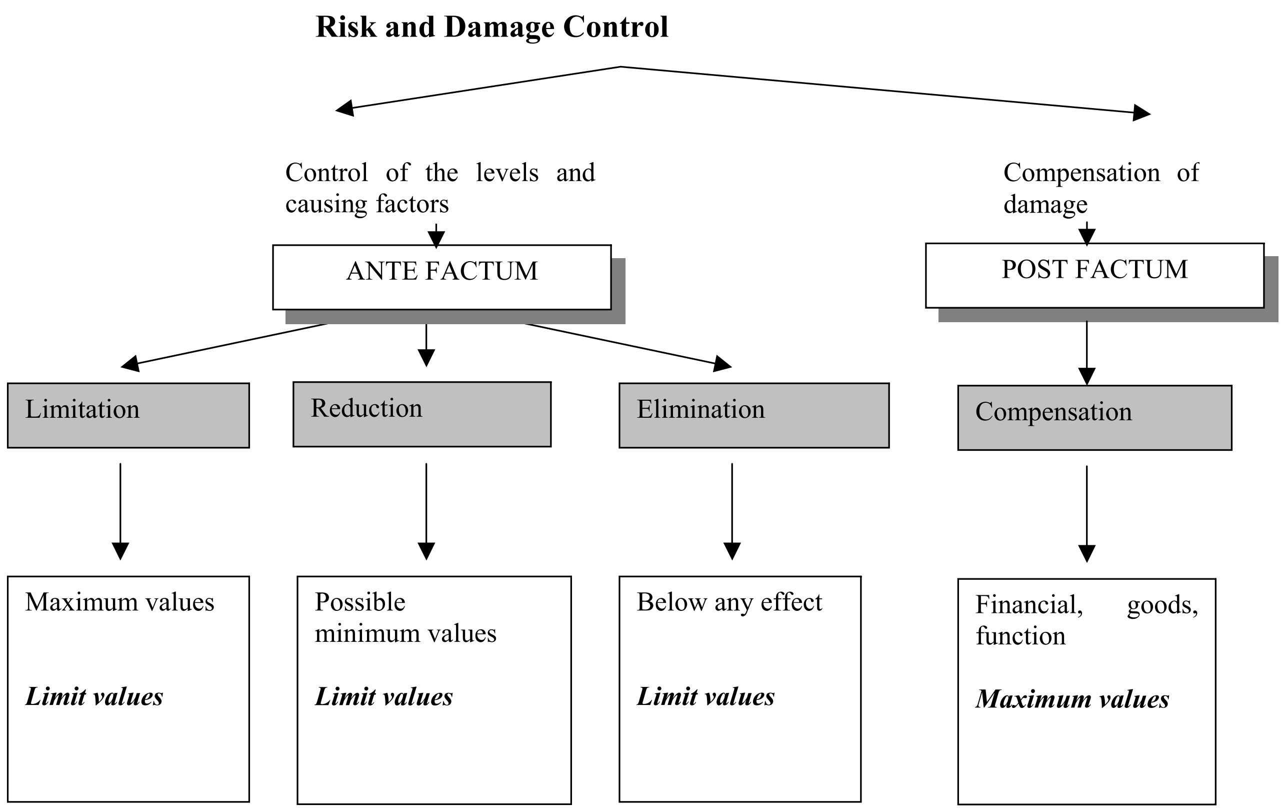

Fig. 2: *Classical risk and damage control (according to P.C. Compe (1994), S. 33)*

3 Some Remarks on Threshold Values

All ding sind gifft, und nichts ohn gifft.
Allein die gabe macht, daß ein ding gifft ist
Everything may be a poison and there it nothing without poison.
It is only the quantity that makes a thing to be a poison.

Aurolus Theophrastus, Bombast von Hohenheim, named Paracelsus (1493-1541)

3.1 Fundamental Remarks

Again with noise, we have a particular case. The intensity of a sound source may be harmful or not – in any case the meaning of a sound signal is independent from the intensity to a certain extent. Meaning is invariant to the loudness of the speech. On the other hand, there are cases in which the intensity of a signal in itself is carrying an explicit meaning, for instance for warning signals in order to secure attention. With decreasing meaning and increasing intensity we get the impression of noise or fuss. But Fig. 3 may be a little bit misleading. Whereas intensity may be represented by a continuous variable, this is not the case with meaning. It has been done so only for the sake of a scheme and to express the experience that beyond certain loudness there may be no more meaning detectable.[12] The cases are listed in Fig. 3, indicating that a low level of meaningless noise (white noise or background noise) could be considered as harmless, sometimes even as supportive for some situations.

[12] It may be that, for elderly people, the loudness of an open air rock concert supports the experience and the impression that nothing has to be communicated by such a noise source.

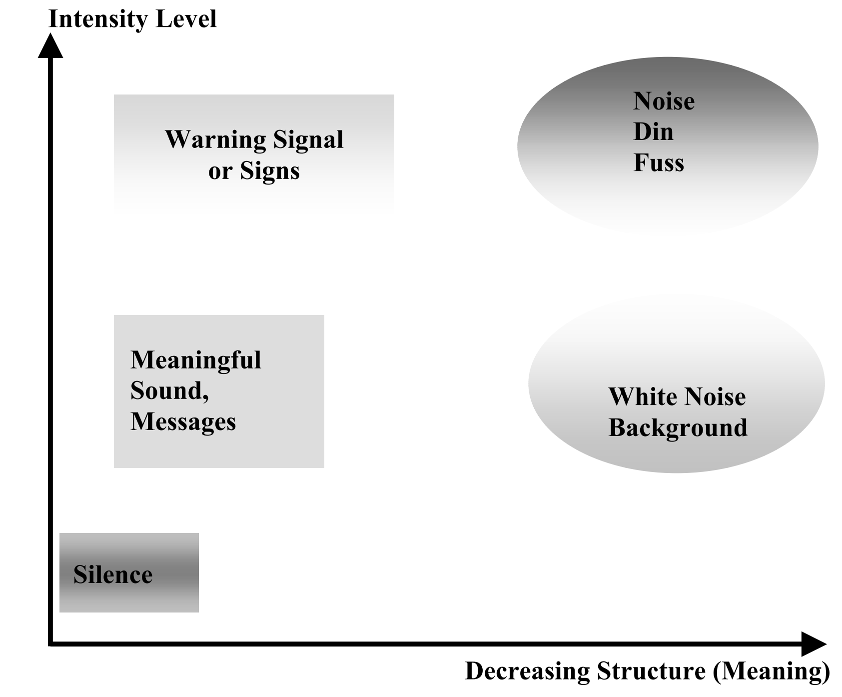

Fig. 3: *Portfolio for intensity and decreasing structure (as a necessary condition to carry meaningful messages)*

Tab. 1: *Different acceptance attitudes toward noise depending upon the situation*

Situation	**Noise**	**Acceptance Attitude**
… At work	Production processes	"Song of progress"[13]
Music making or listening	Band in concert	Up to > 100 db
Travelling	Traffic noise, aircraft noise	Nuisance, stressing, but necessary
Not busy with …	Environmental (natural) noise	No objections

[13] As it has been expressed for instance in the poem by Heinrich Lersch in "Morgenlied der neuen Arbeiter". In: Das dichterische Werk. Deutsche Verlagsanstalt, Stuttgart o. J.

Therefore we must distinguish between the level of nuisance and decreasing acceptance as a subjective level, on the one hand, and a level of sound source and noisy processes that cause provable and detectable damage, on the other.

During the discussion at the workshop it has become clear that the concept of threshold values, sometimes expressed as limit values, can be very misleading. A first distinction has been made in Chapter 2.2: It has to be clarified what the measure of the limit value is related to (limitation, reduction, elimination, compensation) respectively. Further, we have to observe that the damage, caused by noise, cannot be explained or forecast by a simple dose-effect relation as indicated schematically in Fig. 4.

In this well known relation[14] the limit value is defined by 10% of the level that does not show any effect (no observable effect level = NOEL). But this is only meaningful for processes that cause direct effects, but not for cumulative effects. Threshold values are defined by 10% – 25% of the value that marks the beginning of dangerous influences (cf. NOEL in Fig. 4). But who is defining what may be dangerous, what effect may really harm everybody?

In case of noise, we have other conditions. It remains questionable by what yardstick the causing effect could be measured adequately. It has been pointed out that the formula of Paracelsus cited above has often been misunderstood (or abused). Since if there were no definition of meaningful threshold or limit values for noise impact over time, the concept of dosage could be misleading. As Wurzel (2003) showed in the discussion, the dosage is defined as a meaningful value if it expresses the amount of (toxic) matter, electrical charge or particles that are introduced into a certain section of area or volume, given per time unit. But this entity cannot be a predictive variable for sound impact on an organism, since this is not valid for an impact that is expressed in terms of energy.[15] Thus the dose-effect relation should be substituted by an accumulated level of impact, measured in intensities or reciprocal logarithmic relations as a relative level (like deci-

[14] Cf. the use in working sciences like in Luczak (1993, 1998), Reichl (2000).
[15] by amplitudes (air pressure), calculating intensities (square of amplitudes) over time (= power).

bel). Here again we face the problem with a maximum "allowed" level over an accepted time period. Thus, this variable by which the limit value is expressed has two dimensions.

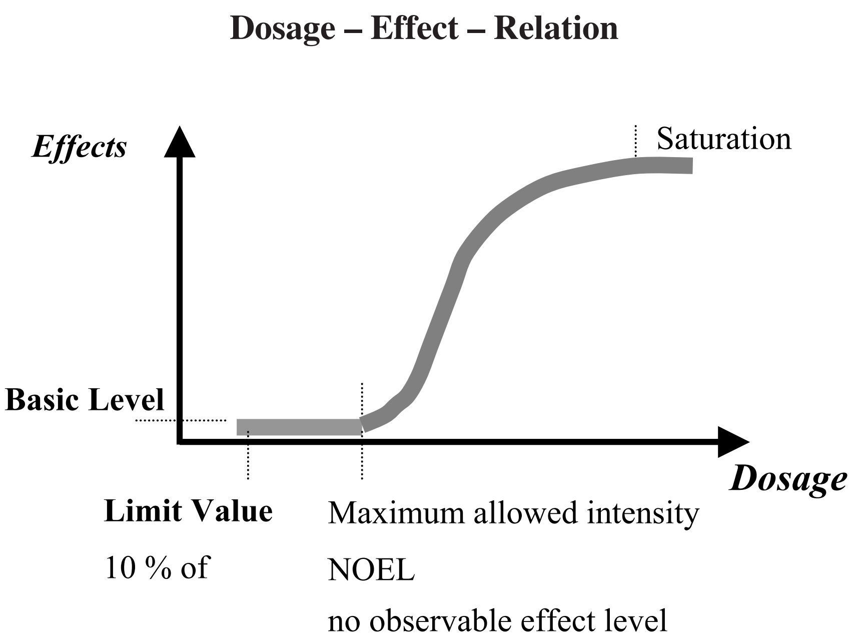

Fig. 4: *Dosage – Effect Relation (schematic). The limit or threshold value is usually defined as 10% of the level that does not show any effects (NOEL).*

It is well known that restrictions of health are dependent upon the relevant and accepted definitions of health (cultural, societal, ecological, economical).[16] The same holds for impacts on the mental system: Mental effects, as a restriction of mental well being, are dependent upon definition of mental norms. Thus the subjective criteria for nuisance up to damage is very subjective according to the dictum of Friedrich Nietzsche: "Anyone who

[16] Cf. the definition of Health given by World Health Organisation (WHO) in the year 1948 according to which health is a state of a perfect physical, psychological, and social well being and not only the lack of illness and affliction. A good investigation of the different concepts of health and illness in literature, philosophy and poetry is given within the PhD Thesis of B. Röscheisen - Helkamp (2000/2003).

knows the "why?" of (his) life, can come to terms with nearly every "how?"[17]

The harmful effects of noise are cumulative. This has two consequences: There is no reasonable definition of threshold values. The subjective feeling of being comfortable or being in a state of nuisance may be relevant to the mental system, but they are not strictly correlated with a resulting restriction of health for a long-term situation. Here we have analogue situations like exposure to radiation, physical absorption of radioactive, carcinogenic or mutational material, permanent strain or stress due to some organisational or bureaucratic structures and others.

Limit values are imposed in order to reduce risk, but in communicating them a certain normative pressure is applied.[18] We therefore could suspect that threshold values are not only the result of intensive and careful measurement of intensities and effects (under the condition that the dose-effect relation holds), but that they are also a result of

1. the decision, that dose-effect relations may be applied,
2. the definition of what is below any detectable limit,
3. what is considered as a nuisance or damage respectively?

Thus, the first thesis may be established: Any definitions of limit (threshold) values are "laden" with potentially conflicting interests and interest driven experiences. To illustrate this, some issues may be mentioned.

There are economic and structural interests in traffic and in the extensive use of aircraft. This is a legitimate interest since without aircraft in transportation for individuals and goods a global economy is unthinkable. This is trivial. On the other hand, doubts have been uttered as to whether the extensive tourist flight activities that accounts for a considerable portion of all air travel activities (even by night, using the border times of traffic schedules), are really "necessary" to this extent. This raises the problem of

[17] "Hat man sein *warum?* des Lebens, so verträgt man sich fast mit jedem *wie?* – Der Mensch strebt *nicht* nach Glück, nur der Engländer tut das." Cf. F. Nietzsche: Götzendämmerung. Sprüche und Pfeile 12; (1967), S. 327 (emphasis by Nietzsche).

[18] Cf. Banse (1993, 1996).

distinguishing between necessary and luxury needs (or true and false needs as Karl Marx said). This question cannot be answered here and it is difficult to pursue a reasonable and public discourse about this problem. So we have the unquestioned fact that air travel will increase enormously within the next years and that we have to balance the economic interest with the environmental noise interests.

The harming potential of permanent noise is obvious. This holds for the inhabitants of cities near big airbases as well as for people living in the neighbourhood of railway tracks, production plants, highways, open air theatres, noisy quarters in cities and so on. It is not the intensity of a single event (like a bang or a clap of thunder), but the sustained duration of a certain level of permanent noise, whereby the damaging effect depends upon the frequency ranges of the noise. These complicated dependencies are not taken into account when threshold values are discussed and (ab-)used in a political context.

After having recognized the precarious situation, actionism can be observed frequently. But a concrete situation (i.e. for residents) should be changed smoothly. It may be of considerable interest that an unavoidable change should not destabilize the whole situation.

If damage of a certain degree cannot be prevented, there is often the attempt to produce a mutual understanding that this damage may be considered acceptable, that it has to be accepted and that it is bearable. This political "brain washing" may have an influence on the subjective feelings and level of acceptance, but it does not change the fact of damaging and harming.

Since the psychological propaganda is easier to perform than a discussion about the multifarious cause and effect relations, it is often observed that threshold values are introduced where they are not justified and where they have no meaning in forecasting or assessing possible damage.

3.2 Two Tricks how to Reduce Estimated Hazards and Risk

The following should not be understood as a moralizing issue. It is only intended to show the mechanisms that are used in order to communicate the relation between cause and effect when different interests play a role.

The first procedure (or trick) has already been mentioned explicitly above: In which cases is it justified to introduce simple threshold values at all? Let us consider a general sign (indicated as an intensity or a dosage) of an effective cause. If the effect is cumulative, say a function of the timely integral over the dosage curve over time (even if there is a decay rate of the effect), a consequence of this is that the dosage should be kept as low as possible or be eliminated completely. If this is not possible, since serious interests are considered to be primordial, very often threshold values are introduced, as indicated in Fig. 5.1. The result of such an introduction can be demonstrated easily: We have suddenly a reduction of the estimated level of damage by introducing threshold values. Since the damage can be estimated equivalent to the area content below the curve of effect – and according to this the cost for limitation, reduction, elimination or compensation – the threshold-like behaviour with an estimated decay rate for each event occurring, if the threshold has been exceeded, enables us to predict lower costs than the cumulative effect. The remaining problem is only how to justify and to define the actual threshold (or limit) value.

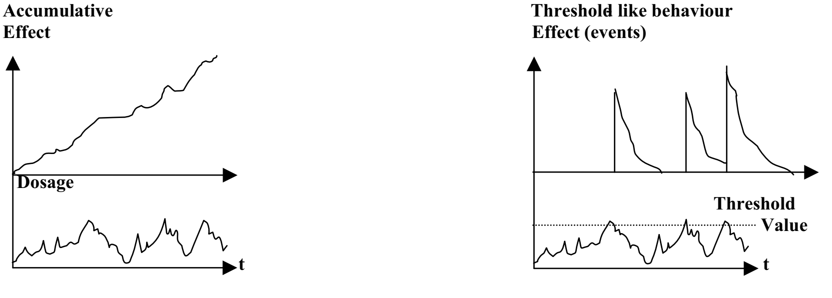

Fig. 5.1: *How to convert a cumulative effect into a threshold effect*

The second step is a slight variance of the threshold value itself. As Fig. 5.2 shows, the probability of occurrence that a threshold value has been exceeded is lowered considerably by a slight upward modification of the limit value. Again we have a more advantageous prognosis for the expected frequency of damaging events and a reduction of possible costs for risk and damage control according to Fig. 1.

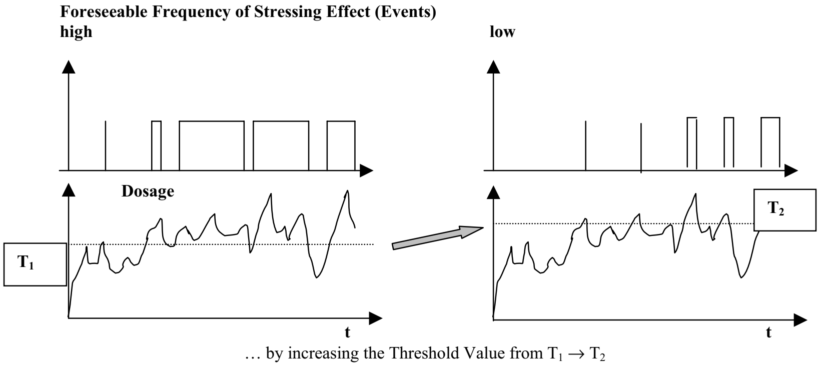

Fig. 5.2: *How to diminish the frequency of serious damaging events*

It is easy to see that the foreseeable frequency of stress or damaging events is reduced considerably by a slightly variation (upsizing) of the threshold value. The effect depends, of course, on the dynamics of the dosage or the intensity curve of the causing process.

The mentioned procedures are used on the level of evaluating and predicting the damage potentialities of the effect under discussion, say when compiling expert reports within the context of projects in Technology Assessment or public hearings. On the other hand, Fig. 5.2 may show also what happens if the dosage is lowered by measures with respect to the causing process; for instance by experimenting with bypasses to engine noise sources, fan design studies, shaping noise reducing wings, flaps, landing gears, exhaust jets attached to the jet propelled aircraft engines etc.[19] Either the dynamics is such that the number of peaks are reduced that exceed the threshold – if defined anyway meaningful – or the basic level is lowered such that the frequency of exceeding the threshold is reduced.

Thus the critical point to argue about noise nuisance is to distinguish whether we are talking about thresholds or about measures practically applicable to the relevant generating processes.

[19] Cf. Wurzel (2003).

We could ask persistently, as philosophers normally do, who is introducing and increasing threshold values? As we have learned, threshold values are not objectives, but normative instruments. Authorities and relevant organizations, using of course the relevant scientific knowledge and measurement technology that is available, will fix them. The author of this contribution is far from maintaining that a threshold value has ever been introduced directly, driven only forward strictly by economic or political interests. Rather the definitions are a result of negotiations between interested parties and are sometimes implemented without being very aware of the theoretical, systemic consequences involved. Therefore a second thesis may be given: The defining boundary of what constitutes human distress is a fabrication created by society.

There are some supporting arguments for this thesis: If we shape technologies, new technologies or better technologies,[20] then we are producing stress and strain by a surplus of material and energy (radiation, heat, noise etc,). The reason is very simple: There is no machinery or technologically controlled process with an efficiency of 100%. The limitation, reduction, elimination or compensation of these unavoidable side effects means reducing the short-term probability of a winning situation of the user of the technology. This holds *a fortiori* if the cost for risk and damage control can be externalised to a national or public economy.[21] If this externalisation is no longer accepted to a wide extent, we try to urge the relevant people by organizational pressure to increase their levels of acceptance. A lot of ideological means is available to do this: "The song of progress", the autonomous dynamics of every technological development, the observation that every technology bears some risk normally acceptable in everyday life, the extended debate about acceptable risks in our society, and the use of the nice German term *"Sachzwang"*, i.e. to be forced by concrete circumstances, i.e. technology, to act in one certain way as opposed to another, and other similar slogans.

By declaring valid threshold values, we define what is averagely thought to be reasonable. This produces new stress and strain. "Valid values" means

[20] and consequently their organizational closure.
[21] Cf. Krohn, Krücken (1993-1998).

here that they have to be accepted by anybody who accepts science at all. Nevertheless, it is not discussed what may be reasonable in a concrete situation. For this, some ethical consideration should close the philosophical question on noise and technology.

4 Ethical remarks

As we have learnt, the subjective nuisance level particular for noise is not an objective value that can be taken as a means. There is no strain and stress assessment that could be reliable or have any binding force for all relevant individuals involved.[22]

In this situation, the following problem rises: What could be allowed morally when operating a technology that is presumably a sure source of damaging effects when the definition for evaluating the cause-effect relation is still unclear? One could take the position that there could be no morally competent instance to judge the risk and strain for other individuals. Only those individuals actually involved themselves could assess their responsibility for their own risk (Ropohl 1994). According to that the neighbours of an airport should then decide about threshold values, about economic consequences and noise protection or noise prevention measures.

On the other hand, if one asks under what conditions such a discourse with the individuals involved should take place, one usually discovers that there are mainly practical obstacles that prevent it. The delegation procedure is not clear, political and local interests will interfere. Very often people have decided to settle nearby an airport for economic reasons. However, if then the airport expands, the nuisance level caused by noisy take-offs can become unbearable. Such a situation, however, can only be judged on the merits of each individual case.

[22] The same problems hold for the extreme electro-smog super sensibility that is proclaimed by a lot of individuals, whereas the health organizations and the physicians cannot detect any cause-effect relation. In scientific terms, the protest against transmitter stations for mobile phones and others (radar, direct wave radio transmitters, etc.) has no objective basis whereas the individual pain and health restriction in many cases are not only maintained by the person involved but can also be observed by physicians. But they have no scientifically based evidence for connecting the health reduction with the alleged cause, "electro-smog". Early literature sources on this problem cf. König (1975). See also Meitzke at al. (1994).

One could enter into discussion about a democratisation of the decision making process, about threshold values, and about the reasonableness of possible risks and nuisance, as already proposed by Günter Ropohl (1994). It may be that this discussion will become possible thanks to this TA project run by the Europäische Akademie.[23]

Besides this more public aspect of a mature handling of conflicts between well justified interests, it remains to be said that the procedure itself for defining threshold values is not only driven by interests but is also dependent upon some prejudice or pre-assumptions with respect to philosophical anthropology. To say it in plain English: "Tell me something about your threshold values and I will tell you something about your conception of man". This relation will be demonstrated very briefly by some examples. For this purpose, some basic anthropological views of man and some attitudes are correlated.

An engineer or a systems designer may regard man as one element of a means-ends relationship. In this case, man is serving to achieve an end, the end is useful for the designer or for the community (according to the scope of definition of interest), at least man is serving the designer or user of a man-machine techno-sociological system or a community, however defined. In this case the designer will be inclined to increase the threshold value since he assumes that man can stand a certain stress. As an organisational result, in this case the threshold value may be simply dictated.

Let us conceive man as a free individual. One could have the opinion that technology involves some risks that have to be borne or tolerated and anybody who does not want to bear such burdens can go back to nature or the jungle or elsewhere. In this case, thresholds will be enforced and maintained on a level that is accepted by the average individual in a community.

Conceiving man as an optimiser, as a survivor, one could argue that the *homo technicus* has always tried to cope with the impacts of technologies

[23] This seems to be urgent due to the fact that the government of Baden-Württemberg has decided to close the Academy for Technology Assessment in Stuttgart as from the end of 2003, allegedly due to unavoidable budget cuts. This institution, in particular, has developed a lot of methodologically well designed instruments to perform discourses and public debates about local and general interests and the conflicts ensuing therefrom.

by inventing further technologies. He is applying prostheses, he simulates, he is gambling and playing the game of technology and therefore the designer could expect that man, faced with nuisance caused by his technology, will start to change and to alter it in order to decrease the threshold value as low as possible.

Let us – at least – consider man as one part of a society and of a concrete community. This *homo sociologicus* may be involved in discourse, in politics, in understanding science, society and technology and may participate in public and technological decisions. Here the imperative is to talk about thresholds, to reflect about the necessity of shaping a technology in a certain fashion and as opposed to another, or better, to try to answer the question whether we have the technology we need and whether we need the technology we have.

If one agrees upon simple imperatives such that one should preserve the conditions for responsible behaviour for everybody involved, it may be a consequence thereof that we should not urge people to accept a short time advantage at the cost of long term disadvantages. A lot of individuals have become aware of this dichotomy. Maybe this is a good reason to reflect again about the great nuisance caused by and the price to be paid for modern technology: Noise.

Last but not least: If one is talking about noise, one should consider also silence. Silence and noise are concepts that are laden with moral, cultural, social and physiological expectations, fears and hopes. The health harming effect of too much noise has been explored extensively, and the necessity of a base level of noise is well known in psychology, information theory and social systems. So we have to ask under what circumstances we need silence and when we need a certain level of noise?

The focus on aircraft noise should not neglect the fact that also military aircraft constitutes a major contribution to the everyday nuisance. Moreover, the noise that is produced by production activities, marketing measures and commercial entertainment should also be taken into account. In all these fields the dilemma between noise reduction and economic factors, or – better – between the reduction of harmful effects as opposed to economic benefits (like mobility, acceleration, progress, growth, welfare) is obvious, but additionally another dilemma can be found:

If one considers noise as an unavoidable part of energy waste that is produced by our technical processes, we have to face the general dichotomy between the benefits of high quality (effective but expensive) in technical processes like transportation, production or communication, on the one hand, and the readiness to accept lower quality involving higher risks for other people in favour of shareholder values (risky but cheap) on the other hand. An assessment of the relative merits of a certain course of action can only be made if the respective priorities to be considered in attaining the desired ends are clearly defined. Thus the ethical task remains to discuss the underlying values involved when defending or complaining about noise. At least we should try to safeguard the conditions for responsible behaviour for all people involved.[24]

[24] Cf. also Kornwachs (2000).

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Medical Aspects: Physiological and Psychological Consequences of Noise with Special Regard to Aircraft Noise

Barbara Griefahn

Abstract:

The paper is focused on aircraft noise. Based on an extensive and detailed review evaluation, criteria are suggested for the prediction of the effects and for the protection of residents living in the vicinity of civil airports. The protection concept provides graded assessment values:

- *Critical Loads* indicate noise loads that shall be tolerated only exceptionally during a limited time.
- *Protection Guides* are central assessment values for taking actions to reduce noise immission.
- *Threshold values* inform about measurable physiological and psychological reactions due to noise exposures where long term adverse health effects are not expected.

Evaluation criteria in terms of noise levels are provided for various protection goals. Apart from hearing damage, evaluation criteria are provided for the avoidance of primary extra-aural effects on communication and on sleep, for the avoidance of annoyance as a secondary effect and for the avoidance of suspected cardiovascular diseases. They enable authorities to outline the areas around airports, where appropriate measures are mandatory to protect the residents against the deleterious effects of noise.

Protection of the residents is a dynamic process that must be followed up. The evaluation criteria must be repeatedly tested in view of new scientific findings and adapted, if necessary.

1 Introduction

Noise is consciously perceived, it interferes with various activities and is therefore the most annoying environmental pollutant. Concerning transportation noise, 20 % of the European population are exposed to equivalent noise levels of 65 dBA and more and a further increase in noise load is expected, more during the night than during the day [1].

Ninety percent of information is visually perceived, but the auditory channel is undoubtedly more important and essential for the mental and social development. This statement is based on the fact that persons blind from birth achieve higher education levels more often than deaf people. The main reasons are firstly the fact that hearing does not presuppose directed attention and secondly that the hearing system is designed as a permanently working alarm system which is able to perceive acoustic information at any time, even during sleep, to analyze it and to cause the organism to respond adequately.

Apart from aural effects noise evokes various extra-aural effects (Fig. 1) that are – applying functional and temporal criteria – reasonably and sufficiently categorized as follows:

– Primary effects which occur during exposure periods are disturbances of communication, of sleep, and of autonomous functions. They are recorded as acute effects shortly after noise onset and/or as cumulative effects that are acute responses aggregated over a defined exposure period.

– Secondary effects, i.e. annoyance and impaired performance are the consequences of the primary effects. They occur already during the exposure period and often outlast it.

– Long-term effects, such as multifactoral chronic diseases, chronic annoyance, and permanent behavioral alterations are suspected to be caused by repetitively evoked primary and secondary noise effects.

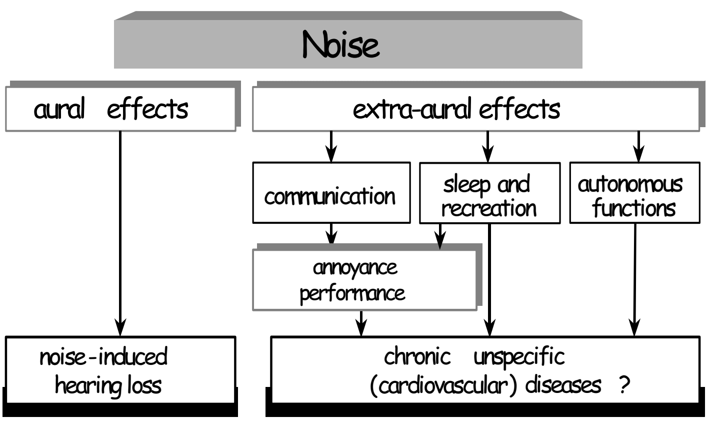

Fig. 1: *Aural and extra-aural effects of noise.*

Apart from hearing loss and from the masking of acoustic information, noise effects are non-specific, meaning that other environmental stressors cause the same effects. The elucidation of causal relationships therefore becomes more difficult and even impossible the greater the time lag between the onset of noise exposure and the manifestation of an effect in question.

Acute reactions that occur shortly after stimulus onset are obviously evoked by noise and their registration is most appropriate for the evaluation of distinct noise events. There are, however, doubts concerning the causal relations for cumulative responses as the non-specific noise effects cannot be separated from the responses to non-acoustic stimuli that occur also during the observation period and which evoke similar effects.

The uncertainty about causal linkages is even greater for the secondary effects, whereas the relations between noise exposure and the suspected health disorders remain on the level of hypotheses [2, 3]. Adopting, however, the WHO-definition [4] of health as ‘a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity’ the extra-aural effects of noise, the impairments of rest and sleep, of communication, psychosocial well-being, and performance are clearly classified as health effects [5].

2 Objectives

Concerning transportation noise, extensive meta-analyses have shown that aircraft noise annoys the most and rail transportation noise the least (Fig. 2) and this is true for ‘Nighttime Annoyance’ as well [2, 6]. The outstanding significance of aircraft noise is explained by its irregular occurrence, its high levels that cannot be ignored anymore, its origin – high up in the sky – which prevents an easy escape by moving to the opposite side of the house which is an effective strategy against the impact of noise emitted from surface transportation. Accordingly, the largest studies on the effects of noise concerned aircraft noise and many countries have established special regulations. But these regulations vary between airports even within one and the same country.

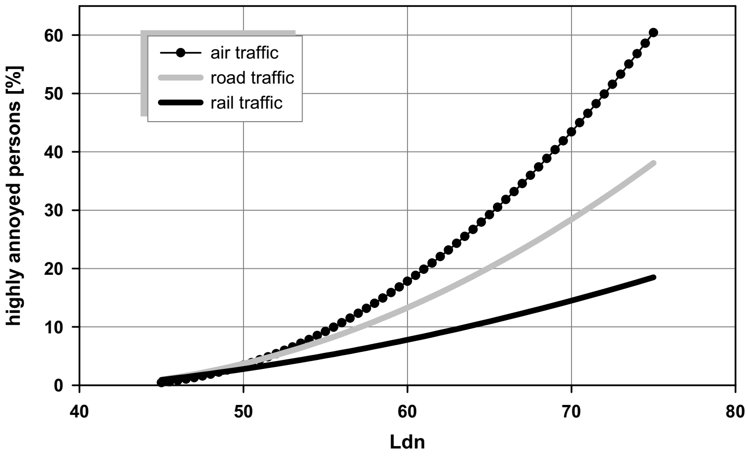

Fig. 2: *Annoyance due to traffic noise. Amount of highly annoyed person related to day-night level [Miedema & Vos 1998].*

It is at present planned to construct a new runway at Frankfurt Airport that allows 660 000 annual flights as compared to the current 460 000 flights. Beforehand, extensive expert reports were compiled which reviewed the state of the art as a basis for the evaluation of noise-induced effects on the residents in the vicinity of airports in general. These reports examined aural and extra-aural effects, where the latter concerned communication, sleep and autonomic functions, performance and annoyance as well as the speculated long-term effects on health. Based on these reports evaluation criteria were defined for aircraft noise. It was suggested to adopt the maximum noise level (Lmax) for the assessment of individual noise events and the calculation of the equivalent noise level for time periods while using the equivalence parameter q = 3 (Leq3). For both, the equivalent and the peak level, it was recommended to weigh the frequencies with the A-filter and the time constant with 'slow'. Daytime and nighttime were separately considered, while the discussion concerning a special protection during the shoulder hours, especially in the evening remains, however, open. A subdivision of the night was regarded as appropriate due to a clear decrease of sleep depth during the night.

Evaluation criteria in terms of noise levels were defined for various protection goals which refer to the primary effects on communication, on sleep and on autonomic functions, for annoyance as a secondary effect and for the speculated long-term effect on health (Table 1). The following criteria were defined:

***Tab. 1:** Evaluation criteria for various protection goals*

Aircraft noise – Evaluation criteria
Griefahn, Jansen, Scheuch, Spreng, 2002

noise level	threshold-value	protection guide	critical load
hearing damage			
L_{max}	90 dB(A)	95 dB(A)	115 dB(A)
$L_{eq, 24\,h}$	70 dB(A)	75 dB(A)	80 dB(A)
communication			
$L_{eq, 16\,h, indoor}$	35 dB(A)	40 dB(A)	45 dB(A)
$L_{eq, 16\,h, outdoor}$	56 dB(A)	59 dB(A)	62 dB(A)
sleep, two periods (2/3 of flights between 22.00 and 1.00)			
$L_{max, 22\text{-}1\,h, indoor}$	23 x 40 dB(A)	8 x 56 dB(A)	6 x 60 dB(A)*
$L_{max, 1\text{-}6\,h, indoor}$		5 x 53 dB(A)	
$L_{eq, 22\text{-}1\,h, indoor}$	30 dB(A)	35 dB(A)	40 dB(A)
$L_{eq, 1\text{-}6\,h, indoor}$		32 dB(A)	
sleep, one period			
$L_{max, 22\text{-}6\,h, indoor}$	23 x 40 dB(A)	13 x 53 dB(A)	6 x 60 dB(A)*
$L_{eq, 22\text{-}6\,h, indoor}$	30 dB(A)	35 dB(A)	40 dB(A)
high annoyance			
$L_{eq, 16\,h, outdoor}$	55 dB(A)	62 dB(A)	65 dB(A)
recreation			
$L_{eq, 16\,h, outdoor}$	50 dB(A)	57 dB(A)	64 dB(A)
diseases			
$L_{max, 16\,h, outdoor}$	-	25 x 90 dB(A)	19 x 99 dB(A)*
$L_{eq, 16\,h, outdoor}$	-	65 dB(A)	70 dB(A)

*This number-and-noise value must not be excreeded

Critical loads: Excession of these values forces the establishment of noise abatement measures as health hazards are no longer excluded. These values shall be tolerated only exceptionally during a limited time.

Protection guides: The exceeding of these noise loads gives reason for counter measures. Their undercut is expected to exclude health hazards for the average person. Impairments might occur in sensitive groups.

Threshold values cause significant effects that are essential signs of life and do not bear a pathogenic risk in the long run.

3 Evaluation Criteria for Aural Effects

Protection goal: Avoidance of hearing damage – The effects on aural perception were most extensively studied, in particular, as noise-induced hearing loss (NIHL) is the only disease that is unequivocally and mono-causally related to the impact of noise. NIHL is acknowledged as an occupational disease. Reliable population based dose-response curves are provided in ISO 1999 [7]. Based on an 8 hours exposure per day this standard allows the prediction of NIHL under consideration of equivalent noise levels, lifetime exposure (in years), age, and gender.

Exposure periods of residents in the vicinity of airports are, in the worst case, 24 hours a day. For this exposure period the U.S. Environmental Protection Agency has extrapolated an equivalent noise level of 75 dBA which is regarded as a load below which hearing damage is not expected [8].

The risk of hearing damage depends also on the maximum levels, in particular on the rise time. An increase of 60 – 80 dB per second is regarded as critical, however, scarcely reached by civil aircraft. Thus, concerning civil airports, hearing damage is regarded as unlikely if the evaluation criteria presented in Table 1 are obeyed.

4 Evaluation Criteria for Extra-aural Effects

4.1 Protection Goals for Primary Effects

4.1.1 Avoidance of communication disturbances

Due to its overwhelming significance for mental and social development, the ability to communicate is routinely concerned in large social surveys on noise-induced annoyance. Research is predominantly performed in the laboratory and was initially focused on the determination of signal-to-noise ratios that are required for communication in various situations and where the behavior of speakers and listeners in different acoustic situations were intensively studied [9]. The intelligibility of syllables, words, and sentences were quantified under the influence of various relevant and irrelevant noises. The relationships between speech intelligibility and background noise levels have been well quantified for the average person and the preconditions for various requirements have been specified.

Acoustic communication can be disturbed by at least 3 different mechanisms, directly by masking and indirectly by hearing loss and by distraction (Fig. 3).

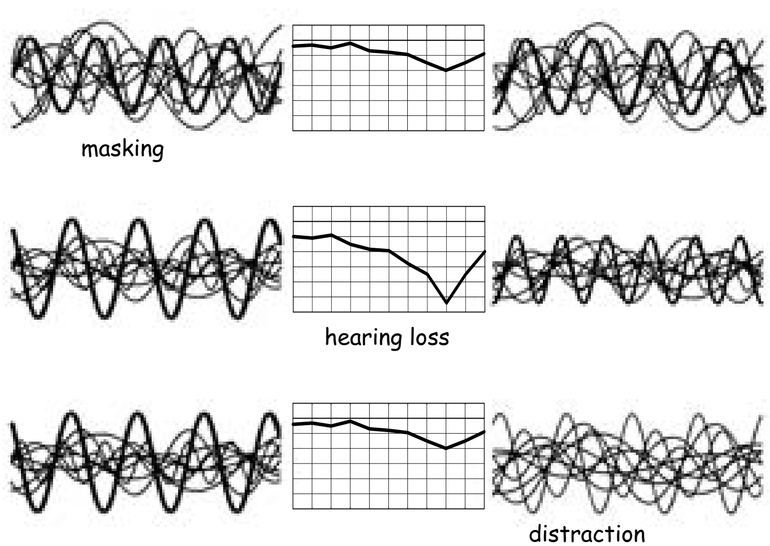

Fig. 3: *Mechanisms for disturbances of communication.*

- Masking: Masking is a pure, physical phenomenon and, apart from aural effects, a specific noise effect. Noise interferes with the relevant acoustic information which then becomes undetectable for the listener.
- Noise-induced hearing loss: The detection of relevant acoustic information becomes difficult in the case of noise-induced hearing loss (as well as in the case of reduced hearing acuity for any other reason).
- Distraction: Various noises, particularly those with high information content, distract attention. Thus, the relevant acoustic information that is otherwise well detectable is no longer consciously perceived.

The consequences of impaired communication are manifold. Annoyance is almost unavoidable if face-to-face or telephone conversations are disturbed by environmental noise thus increasing the effort of the speaker and of the listener and causing more or less frequently repeated questions and answers. Annoyance is most likely in the case of interrupted, one-way communication, where, for instance, the news provided by radio or television are masked and then definitely lost. In the long run, noisy environments may influence communication behavior such that people prefer short and clipped speech.

Performance is impaired if task-relevant acoustic information is no longer or only partly perceived. Even dramatic consequences are possible, as for instance accidents when warning signals are masked.

Concerning the evaluation criteria presented in Table 1 a good to perfect quality of communication is recommended indoors, whereas a sufficient quality can be tolerated outdoors. Maximum levels are not provided due to an insufficient database.

4.1.2 Avoidance of noise-induced sleep disturbances

The nature and the function of sleep: Due to the undisputed restorative function of sleep, sleep disturbances are regarded as the most deleterious effects of noise. The respective preconditions are the permanently open auditory channel and the ability of the brain to discriminate between various sounds even while asleep.

Sleep is structured by a sequence of 4–6 cycles of 90 to 100 minutes each, that are characterized by increasing and decreasing sleep depth and that are terminated by REM-sleep where bursts of rapid eye movements occur (Fig. 4).

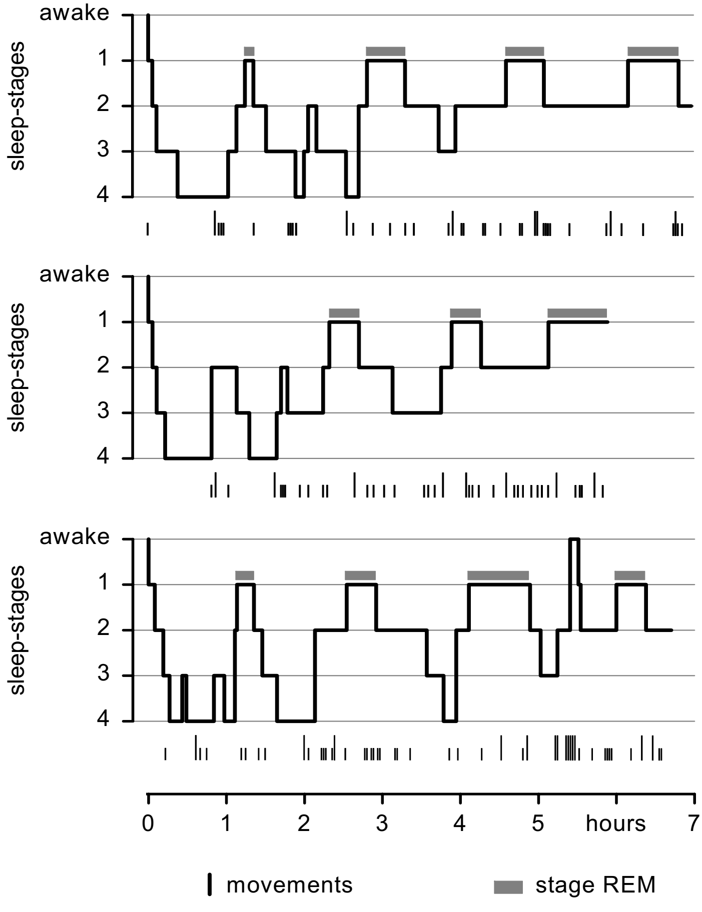

Fig. 4: Normal cyclic variation of sleep depth

Methods for the recording and evaluation of sleep: The simultaneous recording of the electroencephalogram, the electro-oculogram, and the electro-myogram is the only measure that reliably indicates whether a person is awake or asleep and which provides information on sleep depth. This most sophisticated and rather costly method is indispensable for laboratory studies. Autonomic responses are indicated by alterations of heart rates or by the urinary excretion of stress hormones.

Subjectively perceived, quantitative and qualitative parameters of sleep are assessed by means of short questionnaires that are completed just before bedtime and just after getting up. Performance tests are completed in the evening and in the morning to measure working speed and errors.

Noise-induced sleep disturbances: Sleep disturbances are defined as measurable and/or as subjectively experienced deviations from the usual or from the desired sleep behavior (Fig. 5). Primary effects that occur during bedtime are prolonged sleep latencies, intermittent and premature awakenings, sleep stage changes, body movements, autonomic responses, etc. The total time awake and/or in flat sleep increases at the expense of deep sleep and/or of REM sleep. Secondary effects such as decreases of self-estimated sleep quality, mood, and performance are expected after one or after several disturbed nights. Sleep quality is assessed as worse, mood and performance might be impaired.

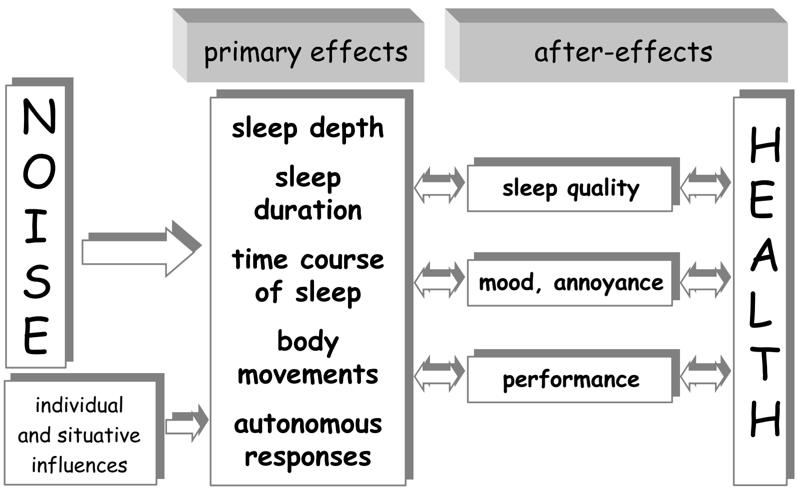

Fig. 5: *Noise-induced sleep disturbances*

The thresholds and the extents of noise-induced sleep disturbances depend on acoustical features, personal characteristics and on environmental conditions.

Information content: The brain is able to perceive and to recognize the significance of external stimuli even while asleep and to cause the organism to respond accordingly. Thus, unfamiliar noises and those that are significant for an individual disturb more than familiar and less significant sounds. The individual significance of a given stimulus may alter over time and a corresponding response occurs not before a few repetitions. Based on these mechanisms, sensitizations are possible with time as well as habituation. Habituation occurs in most cases but is mostly limited, as indicated by field experiments, where long-term residents in noisy areas still wake up more often, have less deep sleep or less REM sleep, assess their sleep quality as worse, perform less in the morning and benefit from sound attenuation [13 – 17]

Acoustic features: The probability and the extent of noise-induced sleep disturbances increase with maximum noise levels and with emergences. The number of noise-induced awakenings and noise-induced body movements increase also with the number of stimuli (partly at the expense of spontaneous awakenings and body movements). The increase becomes, however, successively smaller, as the risk of these responses to an individual stimulus decreases. This explains why people are less disturbed by rather continuous noises that are produced by constant, heavy road traffic than by intermittent noises that are emitted by air traffic, rail traffic, and low-density road traffic. Therefore, noise-induced awakenings are much better assessed by the maximum noise level than by the equivalent noise level [18]. The latter is certainly a suitable predictor for rather continuous noise as emitted by high density road traffic.

Individual and situational characteristics: Gender has no influence on the susceptibility to noise, but sleep disturbances increase with age [19]. Contrary to a common belief, children are about 10 dBA less sensitive than adults [20, 21]. Several personality traits such as self-estimated sensitivity to noise and neuroticism are associated with the probability and the extent of noise-induced responses.

The thresholds of noise-induced responses are inversely related to sleep depth that alters periodically during the night and becomes successively flatter towards the morning [19], meaning that noise-induced awakenings are more likely in the late than in the early night. The circadian rhythm reveals a significant influence. Under similar acoustical conditions, night workers sleep considerably less during the day than during the night; but day-sleep usually takes place under worse conditions: the noise levels are then 8 to 15 dBA higher and interspersed with meaningful and thus more disturbing noises.

The sleeping environment is also decisive and investigations performed in the field have accordingly shown much smaller effects than in the laboratory [22]. The possible reasons are in the first place habituation [23] and the simultaneous influence of other acoustic and non-acoustic stimuli that modify or mask the responses to noise in the field.

Evaluation criteria, critical noise loads: Using self-estimated sleep quality and cardiac responses as relevant criteria, the critical loads for continuous noises seem to be between equivalent noise levels of 37 and 40 dBA [24, 25]. Concerning intermittent noises, 2 models were developed, that allow the calculation of noise and number combinations that cause the same predefined admissible risk [26, 27]. The evaluation criteria suggested here are based on the physiological model that refers to the admissible noise-induced release of cortisol [27]. It was chosen as the respective results match almost perfectly the noise and number relation determined for awakenings in the largest study ever done on the effects of aircraft noise [18].

To protect residents in the vicinity of airports from noise-induced sleep disturbances, the undoubtedly best solution is the avoidance of any noise emission during the night. If this is not achievable, it is suggested that air traffic should be concentrated during the less sensitive first part of the night, in particular as disturbances experienced during this period can be compensated in the following quieter section of the night [28, 29].

In the case that traffic density cannot be reduced adequately in the second part of the night, it is recommended to lower the maximum levels even within the first part, as compensations are no longer possible thereafter.

4.1.3 Avoidance of critical autonomic responses

Autonomic responses correspond to activations of the sympathetic branch of the autonomic nervous system that are based on well-defined neuro-anatomical pathways. Numerous experimental studies were performed to identify and to quantify the great variety of autonomous responses such as acceleration of heart rate, increase of peripheral resistance, elevation of blood pressure and elevated release of stress hormones. These acute responses occur immediately after noise onset; they are non-specific and evoked by other environmental stimuli and by emotions as well.

The release and excretion of stress hormones are usually determined as cumulative responses over defined exposure periods. But as these responses are also evoked by other stimuli that occur during the sampling period, it is difficult to quantify the amount that is exclusively related to the impact of noise.

The cardiovascular responses are clearly related to the acoustical parameters of noise but the thresholds and the respective dose-effect curves are modified by simultaneously acting environmental agents, by personal characteristics (age), and biorhythmically altering tension of the sympathetic nervous system, e.g. with the circadian rhythm. Concerning the latter, the thresholds for autonomous responses are between 60 and 70 dBA while awake and between 50 and 60 dBA during sleep [31–34].

Autonomic responses are primarily normal physiological responses of the organism to its environment. But as they do not habituate, they are suspected of being contributive to the possible causes of multifactorial chronic diseases, particularly of cardiovascular diseases. A critical maximum level of 99 dBA for intermittent noise was experimentally elaborated by Jansen [32]. This led to the hypothesis that frequently exceeding the prescribed level might accelerate the manifestation of cardiovascular diseases. Though this assumption has not yet been proved, this level is nevertheless regarded as a Protection Guide that shall be obeyed for the prevention of chronic health disorders (see Section 4.3).

4.2 Protection goals for secondary effects

4.2.1 Avoidance of impaired performance

Performance can be adversely affected by several mechanisms, directly by arousals (brain activity) and by masking and indirectly by distraction and by noise-induced sleep disturbances.

- Arousal: Optimal performance presupposes a certain arousal level that might vary with the type of a task. Thus, performance is related to noise loads by an inversely u-shaped function indicating impairments in extremely quiet as well as in loud environments.
- Masking: Tasks that presuppose the perception of acoustic information or which are at least facilitated by acoustic signals become difficult and even impossible if this information is masked.
- Distraction: Various noises, particularly those with high information content (speech, music, etc.), distract attention, the task-relevant acoustic information is then only partly or no longer consciously perceived and performance degrades.
- Noise-induced sleep disturbances may degrade the ability to concentrate on a task.

The effects of noise on performance reported so far are highly controversial. No remedies or measures to alleviate these effects have yet been discovered.

The effects on performance depend to a large extent on the task itself. Complicated and demanding tasks, those which presuppose creativity and a great memory capacity and which are executed over a long time are most likely adversely effected [37].

Studies on performance are predominantly performed in the lab, where, in the very first experiments, artificial and continuous noises, such as white or pink noise, were almost exclusively applied and the extent of the effects were related to the noise levels. Recently performed studies have shown, however, that by the measurement of cumulative noise metrics, e.g., the equivalent noise level is almost irrelevant when compared with common noises that are characterized by frequent changes in levels and frequencies. Speech was identified as most bothersome, followed by transportation noise, where air traffic disturbs most and rail traffic the least [38, 39].

Performance is hardly associated with childhood. But children are particularly challenged during language acquisition and they are most vulnerable during that period. In noisy environments children learn to tune out or to ignore auditory stimuli and seem to be more resistant to auditory distraction. Mental performance is more disturbed by intermittent than by continuous noises. Concerning aircraft noise, impairments occur in attention, speech, reading, long-term memory and complex information processing [40, 41] and these effects increase with the duration of noise exposure.

Currently available knowledge provides an insufficient basis upon which to establish a threshold above which impairments of mental performance may be expected.

4.2.2 Avoidance of high annoyance

Annoyance is the most frequently ascertained effect of noise. Annoyance in general is any feeling of resentment, displeasure, discomfort and irritation when external stimuli intrude into someone's thoughts and moods or interferes with activities. Noise annoys only when it is not considered to fit with current intentions which is most frequently the case when people communicate and when they (try to) sleep.

Within the last 5 decades more than 500 social surveys have been completed [42]. The methods used are more or less extensive personal interviews, rather short interviews conducted via telephone or by the mailing of questionnaires.

Noise is felt as a severe impairment of the quality of life and causes residents in the vicinity of airports or along major roads and railway tracks to protest and even to form pressure groups, as soon as the construction or the extension of the respective traffic facility becomes known. People exposed to high aircraft noise may alter their behavior. They close their windows more often, they use terraces, gardens and balconies less often, they go out more seldom and have less often guests than residents in quiet areas.

Concerning transportation, noise emitted from aircraft appears to be most annoying and rail noise the least [6, 44] (Fig. 2). Annoyance is prone to habituation but to sensitization as well where among others the attitude and the context where noise occurs are significant.

Annoyance is undoubtedly related to noise load in terms of the equivalent noise levels or other integrated metrics. The correlations between individual noise load and individual annoyance are relatively low, but population-based means of evaluation provide significant correlations [45], thus indicating that individual annoyance is modified by a large variety of non-acoustic intervening variables, where behavioral variables such as fear related to the noise source, the conviction that authorities do not properly combat the noise and individual noise sensitivity are most important whereas demographic variables are of minor significance [46].

The evaluation criteria presented in Table 1 refer to the most common criterion, whereby aircraft noise is regarded as intolerable if 25 to 28 % of the people concerned are highly annoyed. No maximum values are advocated, as the data base provided by the literature is inadequate.

4.3 Protection goals for long-term effects on health

Frequently evoked primary and secondary responses are tolerated for a while but in the long run, in the case of chronic noise exposure, it is suspected that these responses contribute to the causes of multifactorial chronic diseases and to accelerate their manifestation.

This well-founded hypothesis was examined with many epidemiological studies, that concerned cardiovascular diseases and cardiovascular risks. A few studies dealt with biochemical and humoral alterations, with the immune system, with reproduction and with sick leave from work.

The crucial significance of the hypothetical relationship between noise and chronic health effects caused several authors to pool their results, to perform analyses while concerning different aspects. These analyses revealed highly contradictory results which led to the assumption that the pathogenic impact of noise presupposes a particular individual or situational vulnerability. It was hypothesized that noises with a high emotional content evoke stronger responses and contribute more to adverse health effects rather than neutral noises [47]. The respective studies were then grouped according to the possible emotional content of noise. According to this, occupational noise, where the emotional strain is usually low, is less likely to contribute to the long-term effects than transportation noise which causes emotional responses during leisure time.

Further epidemiological studies made a strict distinction between occupational and transportation noise [2, 3, 30, 48–52]. Reports on occupational noise indicate that levels of considerably more than 80 dBA are associated with a higher risk for hypertension and very high long-term exposures of more than 90 dBA with other cardiovascular findings. Concerning transportation noise, equivalent noise levels exceeding 70 dBA are suspected of being contributive to the causes of hypertension and levels between 65 and 70 dBA might increase the risk for ischaemic heart diseases [48]. Some authors and committees [2, 30] consider the evidence for causal relationships as sufficient whereas other [52, 53] stated that ‘rigorously controlled studies which eliminate the numerous confounding factors or at least a number of them, are rare.’ and that ‘research has not definitely ‘proved’ any causal linkage between environmental noise and long term adverse health effects’ but that ‘it remains plausible that excessive noise might contribute to long-term adverse health effects’ [3, 5].

Another founded hypothesis, the development of psychiatric disorders (at least in particularly susceptible persons) was tested several times and psychiatric hospital admissions were indeed somewhat higher in the vicinity of large airports but this needs to be confirmed by well designed studies [50].

Apart from hypertension, ischaemic heart diseases and possible psychiatric symptoms, it is assumed that people who are daily exposed to noise are more susceptible to effects on the immune system, for other diseases and symptoms such as common colds, and digestive problems. The respective investigations, however, are inconclusive as they were again poorly designed and did not take into account possible confounders. The same has to be stated for the effects on the unborn child, whether the pregnant women were exposed to environmental or to occupational noise [30, 53]. The respective evaluation criteria refer therefore to the results from studies on cardiovascular effects, they indicate values above which long-term effects on health cannot be excluded anymore (Table 1).

5 Protection Goal: Persons/Areas with Special Needs

The protection goals given above refer to the average person. There are, however, persons and situations where special noise abatement is appropriate. The noise levels presented in Table 2 are suggested for the indoor environment and refer predominantly to undisturbed communication and to undisturbed rest and sleep.

Tab. 2: *Protection Goal: Persons/areas with special needs (indoor levels)*

Kindergartens:		L_{eq} = 36 dB(A) (sleep in the afternoon)	
Schools:		L_{eq} = 40 dB(A)	
Hospitals:	Day:	L_{eq} = 36 dB(A)	L_{max} = 25 x 45 dB(A)
	Night:	L_{eq} = 30 dB(A)	L_{max} = 13 x 40 dB(A)
Old people's homes:	Day:	L_{eq} = 36 dB(A)	L_{max} = 25 x 51 dB(A)
	Night:	L_{eq} = 32 dB(A)	L_{max} = 13 x 45 dB(A)

6 Standard values for the calculation of isocontours

Under the aspect of noise abatement, the effects of aircraft noise on the residents in the vicinity of airports is estimated by the calculation of outdoor levels. Where the evaluation values were defined for the indoor environment an additional 15 dBA is regarded as appropriate due to tilted windows. The standard values to be calculated are listed in Table 3.

The Protection Guide defined for 'High Annoyance', namely L_{eq3} = 62 dBA includes, the critical loads for the suspected health effects and for outdoor communication.

The evaluation criteria presented here were designed for the prediction of noise effects expected on residents living near airports but the protection of the residents is a dynamic process and the evaluation criteria must be repeatedly tested and – if necessary – adapted to new scientific findings.

A major disadvantage, and thereby one reason for future revisions, is that there are currently no models for the assessment of the effects that are caused by the simultaneous influence of noise from different sources. This is particularly relevant for airports where an increase of air traffic is always associated with an increase of road and rail traffic.

Tab. 3: *Standard values for the calculation of isocontours*

	Protection Guides			**Critical Loads**		
Daytime:	L_{eq}	=	62dBA	L_{eq}	=	65 dBA
	L_{max}	=	25 x 90 dBA	L_{max}	=	19 x 99 dBA
Nighttime:	$L_{max, 22\text{-}1h}$	=	8 x 71 dBA	$L_{max, 22\text{-}6h}$	=	6 x 75 dBA
	$L_{max, 1\text{-}6h}$	=	5 x 68 dBA			
	$L_{max, 22\text{-}6h}$	=	13 x 68 dBA			
=	$L_{eq, 22\text{-}1h}$		50 dBA			
	$L_{eq, 1\text{-}6h}$	=	47 dBA			
	$L_{eq, 22\text{-}6h}$	=	50 dBA	$L_{eq, 22\text{-}6h}$	=	55 dBA

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Technical Developments in the Field of Aircraft Noise Reduction

Dietmar Wurzel

Introduction

"One day man will have to fight noise as bitterly as cholera and pestilence!" Nobel Laureate Robert Koch, 1910

People desire to travel and to satisfy economic wants. The answer to these basic human needs is mobility. Mobility is also an essential precondition for economic growth. But mobility on roads, on rails, and in the air is associated with noise. With more and more people feeling affected by and complaining about noise, traffic noise has become a severe environmental problem.

In Germany, located in the heart of Europe and with a high population density, more than 50% of the population feel affected, 65% by road traffic noise, 37% by air traffic noise, and 23% by rail traffic noise according to the latest data published by the German Federal Environmental Agency (Umweltbundesamt UBA); an online poll suggests even higher numbers[1]. With traffic density on the rise, noise pollution will increase considerably over the years to come. Transport projections recently published by the IEA suggest a growth around 50% for OECD-Europe[2] by 2020, Fig. 1.

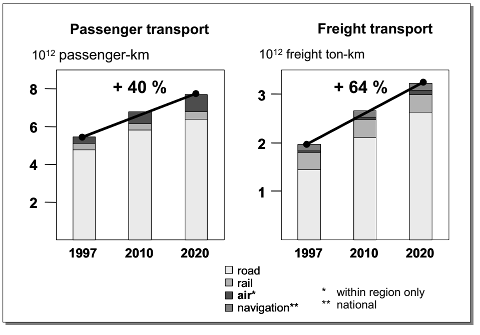

Fig. 1: *Transport projections for OECD Europe 1997–2020*

[1] online-Lärmumfrage-Auswertung der online-Umfrage des Umweltbundesamtes, Bericht Oktober 2002. Zusammengestellt von Jens Ortscheid, Umweltbundesamt, 2002

[2] Transport Projections in OECD Regions – Detailed Report. Michael Landwehr, Celine Marie-Lilliu, International Energy Aceny, May 2002

If "livability" in communities affected by traffic noise is to be maintained or even enhanced without letting noise bottleneck economic development, measures must be taken to reduce noise created by road, rail, and air traffic. Among those working on transportation noise abatement are German companies, operators, research institutions, and agencies which conduct their work within the national research network "Quiet Traffic"[3], and cooperate across traffic branches.

Unlike ground transportation which causes noise wherever vehicles travel along roads or rails, air traffic noise is a problem only during the initial and final flight phases and accordingly is limited to communities close to airports. The comparatively high rate of complaints about air traffic cited above suggests that the aircraft noise is perceived as especially aggravating. In September 2002, the Frankfurt Airport received more than 56.000 complaints from local residents – that is one per minute of every day – and a 30% increase on the same period in 2001[4], despite the fact that engine and airframe manufacturers can justly claim major advances in reducing aircraft noise, Fig 2.

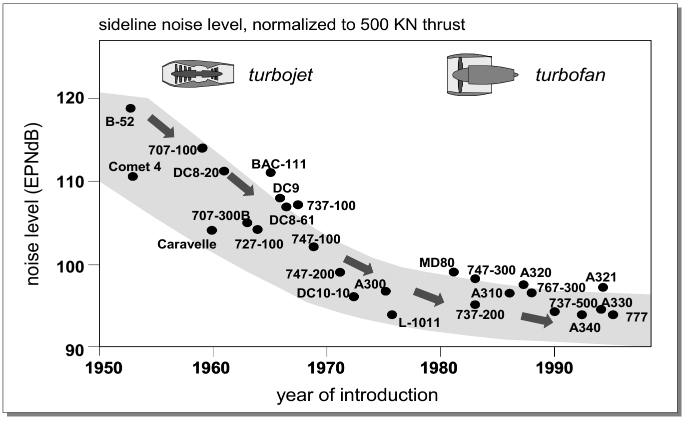

Fig. 2: *Noise levels of modern aircraft/engine combinations have decreased*

With noise reduced by 10 dB being perceived as half as loud, the 25 dB reduction achieved since the introduction of jet aircraft means that the noise

[3] Research Network Quiet Traffic: www.fv-leiserverkehr.de
[4] Sound Thinking – Flight International, 17–30 Dec. 2002

of a modern aircraft has shrunk to well below a forth of that of the first generation.

Despite the dramatic reductions accomplished for the individual aircraft so far, the noise issue has not subsided. Instead, it will stay with us as the dominant environmental problem of aviation – and will intensify – as the growth of air traffic neutralizes or even outgrows the technical noise mitigation successes. With an annual growth of about 5%, Fig. 3, air transportation has the highest annual percentage increase of all traffic branches. According to the forecasts of the two leading aircraft manufacturers and in spite of the current slump, the number of aircraft will more than double over the next 20 years, from about 15.000 to 32.000.

Adding to the gravity of the noise problem are the growing sensibility and the decreasing tolerance towards noise exposure in our society. Thus engine and airframe manufacturers and the air transportation industry, airlines and airport operators alike, are facing increasing pressure to further cut down on noise. If this cannot be achieved through technical and operational advances, regulatory and operational restraints loom above those already put in place by some airports, Fig. 4, to counter the rising tide of objection and anger. Thus the growth of the air transportation system may be severely constrained by the noise issue.

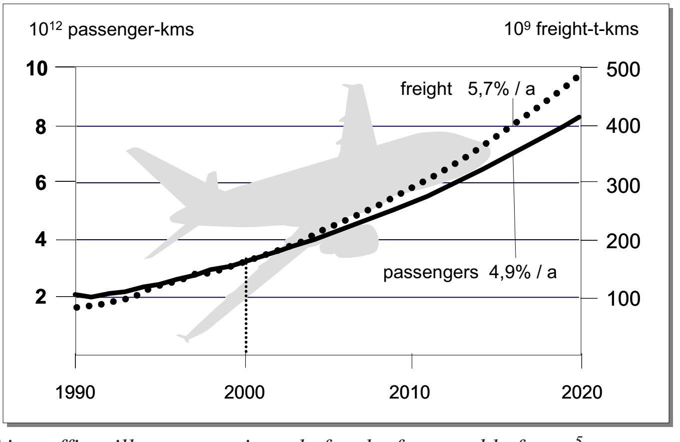

Fig. 3*: Air traffic will grow consistently for the foreseeable future*[5]

[5] Airbus Global Market Forecast 2000-2019, July 2000

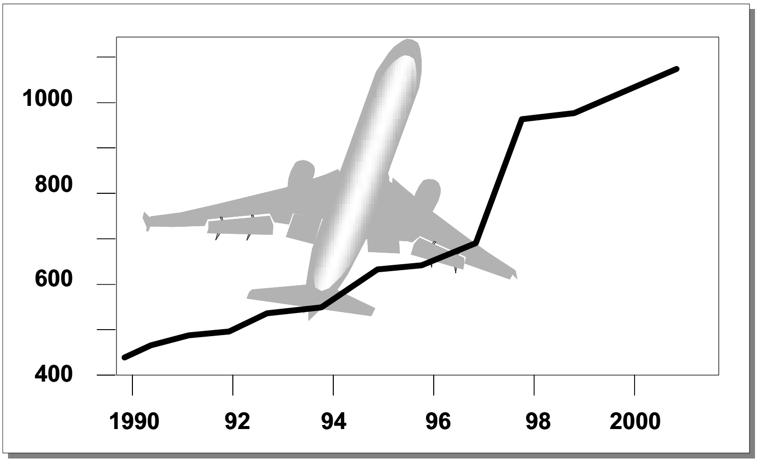

Fig. 4: *The number of airports worldwide with noise restrictions is growing*[6]

Making Aircraft Quieter

Aircraft noise is generated by the engines and the airframe. The noise disturbance of communities near airports depends on the noise produced by individual aircraft, the number of flight movements and on operational procedures during takeoff and landing. Accordingly, to achieve noise performance improvements, technical, operational and regulatory measures must be adopted.

Advanced technologies and new designs must be introduced to further reduce noise at the source, i.e. make engines and airframes quieter. During takeoff and landing, flight procedures must be followed that minimize noise contours on the ground. Finally, noise reduction policies must be put in place which provide both incentives to modernize fleets and restrictions for the noisiest aircraft.

In the following section the quest for new or improved noise reduction technologies for aircraft/engine systems is illustrated with a few examples with emphasis on work done by the German Aerospace Center (DLR) in its research centers and in cooperation with its partners.

[6] NASA Aviation Blueprint, 2002

Engine Noise

The engine system noise is generated by the rotating machinery, the combustion process and the jet flow from the nozzle. Turbo-machinery noise is composed of both broadband and tonal noise components, while the jet noise is broadband in nature (broad frequency range with no major amplitude changes or peaks). Since the introduction of the jet engine, improvements in aircraft engine technologies have brought dramatic benefits. With the appearance of bypass engines with current ratios of up to 6–9, the amount of the dominant noise caused by turbulence when the hot jet enters and mixes with the ambient air has decreased. While the jet engine exhaust from the core engine is still a major source of engine noise, the amount of noise from the bypass fan on a turbofan engine began to dominate, though on a lower level, as bypass ratios continued to grow, Fig. 5.

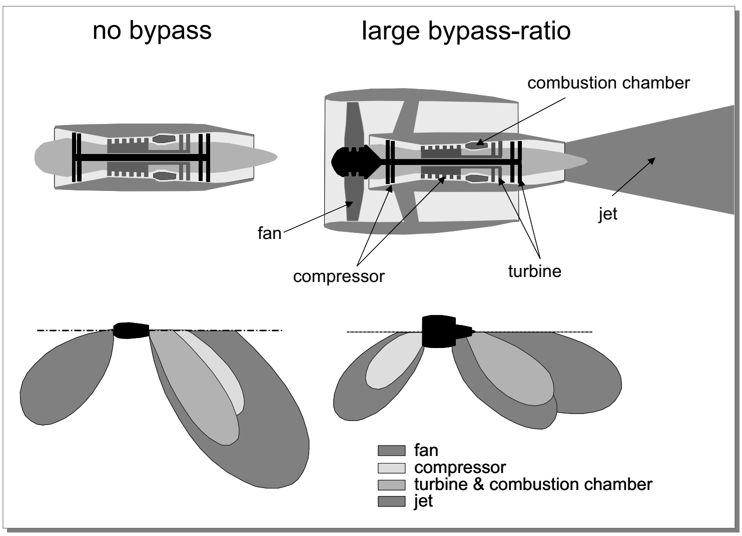

Fig. 5: *Schematic of engine noise sources and relative noise patterns for no-bypass and large-bypass engines*

In spite of the progress already achieved, a lot more can be done to reduce engine noise. There is a whole array of features and measures being studied. Many studies are directed at reducing fan noise by means of active noise control (ANC). ANC makes use of the principle that one sound can be canceled out by the opposite sound wave. That ANC can be successfully applied to reduce or remove tonal noise which is especially disturbing, was demonstrated by DLR and its partners. In an experimental setup simulating a turbofan engine, the inlet sound field was measured with microphones, and loudspeakers were used to produce the "counter sound" to reduce the forward fan-noise propagation, Fig. 6.

For the foreseeable future though, loudspeakers are too heavy, unreliable and consume too much space. As an alternative, aero-acoustic anti-sources could be generated by means of steady air jets in the casing in the blade-tip region of the rotor plane to "disturb" the flow around the blade tips[7].

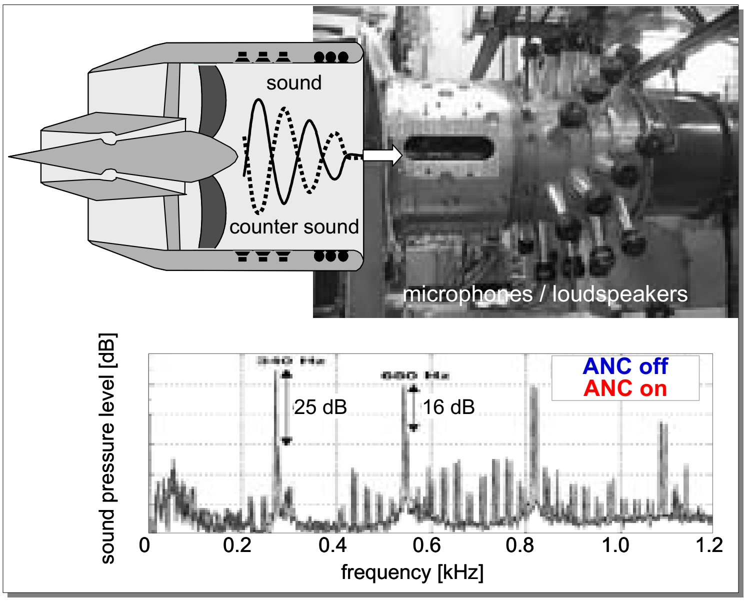

***Fig. 6:** ANC schematic and results of DLR test*

A goal further out in the future is an overall sound level reduction of 10–12 dB, deemed feasible with very high bypass engines, i.e. bypass ratios of 14 and higher. These engines would incorporate a geared fan to keep the relative flow speeds at the rotor tips subsonic, a low jet velocity and a low-noise core engine. Another feature of a "designed-to-noise engine" might

[7] Which technologies for future aircraft noise reduction? DLR's Researches, Ulf Michel, DLR, Institute of Propulsion Technology, Arcachon, France, 9-11 October 2002

be a scarfed inlet with a protruding lower front lip of the nacelle to shield off downward directed noise from the fan tips. Improved and area-maximized acoustic liners (sound energy absorbing materials inside the engine) can help dampen noise generation within the engine, including variable depth liners and active liners to adapt to different engine power settings.

At the near end of the time scale, noise reduction nozzles and nacelles also promise some alleviation of the noise problem. Studies have shown that the exhaust noise of the jet exiting the core can be reduced with a serrated or "chevron" nozzle. One of the studies involved a DLR-designed nozzle that was flight tested on a Lufthansa A319, Fig. 7. The saw-tooth geometry of the nozzle exit accelerates exhaust mixing by increasing the mixing area. In addition the engine shell or nacelle can also be serrated to accelerate the bypass exhaust mixing. Depending on the type of engine, chevrons can help reduce the takeoff jet exhaust noise by up to 4 dB[8].

Because of the positive results and because they can be retrofitted to existing engines, chevron nozzles may become a familiar sight in the years to come.

Fig. 7: *A319 equipped with chevroned nozzle (DLR-Lufthansa project)*

[8] Boeing, Rolls-Royce Work On A Quieter Future For Commercial Aviation, Boeing Press Release, SEATTLE, Nov. 2001

Airframe Noise

With aircraft engines having become quieter, the aerodynamic noise of the airframe now can be as loud or even louder than the engines during landing approach. Further improvements in engine noise reduction require similar accomplishments in airframe noise reduction.

Airframe noise is the non-propulsive noise made by an aircraft in flight because of the turbulent flow around the airframe, the biggest contributors being high lift devices and the landing gear, Fig. 8. Aircraft wings are designed for optimal cruise performance. Takeoff and landing require larger wing area and camber to ensure adequate lift and stall margins at low speeds. This is achieved by extending slats at the leading edge and flaps at the trailing edge of the wing, with the exposed edges, gaps and cavities of the high lift system and vibrating panels becoming noticeable noise sources. When the landing gear is deployed the turbulent flow past the landing gear structure generates additional noise. The noise is further augmented due to interaction between the jet and flaps and gear wake–gear and gear wake–flap interaction. Still other noise sources are uncovered wheel wells, cutouts and holes and vents.

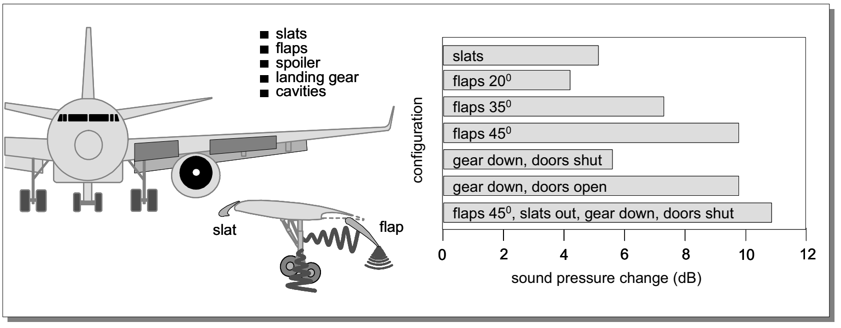

Fig. 8: *Airframe noise sources and sound pressure changes for different aircraft configurations (source: DLR and Lufthansa)*

The amount of noise and the respective sources during approach and the initial climb phase can be "seen" and mapped by means of acoustic cameras, large arrays of microphones on the ground below the flight path, Fig. 9. Acoustic cameras are a valuable if not indispensable tool to minimize – in addition to wind tunnel tests and simulation models – the noise generated by the aircraft system. They can distinguish between engine and airframe noise and locate with great accuracy the individual sources and measure noise sources reduction.

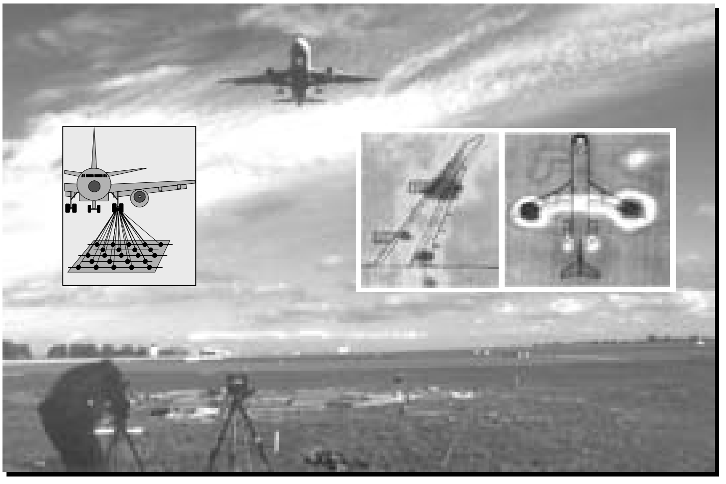

Fig. 9: *Acoustic camera arrangement (inserts: schematic and noise maps)- Source DLR*

To make the landing gear quieter, various noise reduction measures were considered and their effectiveness determined, Fig. 10. While a complete fairing may reduce noise by 10 dB, it is not a realistic solution because of weight and ability to stow the gear. Add-on treatment, like partial fairings to minimize flow separation and covers for pin-holes to avoid tonal noise, promise solutions with an average noise reduction potential between 2 to 3 dB in the near term. Higher noise reduction levels can only be achieved by completely redesigning landing gears, specifically by making them much shorter.

To study noise reduction solutions for in-service aircraft, DLR and Lufthansa have flight tested several modifications on the wing of an A319, demonstrating a short term noise reduction potential between 3-6 dB(A). The modifications included vortex generators to eliminate tone noise from holes in the wing surface, sealing of slat track cut-outs in the wing leading-edge and foam fillers for flap side-edge cavities, Fig. 11.

In addition, efforts comprising experiments as well as simulation models are under way that look at high lift concepts which promise to have low noise and high aerodynamic performance. This includes replacing slats with other means for high-lift generation avoiding gaps and edges for smoother air flow. In the very long term mission adaptive or morphing wings might provide a more thorough solution.

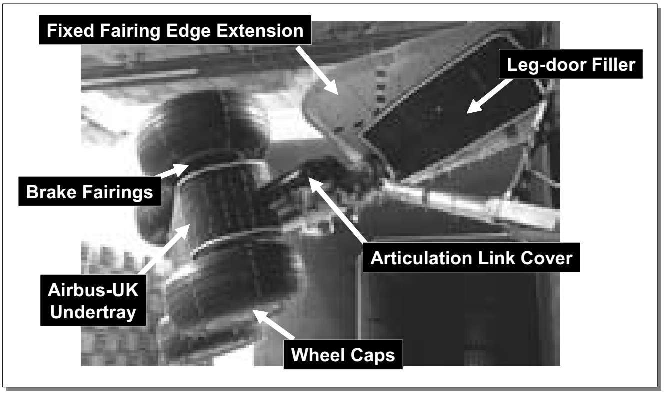

Fig. 10: *Wind tunnel test setup of landing gear fairings*[9]

Fig. 11: *Wing modifications to reduce noise of venting holes (left), edges (center) and track cut-outs (right) Source: DLR-Lufthansa*

Low-noise Flight Operations

Besides purely technical efforts to reduce noise at the source other ways of noise reduction must be exploited. Adopting low-noise operational procedures is expected to be an efficient way to reduce noise disturbance near airports. Among the "Quiet Traffic" network activities supported by the

9 Research into Landing Gear Airframe Noise Reduction, W. Dobrzynski et al, 8th AIAA/CEAS Aeroacoustics Conference, Breckenridge / USA June 2002

German Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) is a study that will also take a look at air traffic management issues, safety and pilot acceptance.

A continuous descent approach will keep incoming aircraft at higher altitudes before the final descent and will reduce noise related to changing power settings and airframe configurations required for the level flight segments of a stepped descent. Using higher glide slopes like 5^0 in lieu of the current 3^0 would have very noticeable effects on the footprint, Fig. 12. Other procedures include optimized track keeping to avoid highly populated areas or adjusting the flight path sideways to take into account prevailing crosswinds. Another measure to be studied is whether routing arriving or departing aircraft above and along high-noise bands created by ground traffic like autobahns or freeways will alleviate noise disturbance.

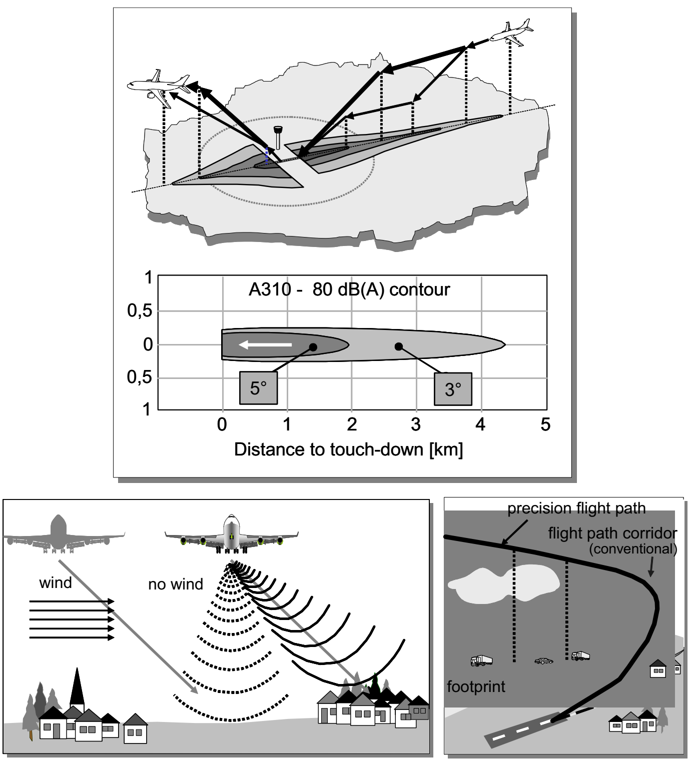

Fig. 12: *Low-noise flight operations: Continuous descent approach (top), optimized flight paths at crosswinds and above noise corridors (bottom)*

Conclusion

There appear to be sufficient technical and operational reduction potentials to make aircraft less noisy, Table 1.

Tab. 1: *Noise Reduction Potentials and Measures*[10]

Time frame	Measures
Short term (3-5 years): 2-3 dB	- airframe and landing gear modifications - serrated (chevron) nozzles, passive liners
Medium term (5-10 years): 5-6 dB	- low-noise flaps and landing gear; scarfed inlet - low-noise turbomachine design - active/passive noise reduction - low-noise takeoff and landing flight procedures
Long term (15-20 years): 10-12 dB	- "designed-to-noise" aircraft configurations - no gaps, unconventional edges, short landing gears - geared, high bypass fan (>14); airframe-engine integration - adequately quiet core engine - optimized air traffic management - steep, unconventional approaches and takeoffs

Ultimately the vision of quiet aircraft will be realized. Revolutionary "designed-to-noise" aircraft incorporating ultra high bypass engines equipped with geared fans will exhibit a 10-12 dB specific sound level reduction. These aircraft will necessitate alternative airframe-engine integration concepts that overcome ground clearance issues due to larger engine diameters and minimize the downward propagation of engine noise. They may look markedly different from today's aircraft, Fig. 13.

However, the noise problem will not be solved quickly because airframes and engines may stay in service for 30 years or more and the time span for fleet renewal consequently is long, Fig. 14. Also, the cost for research and innovation, development of unconventional solutions, procurement and service is high. Therefore, incentives for fleet modernization and regulatory measures are needed to accelerate the development and market introduction of innovative noise reduction technologies. Reward the best, punish the worst: Discounts on landing charges for quieter aircraft and the imposition of very high charges for noisy older aircraft would encourage airlines to use the "best available" technology and to modernize their fleets. Restrictions

[10] Potenziale der Lärmminderung im Flugverkehr, Heinrich B. Weyer, DLR. 10. Kolloquium Luftverkehr, Darmstadt, 27. Nov. 2002

or even curfews imposed on noisy aircraft during night hours would hasten their retirement. In Germany, some noise restrictions have already been introduced by the airports in Frankfurt and Hamburg. But regulatory measures should also include restrictions on settling close to airports.

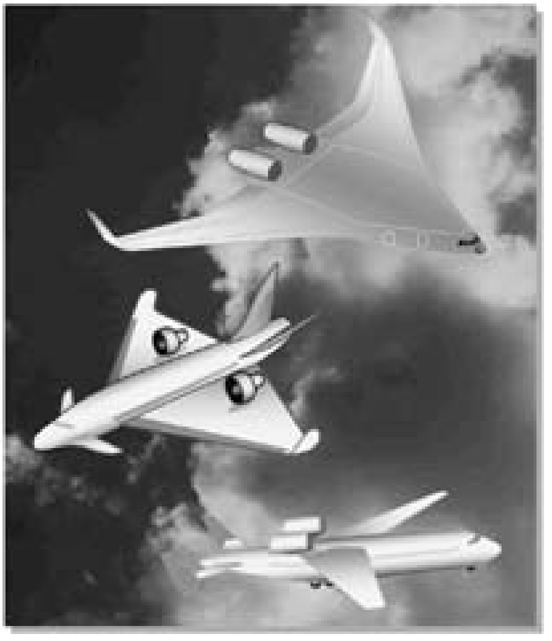

Fig. 13: *Vision of quiet aircraft*

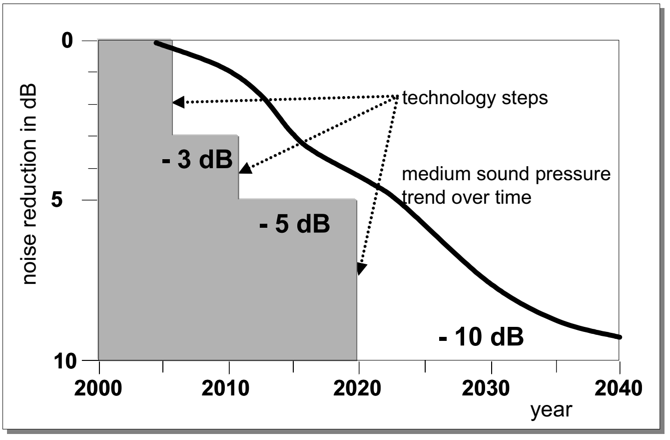

Fig. 14: *Schematic: Market penetration of low-noise technology innovations*

The combination of technical and operational measures supported by incentives and regulations seems to allow a fairly optimistic outlook. In the long term, air traffic growth will not be impaired by its noise emissions. The realistic goal is to confine objectionable noise to airport boundaries. Then there will be no further need for curfews, noise budgets or noise abatement procedures.

External Costs of Aircraft Noise

Rainer Friedrich

1 Introduction

The production and application of technologies, and here especially the transport of passengers and goods, cause considerable damage to human health, flora and fauna, ecosystems and materials. These impacts are mostly externalities, i.e. not reflected in the prices of goods. An external cost arises when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated for, by the first group.

This damage, however, should be considered in the framework of technology assessments and when taking decisions that have an impact on the amount of emissions, noise or accidents. A direct way to do this is the quantification of the damage and the subsequent transformation into monetary units based on the 'willingness-to-pay-approach'. The resulting external costs can then be used for the following purposes:

- Internalising external costs ('getting the prices right'). The Göteborg European Council (June 2001) for instance states: "Getting prices right" so that they better reflect the true costs to society of different activities would provide a better incentive for consumers and producers in everyday decisions about which goods and services to make or buy.
- Cost-Benefit-Analyses, e. g. for measures and directives to protect the environment and human health, e.g. the Amsterdam treaty (Art. 175) demands: 'In preparing its policy on the environment, the Community shall take account of the potential benefits and costs of action or lack of action'.
- Carrying out Technology Assessment, especially comparison of techniques, identification of weak points.
- Using external cost estimates to generate sustainability and welfare indicator: including sectoral impacts and import/export relationships.

Besides air pollution, congestion and accidents, noise is an important problem of transport causing external costs that should be internalised. Ideally, marginal costs (the costs of one additional air plane taking off from an airport) should be priced. Therefore, these external costs need to be quantified, preferably based on a clear, rational and consistent methodology. Especially for transport noise, the occurrence and impacts are obviously highly site and technology specific, i.e. noise damage depends on the number of persons affected and such on the population density and of course on the noise level. Therefore, a model must be able to represent the environment, the vehicle technology (e.g. low noise vehicles) and traffic situations (e.g. speed and traffic volume) adequately. This is essential when it comes to evaluation of transport policies and cost-benefit analysis. Only a detailed bottom-up approach meets these requirements.

In recent years there has been much progress in the analysis of environmental damage costs, thanks to several major projects evaluating the external costs of energy in Europe, especially a series of projects financed by the European Commission, DG Research, called ExternE (European Commission 1995a–f, 1999a–d). The report of the 1998–2000 phase is just published (Friedrich and Bickel 2001), and the latest phase – continuing until 2003 – has just started. The approach developed here is called impact-pathway approach.

2 The Impact Pathway Approach

The impact pathway approach – and coming along with this approach, the EcoSense model, an integrated software tool for environmental impact pathway assessment – was developed within the ExternE project series and represents its core. Impact pathway assessment is a bottom-up-approach in which environmental benefits and costs are estimated by following the pathway from source emissions dispersion and propagation in air, soil and water to physical impacts, before being expressed in monetary benefits and costs. The use of such a detailed bottom-up methodology – in contrast to earlier top-down approaches – is necessary, as external costs are highly site-dependent and as marginal (and not average) costs have to be calculated. An illustration of the main steps of the impact pathway methodology applied to the consequences of pollutant emissions is shown in the following diagram.

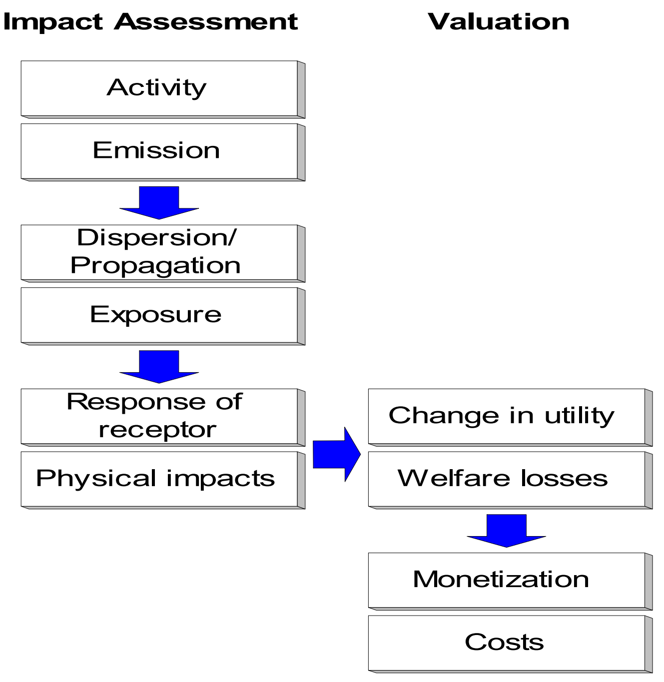

Fig. 1: *The Impact Pathway Approach*

The following table gives an overview of the health and environmental effects currently included in the analysis (please note that current research aims at constantly enlarging this list). The main categories are human health (fatal and non-fatal effects), effects on crops and materials. Moreover, damage caused by global warming instigated by greenhouse gases have been assessed on a global level within ExternE; however the range of uncertainty is much higher for global warming impacts than for other damage.

In addition to the damage cost estimates, for impacts on ecosystems and global warming, where damage cost estimates show large uncertainty ranges, marginal and total avoidance costs to reach agreed environmental aims are calculated as an alternative second best approach. The costs for ecosystems are based on the political aim of reducing the area in the EU where critical loads are exceeded by 50%. For global warming a shadow price for reaching the Kyoto reduction targets is used.

Tab. 1: *Impact pathways of health and environmental effects included in the analysis*

Impact Category	**Pollutant/ Burden**	**Effects**
Human Health – mortality	PM_{10}[a], SO_2 NO_X, O_3	Reduction in life expectancy
	Benzene, Benzo-[a]-pyrene 1,3-butadiene Diesel particles	Cancers
	Noise	Myocard infarction
	Accident risk	Fatality risk from traffic and workplace accidents
Human Health – morbidity	PM_{10}, O_3, SO_2	Respiratory hospital admissions
	PM_{10}, O_3	Restricted activity days
	PM_{10}, CO	Congestive heart failure
	Benzene, Benzo-[a]-pyrene 1,3-butadiene Diesel particles	Cancer risk (non-fatal)
	PM_{10}	Cerebro-vascular hospital admissions, cases of chronic bronchitis, cases of chronic cough in children, cough in asthmatics, lower respiratory symptoms
	O_3	Asthma attacks, symptom days
	Noise	Myocardial infarction, angina pectoris, hypertension, sleep disturbance
	Accident risk	Risk of injuries from traffic and workplace accidents
Building Material	SO_2 Acid deposition	Ageing of galvanised steel, limestone, mortar, sand-stone, paint, rendering, and zinc for utilitarian buildings
	Combustion particles	Soiling of buildings

[a] particles with an aerodynamic diameter < 10 μm, including secondary particles (sulphate and nitrate aerosols)

Crops	NO_X, SO_2	Yield change for wheat, barley, rye, oats, potato, sugar beet
	O_3	Yield change for wheat, barley, rye, oats, potato, rice, tobacco, sunflower seed
	Acid deposition	Increased need for liming
Global Warming	CO_2, CH_4, N_2O, N, S	World-wide effects on mortality, morbidity, coastal impacts, agriculture, energy demand, and economic impacts due to temperature change and sea level rise
Amenity losses Annoyance	Noise	Amenity losses, annoyance due to noise exposure
Ecosystems	Acid deposition, nitrogen deposition	Acidity and eutrophication (avoidance costs for reducing areas where critical loads are exceeded)

As it can be seen, morbidity and mortality impacts of noise as well as annoyance and amenity losses are considered.

To get monetary values for the damage, in some cases (material and crop damage) market prices can be used. For the other impacts, including the most important damage categories mortality and morbidity, market prices do not exist. Evaluation is only possible on the basis of the willingness-to-pay or willingness-to-accept approach that is based on individual preferences. For some non-market goods the willingness to pay can be measured with indirect evaluation methods including hedonic pricing (wage differences due to risks, price changes of houses or rents due to difference in air pollution or noise) and the use of travel costs or prevention costs. For most applications direct evaluation methods (contingent valuation, contingent ranking) are used. In the economic literature, a lot of studies that estimate such values, are available. The monetary values recommended in ExternE by the economic expert group have been derived on the basis of informal meta-analysis (in the case of mortality values) and most recent robust estimates.

3 Impact Pathway Analysis for Noise

For estimating the external costs, the following cost categories should be considered:

- Resource costs / costs for reducing or avoiding impacts e.g. medical costs or noise prevention measures, as long as these costs are not paid by the party responsible for the noise.
- Opportunity costs, e.g. costs of lost productivity.
- Dis-utility i.e. costs from discomfort, inconvenience, pain or suffering, of people affected and concern of others.

Usually the third category is by far the most important.

As the first step, the exposure to noise has to be calculated. As measure for noise exposure usually the Day-Evening-Night-Level Lden is used:

$$L_{den} = 10 \lg 1/24(12*10^{Lday/10} + 4*10^{(Levening+5)/10} + 8*10^{(Lnight+10)/10})$$

with L= A-weighted long-term average sound level in dB(A);
Day: 07 – 19 h; Evening: 19 - 23 h; Night: 23 – 07 h.

For sleep disturbance, $L_{Aeq, 23\text{-}7h}$ is used.

Noise levels are calculated as incident sound at the façade of the buildings neglecting reflected sound. The number and type of buildings exposed are analysed in detail by visual inspection of the sites of urban case-studies and calculated with a GIS approach for the interurban case studies.

Having calculated noise exposure, the following exposure-response functions are used to assess the impacts. They are based on a state of the art summary by de Kluizenaar and Passchier-Vermeer (2001).

Tab. 2: *Exposure-response-relationships for health impacts and sleep disturbance*

Endpoint	Threshold dB(A) $_{LDEN}$	Expectancy value (per 1000 adults exposed)
Myocard infarction (MI), fatal, Years of life lost (YOLL)	70	$0.084\ L_{DEN} – 5.25$
Myocard infarction (non-fatal), days in hospital	70	$0.504\ L_{DEN} – 31.5$
Myocard infarction (non-fatal), days absent from work	70	$0.896\ L_{DEN}$ - 56
Myocard infarction, expected cases of morbidity	70	$0.028\ L_{DEN} – 1.75$
Angina pectoris, days in hospital	70	$0.168\ L_{DEN} – 10.5$
Angina pectoris, days absent from work	70	$0.684\ L_{DEN} – 42.75$
Angina pectoris, expected no. of morbidity days	70	$0.240\ L_{DEN}$ - 15
Hypertension, days in hospital	70	$0.063\ L_{DEN} – 4.5$
Subjective sleep quality		% of adult population
Road traffic	43.2	$0.62\ (L_{Aeq,23\text{-}07h} – 43.2)$
Rail traffic	40.0	$0.32\ (L_{Aeq,23\text{-}07h} – 40.0)$
Aircraft noise	32.6	$0.48\ (L_{Aeq,23\text{-}07h} – 32.6)$

The most important impact category causing the highest damage however is annoyance. For assessing annoyance, two approaches are used:

– Hedonic pricing: a Noise Depreciation Sensitivity Index (NDSI) (average percentage change in property prices per decibel) derived from studies for a number of airports is used to estimate the property price loss due to noise; the change of rental charges is also used. NDSI studies have been mainly performed in the UK (London, Manchester), Canada and the US, values are in the range of 0,4 –2,3 % depreciation in house prices per 1 dB(A) increase in noise level. Depreciation is assumed to start at 55 dB.

– Stated preference: here again two methods are used. In the first method, the willingness to pay (WTP) for a defined noise reduction converted into WTP per decibel per household is directly measured via surveys. The second method converts a change of the noise level in a change in percentage of persons with different qualitative annoyance levels (e.g. little annoyed/ annoyed/ highly annoyed) and then uses a fixed WTP per person and annoyance level.

As an example, Fig. 2 shows the transformation of noise levels into percentage of annoyance categories.

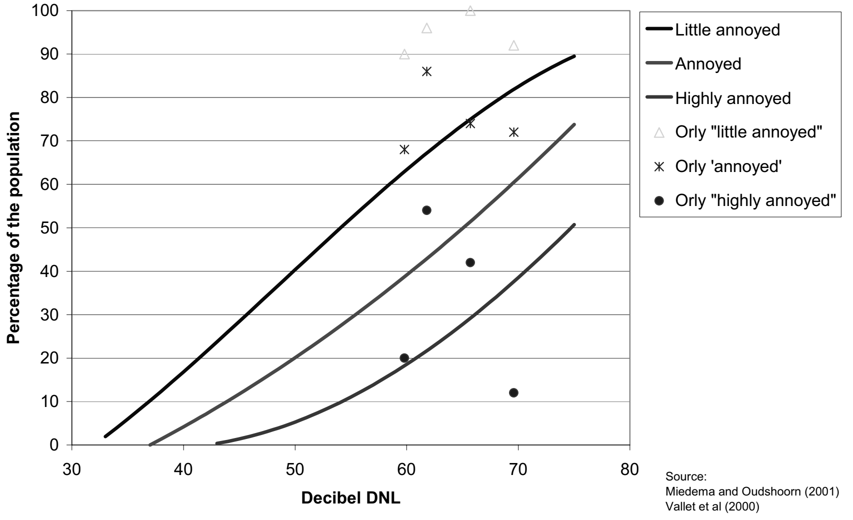

Fig. 2: *Relation between noise level and percentage of population, that is at least little annoyed, annoyed and highly annoyed; results from a survey around Orly are included.*

Currently used monetary values for the assessment of the impacts of noise described above are given in Table 3.

Tab. 3: *Monetary values for health impacts and amenity losses.*

Endpoint	Value	Unit
Myocard infarction (MI), fatal, 7 years of life lost	96500	€ per YOLL
Myocard infarction (non-fatal), hospital costs	680	€ per cardiology-related inpatient day
Myocard infarction (non-fatal), absenteeism from work	100	€ per day of illness
Myocard infarction, WTP to avoid morbidity	14360	€ per case
Angina pectoris, hospital costs	680	€ per cardiology-related inpatient day
Angina pectoris, absenteeism from work	100	€ per day of illness
Angina pectoris, WTP to avoid morbidity	230	€ per day
Hypertension, hospital costs	350	€ per inpatient day
Subjective sleep quality, cost-of-illness	220	€ per year
Subjective sleep quality, WTP to avoid disturbance	370	€ per year
Amenity loss	16	€ per dB(A) over 55 dB(A)

Source: own calculations based on [5].

4 Results

The generation of results is currently ongoing in the frame of different research projects; thus only some preliminary and partial results are shown.

Fig. 3 shows external costs of road transport for different vehicles that are operated in the city of Berlin. External costs for global warming, air pollution and noise are shown. As it can be seen, external costs of noise are time dependent, the same vehicle produces more costs at night than during the day. For individual transport in urban agglomerations, noise is clearly the most important impact. Furthermore, motorcycles cause by far the highest noise impacts per person/km.

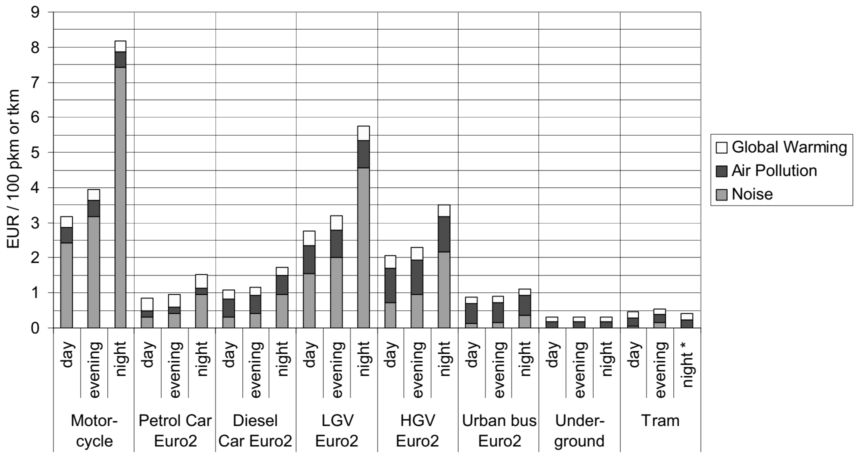

Fig. 3: *External costs of urban transport (in Berlin)*

With regard to aircrafts, Fig. 4 shows the external costs caused by a flight of an aircraft (Boeing 737-400) from Berlin Tegel to London Heathrow. Please note that some effects on global warming due to emissions of pollutants in high altitudes are not included, as due to high uncertainties no quantitative estimate on the contribution to global warming can yet be made. Noise costs only occur during take-off and landing and amount to ca. 55 € per flight and ca. 14% of total external costs.

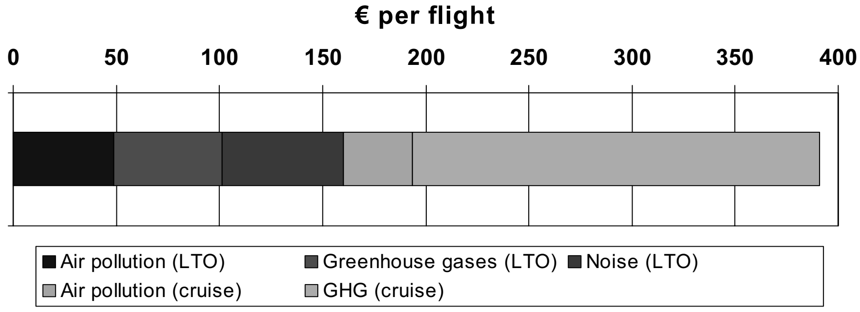

Fig. 4: *External costs of one flight of a Boeing 737-400 from Berlin to London*

While Fig. 4 shows a result of marginal costs, Tables 4 and 5 show results of the external costs of aircraft noise for the whole operation of an airport over one year.

Tab. 4: *Annoyance reactions in the population due to noise exposure at Zürich airport*

Annoyance level	Persons
Total population affected with noise levels of 45-80 dB(A) Laeq 6-22h	638 000
Not annoyed	355 000
Little annoyed	132 000
Annoyed	98 000
Highly annoyed	53 000

Tab. 5: *External costs from noise exposure at Zürich airport (€$_{1998}$/year)*

Cost category	Value
Myocardial infarction (fatal, non-fatal)	371 000
Angina pectoris	4 000
Hypertension (hospital admissions only)	-
Medical costs due to sleep disturbance (per year)	1 850 000
Amenity loss	15 500 000
Total	17 725 000
Source: IER for UNITE	

As it can be seen, amenity loss is by far the most important source of noise impacts. Fig. 5 gives an overview over the total noise costs for different modes in Germany. Aircraft noise costs are less high than those of road, as damage is concentrated near airports and not nearly everywhere as with road transport.

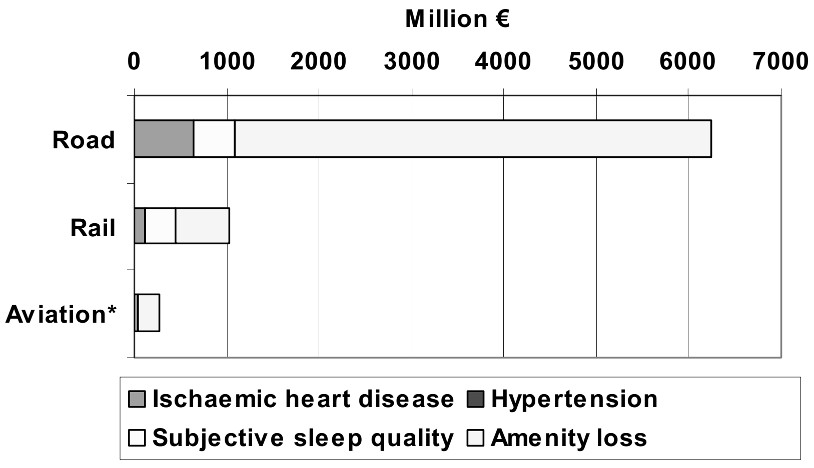

Fig. 5: *Noise costs from transport in Germany 1998 (*for aviation sleep quality loss not included due to lack of data)*

The overall damage costs of transport in Germany is shown in Fig. 6. Total damage amounts to 33 000 Million € (1.7% of GDP 1998).

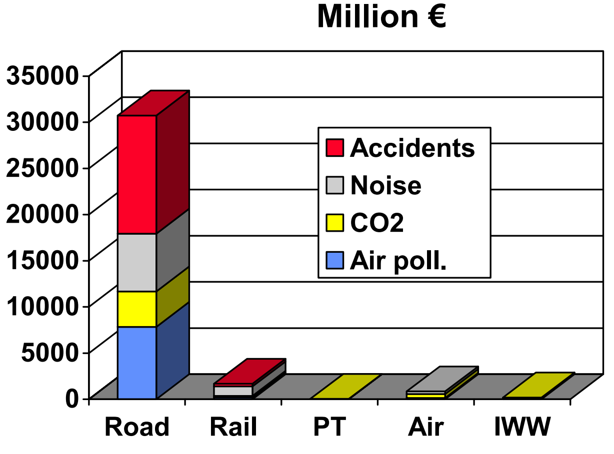

Fig. 6: *External costs of transport in Germany 1998*

The uncertainty associated with these estimations of external costs and the variation of results, if different assumptions are used, are still quite high. Parts of this uncertainty are caused by uncertainties of models and methods used, uncertainties of input data, uncertainties about impacts. However, these reflect uncertainty of current knowledge. An assessment of impacts can not be more certain than the knowledge about the generation of these impacts. Further research can reduce these uncertainties.

Furthermore, a bandwidth of the results is caused by different assumptions and hypothesis, e.g. about interest rates, choice of hypothesis with regard to exposure-response-relationship, method used for monetary valuation. Here, the bandwidth can be calculated by using sensitivity analyses and then presented together with the results, however it is also possible to agree on the assumptions to be used in a process involving decision maker and stake holder.

Despite these uncertainties, the use of the methods described here is seen to be useful, as

– the knowledge of a possible range of the external costs is obviously a better aid for policy decisions than the alternative – having no quantitative information at all;
– The relative importance of different impact pathways is identified (e.g. has benzene in street canyons a higher impact on human health than fine particles?);
– the important parameters or key drivers, that cause high external costs, are identified;
– the decision making process will become more transparent and comprehensible; a rational discussion of the underlying assumptions and political aims is facilitated;
– areas for priority research will be identified.

Furthermore, in many applications the ranking of problems or technologies remains the same when changing external cost estimate within the uncertainty range.

5 Summary

The Impact Pathway Approach is a - is *the* - state-of-the-art methodology for quantifying impacts from airborne emissions and noise, as costs vary with local environment and geographical location. It is a means to estimate damage costs that can be used as decision aid in

- identifying the most suitable form of eco-political instruments like eco-taxes,
- performing cost benefit analysis for assessing measures or strategies for environmental protection,
- identifying environmental aims (e.g. air pollution thresholds, where marginal damage costs match marginal avoidance costs),
- accounting for changes of the state of the environment (green accounting) and
- comparing the social costs of different technologies, thereby regarding internal costs as well as environmental and health impacts.

The method has already been extensively used to support decisions concerning a number of air quality directives of the European Commission (e.g. the draft ozone directive, the national emissions ceiling directive, the draft directive on non-hazardous waste incineration, air quality guidelines on CO and benzene), the UN/ECE multi-pollutant, multi-effect protocol and a number of national activities. The methodology is constantly further developed.

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Aircraft Noise – Juridical Aspects

Carlos San Martín Castaño

Introduction

Nowadays, noise has turned into one of the most important among the environmental factors on which industry, transport and community set down a big part of their efforts and concerns. It is particularly relevant in urban environments, where the sustainability of new developments has achieved different levels that are very difficult to balance.

At present, nobody forgets that it is impossible to contemplate economic development without regarding its sustainability. Our levels of progress keep increasing, as far as interference and potential impacts are concerned.

Airports, as big economic centres and true driving forces for both social and cultural development, can not ignore their responsibility for the preservation of the quality of life of the society it serves. In this sense, noise is one of the main concerns of the community in the vicinities of the airports.

So, from the earliest stages of the planning process (such as Master Plans) to the definition of routes, manoeuvres, procedures, air traffic management, etc., noise must be incorporated as one of the inputs for the final solutions to be carried out and must be given similar levels of priority to the others.

Quoting from the French writer Jean-Henry Fabre (1823–1915), we must "observe first, and then argue". Regarding the juridical aspects, we have to analyse first the elements of the scope that will determine all the legislation framework, decisions to be taken and actions to be carried out.

Sources

Maybe air travel represents one of the most ambitious achievements of our civilisation. But this desire to fly, as ancient as the world, like any other objective, is not free. A plane in the air involves an interaction among complex mechanisms, forces, fluids (air), as well as consumption of natural resources (fuel, water) and causes the emission of pollutant gases and, of course, noise. In this regard, there are 3 main types of noise generated by an aircraft. First, and most important by far, the noise caused by the engines, both mechanical and that caused by the flow of exhaust gases. Then we have the aerodynamic noise, representing the disturbance of the airflow, caused by the surfaces of the aeroplane (wings, fuselage, tail, engines, flaps, etc.) and the connections between them, which produces variations of pressure, resulting in noise. Finally, the operations of the aircraft in the airport, cause the so-called "ground noise", perceived in the vicinities of the airports. It includes the friction between the tyres of the landing gears and the runways and landing strips, as well as auxiliary systems for the energy needs.

Aircraft operations not only in the air, but also at the airports, already follow defined procedures and paths as well as maintaining horizontal and vertical speed limits in accordance with air traffic regulations. So, air traffic control and management is one of the fields in which we can improve noise abatement measures to reduce the negative impacts of air transport. The huge complexity of the systems means that the analysis of noise caused by aircraft requires different approaches. The improvement of aerodynamic behaviour, runway surfacing in airports, the development of quieter engines, more efficient fuels, etc. as well as current certification procedures are all measures to be taken to enhance safety and environmental noise reduction in the field of air transport.

Appropriately conceived flight navigation and routing procedures can achieve substantial reductions in noise emissions, for example by avoiding densely populated areas, by installing efficient instrument landing systems, beacons, satellite controlled global positioning systems and by opening restricted areas, etc. Moreover, apart from aircraft, lots of different noise sources converge in an airport, turning noise into an enormous mixture of elements with very different origins. We have auxiliary vehicles going up and down the aprons, other industrial facilities located in the airport, and the interactive access of a wide variety of traffic means, such as trains, high speed trains, and above all road vehicles, representing an important portion of the total amount of noise perceived by people near the airport. The quantification of each contribution to this total volume is very difficult to achieve, although it is necessary. It would be very helpful to determine the principal sources of noise in each airport, then to take measures in order to decrease noise emissions at each respective source, thus reducing the total noise emission.

To this end, the development of adequate modelling tools and software will help us to determine the better solutions and to allocate responsibilities. To achieve this, co-ordination is imperative. Basically, it is necessary to focus on the protection of the airport environment and to take care of the quality of life of its neighbours. In any case, when developing the land in the vicinity of an airport one cannot simply ignore airport noise: The establishment of restrictions on future development may be required to avoid unnecessary annoyances.

Principles

Airport authorities, as well as the other stakeholders and the legislative bodies must be guided by certain general principles. Abatement measures should be the last choice. Opportunities for improvement must be detected at source and managed accordingly. Preventive action should be taken and environmental damage should be rectified on the spot. We should not wait until damage occurs. The development, implementation and adaptation of effective legislative measures must always remain several steps ahead of the emergence of risk prone activities.

In any case, given that it is impossible to avoid all potential impacts, it is necessary to allocate responsibility according to the "the polluter should pay" principle. In this sense, it is essential to determine who the polluter is (the company?, the manufacturer?, the airport?, …). The answer to that question is as important as the need to determine the responsibilities for the adverse effects of noise on the population and, therefore, who is going to finance abatement or other mitigation measures. This question has received different answers from different countries . In some cases, the passenger, as recipient of the service, is considered responsible and is called upon to pay a small contribution towards noise reduction by means of a tax on his/her ticket. Apart from the juridical concepts that can be involved in that case, it is also a political decision which, therefore, will depend on a lot of factors.

Finally, the precautionary principle reminds us that we are still at an early stage of our scientific and technical development, and, in each particular case where we do not have enough evidence, this principle obliges us – according to the results of the available estimations – to ensure the highest possible amount of security in our decisions by allowing an appropriate safety margin. However, as it can be seen from the European Commission Communication on the precautionary principle of 2000, its scope is far wider and covers those specific circumstances where scientific evidence is insufficient, inconclusive or uncertain and when there are reasonable indications, following preliminary objective scientific indications, that potential, dangerous effects on the environment, or on human, animal or plant health may be inconsistent with the determined level of protection. This precautionary principle is specifically mentioned in many texts relating to environmental matters – not only legal – and it is globally accepted as a rule for improving the conditions of our natural values, heritage and quality of life.

Aiming at widening the scope of legislation in order to meet all the stakeholders' interests, our democratic system offers us many tools for changing the law or enlarging its scope or level of legal enforceability. And they all have to be used, but in the appropriate way.

Legislative scope

Aircraft noise involves a complex field of legislation, integrating different levels: from international recommendations on noise concerns to norms directed to each competent local administration. The integration of such a complex overall system requires different means of implementation can be summarised in 4 groups:

- Planning procedures,
- Assessment procedures,
- Execution procedures for measures against adverse noise impacts,
- Procedures for imposing restrictions on certain operations.

In the first stage, at international level, several organisations have shown their concerns about the influences of noise on the world population, as it is considered to be a problem not confined to developed areas or countries, but as a global issue, affecting in one way or another the global society as a whole.

The Universal Declaration of Human Rights of 1948 recognises the right to privacy, rest, leisure and all those concepts that can be taken as essential for life. Nobody can deny that noise is truly detrimental to all these conditions, apart from the difficulties it creates in the fields of communication, recreation, reflection, etc., which we all have the right to enjoy. As a result, the United Nations, acting as a spokesman of the countries concerned, has approved by means of its General Assembly, several resolutions on the need to ensure a healthy environment for the well-being of individuals. The World Health Organisation has performed studies and taken a complex series of actions in formulating recommendations to ensure this goal. Similar tasks have been performed by several scientific organisations. All of them, though they have no legally binding mandate, have formulated recommendations on practices to be complied with that will help to decide levels, procedures, and so on, to be included in a legally enforceable framework.

Moreover, the air transport services of the various countries are committed to fulfil all the recommendations and rules established by the supranational organisations of which they are part. The ICAO (International Civil Aviation Organisation), created in 1944, establishes rules related to the certification of aircraft depending on noise, by means of the so-called *chapters,* and the way to achieve them and secondly, ICAO sets up recommendations on practices aimed at a more environment-friendly development of air transport. In that sense, the introduction of the "balanced approach" relating to noise management is one of the main keys to join and work together in the search for solutions to the current problems by balancing the different interests and peculiarities of the countries involved under the same organisation. In Europe several Directives are in force which, on the one hand, stipulate the introduction of operating restrictions and, on the other hand, lay down the regulations with regard to different practices in the field of planning and noise impact management.

In the overall context, there is a number of legal texts and several other documents which reflect current concern in Europe regarding the subject of noise. Thus the Green Paper on future noise policy defines noise as one of the main environmental problems in Europe. Subsequently, the resolution of 1997 expressed the Parliament's support for that Paper, urging that specific measures and initiatives should be laid down in a Directive on the reduction of environmental noise. One of the main aims of the Green Paper is to help to give noise abatement a higher priority in policy making, demanding a scope of co-operation across the European Community. Apart from that demand, attention is drawn to the lack of reliable and comparable data regarding the circumstances pertaining to various noise sources. This paper, which shook a lot of consciences, induces several initiatives to take into account the aforesaid information, and put us at work on various directives to come.

Regarding the limitation of noise emissions, the Directive 80/51/EEC of 1979 represented the first step in that process, demanding a noise certification of aircraft registered in the Member States according to annex 16 to the Convention on International Civil Aviation. According to this, Directive 89/629/EEC establishes stricter rules for the limitation of noise emissions from civil subsonic jet aeroplanes, developing the first step aiming at forbidding operations unless a noise certification to the standards at least equal to those specified as chapter 3 is granted. After that first stage, the Directive of 92/14/EEC of 1992 determines that no ICAO chapter 2 aircraft is able to operate at European airports from the first of April of 2002.

The recent Directive of 2002/30/EC of 2002 goes to the same direction, imposing further restrictions on noisy aircraft. This Directive sets down several objectives aiming at improving the noise situation all around the European airports. It does not establish specific actions towards the reduction of noise impacts, but all along its text you may find various targets that have to be achieved. Among them, it can be pointed out that marginally compliant aircraft are likely to disappear from our airports if this is considered necessary for obtaining the set goals. If that is the case, a progressive procedure for restricting the operation of such aircraft is defined. This process (among the states) has no common deadline, but one depending on the moment when the decision to ban the operations of this sort of aircraft is taken.

The aforesaid Directives are related to aircraft noise itself. Given that it is essential to define a common approach in order to reduce the total noise impact, Directive 2002/49/EC of 2002 imposes a solution for that problem in the European Union, providing the common criteria that all the European countries must enforce to achieve their environmental and social objectives. Noise is treated in this Directive as a highest priority concern for the involved authorities and as an essential challenge for the improvement of the quality of life of our societies. Directive 2002/49/EC involves, in fact, a lot of obligatory practices that have to be carried out by every authority and demands determination from them in order to share and co-ordinate efforts. It in fact provides the framework within which noise concerns have to be dealt with, leaving it to the national authorities to conduct further analyses and to decide for themselves on the best way to reach the aims. The large number of definitions of terms (up to 22) shows clearly the will to create uniform criteria and provide a common approach to noise, which, by the way, facilitates juridical considerations.

In its harmonising role, Directive 2002/49/EC proposes common assessment methods following the ISO (International Organisation for Standardization) assumptions and the use of equalising indicators, defining how annoyance and disturbance should be represented. The way in which the 24-hour day should be divided into periods is subject to further decisions in each country, although default values are provided. It is the same case for the limit values, another of the key points to be defined in each country. Additionally, this Directive demands the elaboration of action plans as well as strategic maps for the critical sources and urban zones, subject to periodic revision and adaptation to technical and scientific progress. These tasks are to be performed transparently by means of consultation, public information, and co-ordination among the authorities.

Regarding aircraft noise, the major airports, defined by those with more than 50.000 movements per year, are considered as key points affecting the noise profile of the territory in Europe, and, therefore, the Directive demands the elaboration of strategic noise maps (comprising the present and future horizons) and of action plans. They shall cover all noise matters with the purpose of detecting the critical areas where improvements are needed, including the operating restrictions to be carried out and the noise assessment of airport projects. At national level, several legal texts coexist, depending on the competent administrations that take the responsibility for every related item. State, regional and local authorities must co-ordinate their efforts and resources in order to achieve a comprehensive approach to noise which should integrate and balance the different interests involved. In that sense, individual state laws on the protection against noise pollution should have similar preservation objectives as the European ones, however, in more concrete terms, incorporating the national experience and peculiarities of the individual country and its regions.

In general, these legal texts provide reference levels, indicators, methodologies and criteria for the authorities to apply. Mostly they establish a zoning of the territory, depending on uses and permitted levels in each defined type. Land use planning restrictions will be based on these criteria, so it is of essential importance for a comprehensive co-ordination. Different responsibilities should also be defined, depending on each task. In general it can be concluded that the regional authorities have a great part of the powers over the noise management of the respective regions, depending on their statutes. Thus, municipalities shall have the duty to carry out all the surveillance and abatement measures. The competence to classify noisy activities is also in the hands of local authorities.

Public information and participation are demanded for all the procedures involved in order to improve transparency and promote social acceptance of the projects. Finally, it must be remembered that legislative measures have a far reaching effect which can impinge upon the private life-style and behaviour patterns of every individual even inside his or her own home. In each home, each individual has his/her own rules, and legislators should not forget this. Of course, it is impossible to fit every single opinion into a common text, but there are local and particular circumstances that must be fully taken into account.

Freedom of Access to Information on the Environment

Another legal aspect related to the environmental concerns of our European societies is the freedom of access to information on the environment. The

Council Directive 90/313/EEC of 7th June 1990 on the freedom of access to information on the environment ensures freedom of access to, and dissemination of, information on the environment held by public authorities and sets out the basic terms and conditions on which such information should be made available. Information relating to the environment refers to any available information on the state of environmental matters and on activities (including those which give rise to nuisances such as noise) concerning the environment.

This means that, under certain conditions, everyone shall have the right to be informed (within two months after filing the request) about any legally recognised environmental issue covered by both European and national legislation. For the same reason, all items deemed relevant during an aircraft noise assessment or mitigation process must be public, which is included in the Directive on environmental noise management of 2002. This improves the transparency of the actions as well as social awareness concerning airport projects.

Environmental Impact Assessment

Apart from noise legislation itself and the aforesaid freedom of access to information, there are other legal documents that deal with environmental impact assessment. They establish practices and policies, with regard to the preservation of natural values, heritage and the quality of life of the people affected. They all demand that an assessment of noise impacts shall be carried out for certain projects, plans and programmes. These procedures incorporate the environment (including noise) into the decision making process, from the initial planning phases until the building and operation of the project. As a preventive instrument, this approach has the potential to reveal the most environment friendly solutions because it identifies the environmental impacts and tries to balance them, as well as to define the appropriate mitigation measures. The proper application of these techniques results in savings on inversions and costs and helps to promote social acceptance of the project.

At the European level, Directive 85/337/EEC of 1985, amended by the Directive 97/11/EEC of 1997 demands an environmental impact assessment for certain projects (including airports) with significant potential impacts on the natural values, heritage and, of course, on us and our health. These projects are specified (and listed in the respective annexes) in two types. Those that may be carried out immediately, and those that require consultation with the environmental authority concerning the necessity to proceed with the respective project. This framework is transposed into the national scope, and it reflects the assumptions and methodologies, considering the peculiarities of each country and the appropriate distribution of competencies.

Thus, noise has attained a new legal status, i.e. it is subject to obligatory assessment during the planning phases of some projects. If actions to achieve a proper study of noise impacts at airports are not carried out in time – thus resulting in unacceptable impacts on the population, those responsible must be determined and made accountable.

Every stakeholder, from the project promoter and public administrations to every single affected citizen, gets involved along that process which concludes with the formulation by the Environmental Authority of a declaration of environmental impact. These declarations usually include several conditions in order to improve the environmental feasibility of the projects. Since they are published in the official gazette, these conditions become legally binding requirements. Moreover, Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment goes beyond the execution of certain projects. It means one step more in the direction to a stricter status of environmental protection, enlarging its scope over the decision making process and over the planning figures (plans and programmes). It provides an effective instrument for anticipating the impacts during the planning process, looking for the most environment friendly solutions.

Actions

As an example, we can have a look at the Madrid-Barajas Airport, where several measures have been carried out in order to reduce its potential noise impacts. Madrid-Barajas, as the 16th largest airport in the world and the 5th in Europe in terms of passenger traffic during 2001, is the main resort of Aena. Its huge contribution to the social and economic development of the region must be considered by all the involved stakeholders. Following an increasing capacity demand, different expansions of the airport systems have been carried out, while avoiding, as far as possible, any loss in quality of the services offered. Therefore several actions are being taken in order to reduce the noise due to aircraft operations of the new systems. Airport authorities have three main ways to achieve this goal.

- Firstly, by establishing prohibitions affecting operational items, like landing stream reversals, limitations on traffic, Auxiliary Power Units and engine tests.
- Secondly, by measuring, modelling and surveillance of the noise impacts produced .
- Finally, by using planning tools regarding air traffic management procedures or traffic distributions.

In Madrid, a complex series of actions is being carried out. Among these, it can be pointed out:

- Ban of ICAO Chapter 2 aircraft.
- Operational restrictions between 24:00 – 06:00 hours for the noisiest aircraft.
- Operational restrictions on the noise generated by operations on the aircraft aprons.
- Implementation of a noise quota in the airport for night operations, which guarantees noise will not increase even if the number of operations is higher.
- Ban on gas exhaust stream reversals during landing operations at night.
- Ban on the use of Auxiliary Power Units (APU) during the night.
- Ban on engine tests outside the designated area.
- Redistribution of traffic loads.
- Planning new routes and Air Traffic Management (ATM) procedures.
- Modification of the entrance and exit routes.
- Installation of the navigational aid VOR/DME.

– Revision, by the competent authorities, of the land use plans according to the predicted noise levels.
– Program of Noise Surveillance, with the elaboration of periodic reports.
– Installation of a Flight Paths and Monitoring System and of measuring stations all along the airport system and its vicinities.
– Construction of noise abatement walls.
– Installation of noise protections around the new access facilities.
– Studies to determine new locations or actions on the Engine Test Area.
– Carry out a Noise Insulation Scheme.

One of the most significant aspects that is being applied in Madrid is the higher degree of influence that is given to the parties involved and the vicinities affected, by means of the constitution of a Supervising Commission, in which municipal, regional and national authorities, as well as promoters (Aena) and technical consultants take part. Regarding planning tools, with the distribution of operations among the available runways, together with what can be achieved with evolving systems, engines and aircraft configurations, it is not possible to avoid the spreading of noise footprints, but to make them even smaller, which means a positive effect on the numbers of population concerned. As long as traffic levels are forecasted to grow, the footprint will continue to spread but at least at a slower rate than has been the case till now.

Regarding noise affecting the vicinity of the airport, there are legal regulations to limit the noise levels inside homes, and the airport authorities must find the most suitable and efficient tools and measures to meet these restrictions. The definition of noise contours is the first step. They are the graphic representation of noise effects, by means of establishing the points with a same average noise level. It demands the use of simulation tools, such as INM (Integrated Noise Model) which is the most widely accepted noise model available. INM follows closely the ECAC (European civil aviation conference) document "Report on Standard Method of Computing Noise Contours around Civil Airports" and ICAO (International Civil Aviation Organisation) guidelines. In fact, it constitutes a true legal framework, because given the limitation of the budget for insulation measures, noise contours serve to determine who will be entitled to reimbursement for noise insulation costs. So, it is a crucial element of future decision making in order to mitigate noise effects on the community around the airports. Of course, for the air transport service providers, there is no end to this development. The upcoming saturation of the Madrid Airport system under construction means that every possibility for new configurations must be taken into account. Among them, the most accepted so far is to move the main airport activity to a new location with low population density. Feasibility studies are currently being worked on. The designation of the new location has been declared to be in the public interest by the regional authorities and the area has therefore been reserved, which of course is a paramount decision that goes in the right way for future planning.

Conclusions

We may draw the conclusion that the full enforcement of environmental rights and duties at all levels of legislation will enable any decision making process regarding noise impacts to achieve more and more effectiveness. Legal decisions establish common and suitable criteria as well as reference levels for all stakeholders, and put in the hands of all the involved parties the tools that could permit a balanced approach to more sustainable models of development. Among other guidelines, the precautionary principle, i.e. planning every single step in good time, not waiting till it is too late, is a concept that must always be kept in mind. Moreover, it is an important criterion which helps us to face the environment as a matter that deserves all our efforts and devotion.

All the considerations involved, far from being distant concepts, should lead to practical action being taken by the air transport authorities in response to the demands of the community they serve (Madrid-Barajas is an example). In such complex systems, involving aircraft, aviation facilities, airports, different noise sources, and so on, co-ordination and communication among all parties concerned is not just “best practice”, it is the only possible practice, i.e. the only way to achieve the goals of noise reduction. It is recommended that a critical stance should be adopted towards the legal framework, going beyond the established borders, not simply to cross them, but to revise and improve them in order to meet as many interests and points of view as possible. This is the goal we must set for ourselves, so that we may take things into our own hands to facilitate the improvement of the quality of life in the vicinity of air transport facilities.

Conventional Measurement, Assessment, and Rating of Sound Exposures – a Critical Review from an Ergonomics Point of View

Helmut Strasser, Hartmut Irle

Introduction

Both ergonomists and practitioners responsible for occupational health and safety in a company normally use and appreciate indices of workload and environmental exposures presented in the simplest possible figures and numbers. Therefore, in traditional standards, rules, and safety regulations, the physical environment is normally rated in 8-hour-based mean values via connecting intensity and duration of stress by means of a multiplication, i.e., a mutual settlement of high load within a short exposure time and a low stress level within a longer lasting exposure. This principle is well-based on the experience that a low workload can be tolerated for a longer duration than a high workload. But does this confirm the hypothesis that equal energy or dose, or equal demanded output, also involves equal short or long-term human responses? Unfortunately, standards and conventional guidelines for occupational health and safety are more closely related to physics than to physiology. Yet, in order to really protect man at work, ergonomics must be more concerned with physiological costs of work and environmental stress than with physical principles of equal energetic dose.

Gradual Assessment of Intensity, Frequency, and Exposure Time of Sound Exposures

The intensity of sound events has always been quantified in decibels by the sound pressure level in a logarithmic scale (cp. upper row of Fig. 1). Of course, that is a pragmatic scale because a tremendous span of, e.g., 12 decimal powers of sound intensity can be condensed into easily manageable values of only 3 digits (e.g., 0 to 120 dB).

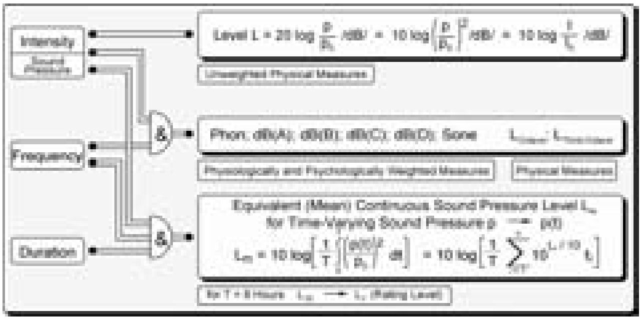

Fig. 1: *Gradual assessment of the physical dimensions "intensity," "frequency," and "exposure duration" of sound events for the development of integral characteristic values*

However, scientists and practitioners nowadays still have to work with this scale, despite the somewhat paradoxical fact that the psychophysical basic law of Weber-Fechner has meanwhile proven to be incorrect for acoustic stimuli. Although the formula for the sound pressure level is, according to Weber-Fechner's law (cp. upper part of Fig. 2), the resulting logarithmic scale, it is not in accordance with human sensation. For example, 90dB are not 10% less than 100 dB but represent just $^1/_{10}$ of the sound energy which is inherent in 100 dB and, e.g., a sound event with a sound pressure level of 100 dB is not twice as loud as an event with 50 dB. Therefore, instead of the incompatible logarithmic scale, a scale of loudness with linear units in Sone (cp. middle part of Fig. 2) due to sensation derived from Stevens's law of power should be used.

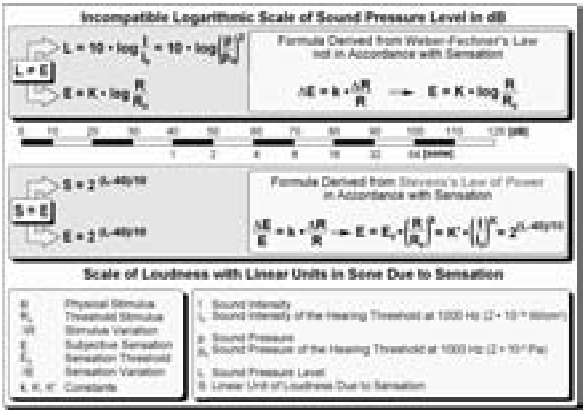

Fig. 2: *Incompatible logarithmic scale of sound pressure level in dB and scale of loudness according to Stevens's law of power*

If we were to make our money transactions utilizing the traditional logarithmic scale, we would, no doubt, deal in decibels a little bit more cautiously than we sometimes do in practice, when we say, e.g., 93 dB seem to be almost the same as 90 dB.

Provided that

- 0 dB corresponds with 1 €,
- 30 dB would be equivalent to 1000 €, and
- 60 dB would mean that we would already be millionaires.
- But also trillions or quadrillions in national debt expressed in the small figures 120 or 150 dB would seem to be not that tremendously much more than the money that "have-nots" have in their pockets (cp. Fig. 3).

With the intention of specifying sound emission with regard to intensity and frequency in one single value frequency-dependent filters A, B, C, or D should take into account the physiological characteristics of hearing (cp. middle row of Fig. 1). The filters A, B, C, and D (cp. Fig. 4), however, as a reciprocal approximation of the phone curves in different volume ranges, are based on the subjective comparison of sequentially presented tones and, therefore, cannot lead to an adequate assessment of noise which normally is a mixture of inharmonious sounds. Furthermore, in most cases today, only the A-weighting network is used for all volume ranges, although doing so conflicts with scientific knowledge. This discrepancy sometimes leads to the fact that, to the disadvantage of man, sound pressure levels of some noise sources do not represent the real sensations of man.

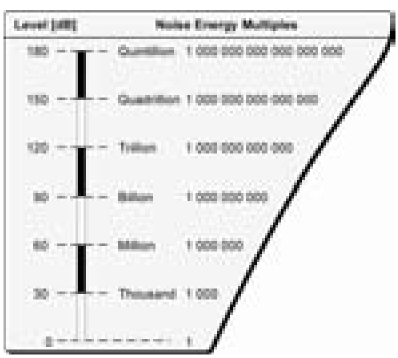

Fig. 3: *Level in dB and noise energy multiples*

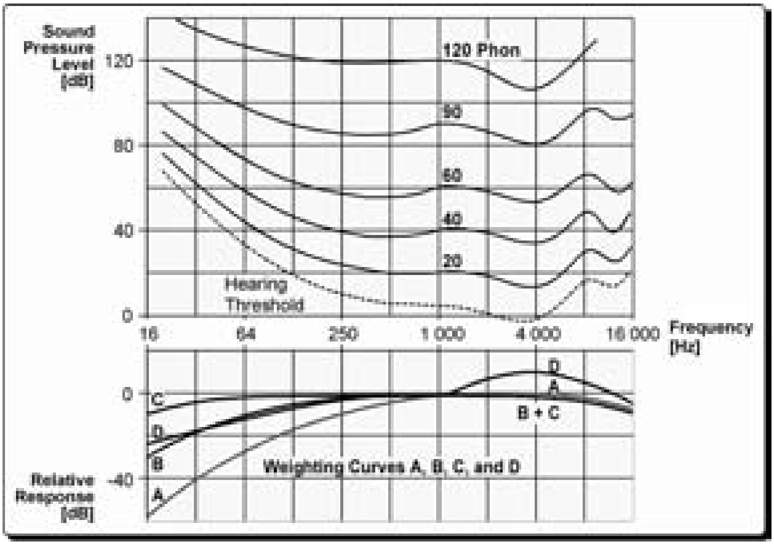

Fig. 4: *Curves of equal subjective sound level intensity (in Phon) and frequency response characteristics of the weighting networks A, B, C, and D*

Sound pressure levels mentioned in ergonomics and in all legal regulations, standards, and prevention instructions (cp., e.g., NN 1990, NN 1996, NN 1998, ISO DIS 1999) do not refer to a momentary sound event; they normally refer to the rating level L_r calculated via the formula in the lower row of Fig. 1, as an average value for the noise exposure associated with an 8-h-working day. The energy equivalent calculation of the mean value is, of course, applicable to a great many working situations. However, situations also exist where a purely formal calculation yields peculiar results which lead to a serious misinterpretation. When applying energy equivalence (cp. Fig. 5), 85 dB for 8 h are equivalent to 88 dB for 4 h, 91 dB / 2 h, or 94 dB / 1 h. This mutual settlement of noise level and exposure time is correct as far as sound dose and sound energy are concerned. However, with regard to physiological and psychological aspects of work, inevitably some discrepancies result.

Ninety-four dB / 1 h (cp. right part of Fig. 6) – as previously described – are energetically equivalent to 85 dB / 8 h, i.e., they correspond to an L_r of 85 dB. If only the energy, i.e., the sound dose, is considered, then what is shown in the left part of Fig. 6 also holds true. In this case, 94 dB for 1 h and an additional 75 dB for the remaining 7 h also result in an L_r of only 85 dB.

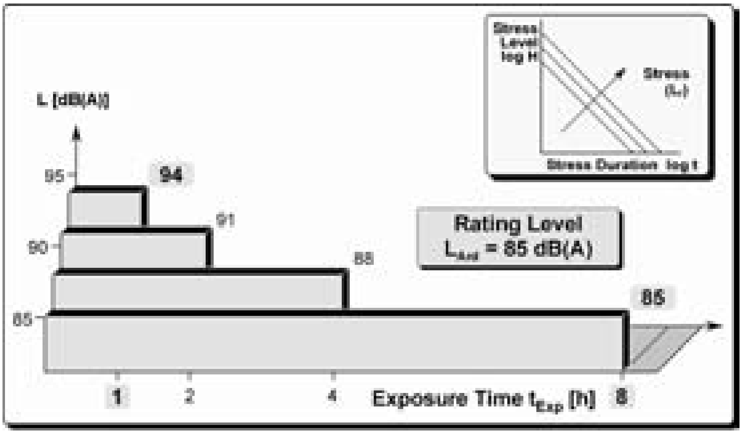

Fig. 5: *Sound pressure levels of different durations leading to an equal rating level (in this case 85 dB(A)) when applying the "3-dB-exchange rate"*

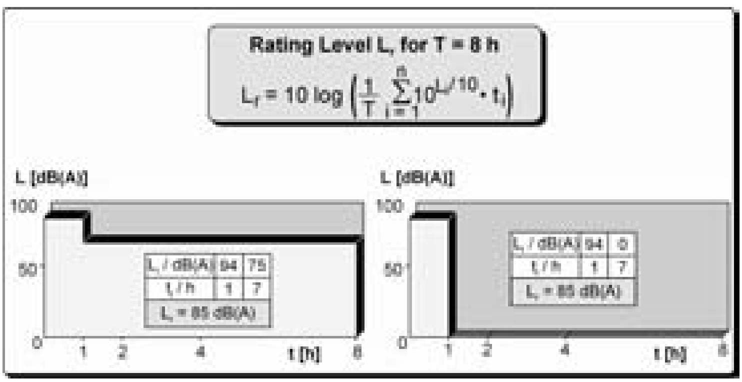

Fig. 6: *Elucidation of discrepancies in rating noise via the 3-dB-exchange rate*

Physically seen, this is correct, but it is comparable to filling up quiet periods with noise, and from a psychological point of view it is likely that nobody would prefer a situation as described in the left part of Fig. 6. Provided that the noise distribution shown here would stem from 2 machines, strange effects would also result with respect to technical approaches of noise control. If an engineer in this case would decide to completely insulate the machine which emits the lower level, the rating level would not be influenced at all. The application of the measure "rating level" consequently allows these strange ratings, as long as the lower value of noise remains a certain amount below the peak levels. For an equal exposure time, a difference of only 10 dB between the two levels is already enough to neglect the lower level, which absolutely agrees with legal regulations, standards, and national or international guidelines.

When continuing to halve the exposure time and when applying the "3-dB-exchange rate" as shown in Fig. 5 – from a purely arithmetical point of view – even a quarter of an hour at 100 dB would correspond to an 8-h-working day at 85 dB, which is still tolerated in the production sector according to almost all international standards (cp. NN 1997). Nevertheless, physiologically seen, high sound levels for a short period of time, e.g., 100 dB over 15 min or consequently also 113 dB for 45 s have to be assessed much more advantageously than continuous noise (cp. Fig. 7).

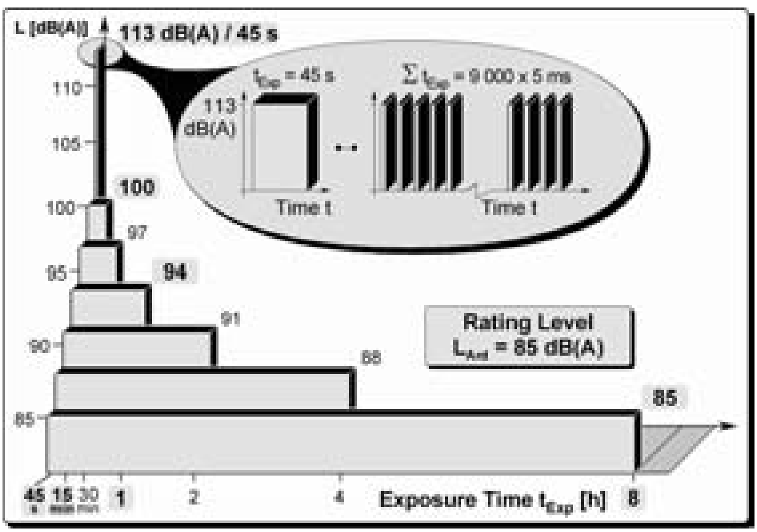

Fig. 7: *Sound pressure levels of different durations leading to an equal rating level when applying the 3-dB-exchange rate*

But may continuous noise also be split up into energy-equivalent impulse noise? For example, do 9000 impulses with a level of 113 dB and a duration of 5 ms, each lead to the same effects as continuous noise with the same level and a duration of 45 s? The answer is no! This can be demonstrated, e.g., by temporary threshold shifts (TTS) resulting from different noise levels with corresponding exposure times in an energy equivalent arrangement (see Irle et al. 2000).

Furthermore, may the mutual compensation of level and exposure time be applied without limit? Can 120 dB, 140 dB, or even 160 dB at an adequately reduced exposure time be assessed to be identical to or even more advantageous than, e.g., the above-mentioned 113 dB / 45 s? From a physiological point of view the answer must be "no," even though TTS may level off completely as physiological responses to an extremely short-lasting peak level. Nevertheless, in the past, the energy equivalent compensation of a halving of the duration with a level increase by 3 dB and vice versa (or the factor 10 in duration versus level) has become the basis for cut-off level diagrams to avoid hearing impairment which are applied in civil as well as in military sectors (cp. NN 1987).

In the case of impulse noise, exposure times even reach down into the range of ms. When establishing a logarithmic scale for the exposure time in addition to the already existing one for the noise level in dB, the straight line in Fig. 8 illustrates the energy equivalence for the rating level of 85 dB, e.g.,

- 1 x 1-ms impulse of 160 dB,
- 10 x 1-ms impulses of 150 dB,
- 100 x 1-ms impulses of 140 dB,
- 1000 x 1-ms impulses of 130 dB,
- 9000 x 5-ms impulses of 113 dB, and
- 85 dB for 8 hours (28 800 s), respectively.

Although the unweighted noise level in industry may not exceed 140 dB according to revised noise regulations (e.g., NN 1990, NN 1997) due to the limit line in Fig. 8, the varying time structures of the sound exposures are not considered.

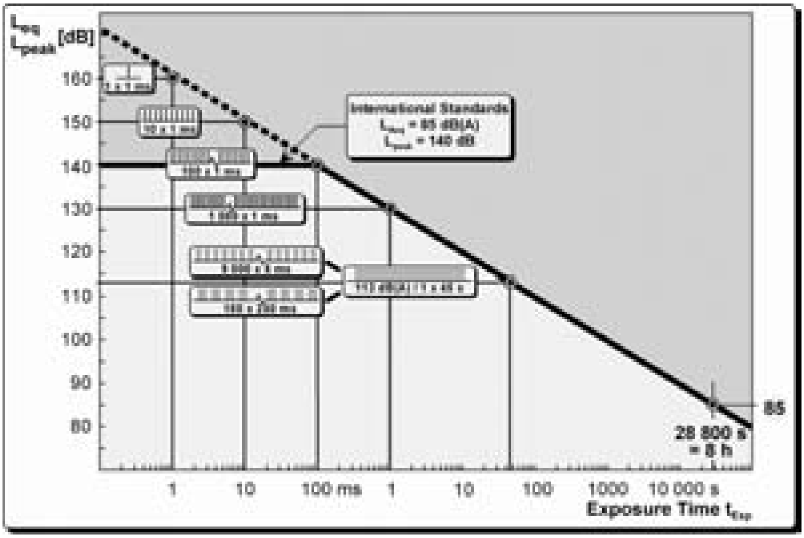

Fig. 8: *Conventional noise rating according to the principle of equal energy with a tolerable rating level L_{Ard} of 85 dB(A)*

Equal Work or Energy, a Principle Beyond Ergonomics Limits

But can these procedures of traditional occupational health and safety, really guarantee a safe hearing? The answer is no, because they are based solely on the principle of equal energy, and this is a principle beyond ergonomics limits. Traditional cut-off level diagrams as well as the determination of the rating level can only represent an aid for the evaluation of the sound energy acting on man. But when stress is quantified only with regard to physical aspects, man and his physiological characteristics are principally not included in the approach of the assessment. The calculation of the total stress by a multiplication of intensity and duration indeed is a common procedure for the assessment of other kinds of the physical environment, too. However, if man is involved in work, which is, of course, unalterable in ergonomics, plausible limiting conditions may never be neglected in the domain of stress.

A performed output (physical work) can be calculated by the intensity and duration of work, e.g., the performance on a bicycle ergometer. However, this is only reasonable within physiological limits of the endurance level. A male worker may be able to perform about 50 Watts for extended periods of time. For instance, the product from 50 Watts and 60 min working time (e.g., $B_3 = H_3 \times T_3$ as seen in the front part of Fig. 9) is identical to the work resulting from 100 Watts and a working time of 30 min or also 200 Watts performed for 15 min (analogous to $B_1 = H_1 \times T_1$). Yet, can the strategy of mutual compensation be continued arbitrarily ad infinitum? The answer must be no. At least in the limiting ranges, human nature does not play along. Nobody will be able to comply with a demand of 500 Watts for 6 min or 1000 Watts for 3 min. The principle of equal work, i.e., the mutual compensation of intensity and time, cannot meet physiological laws.

This can be shown via the general responses of the heart rate to the above-described workload constellations (see upper part of Fig. 9). When working below the endurance level, heart rate responds with a steady state but when physical activities above the endurance level are requested, heart rate rises over-proportionally and critical heart rate values can occur.

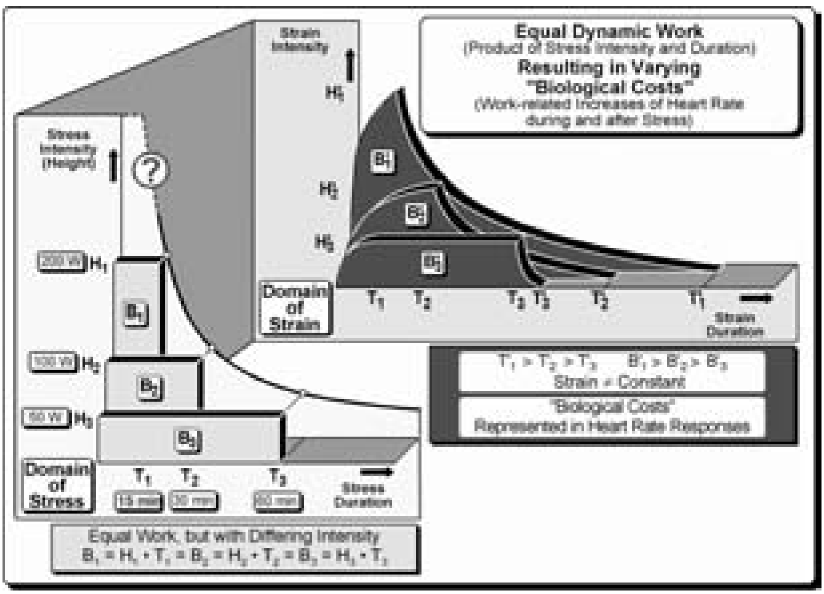

***Fig. 9:** Equal dynamic work, i.e., product of stress intensity and duration (lower frontal part) resulting in varying "biological cost", i.e., work-related increases of heart rate during and after stress (upper part behind)*

For physiological reasons, occupational situations must not occur which, e.g., result in critical heart rates of about 180 beats/min, even if this occurs for only a short time. In this case, the mutual settlement of high workload and short duration must reach an upper limit. But it is exactly this procedure – a procedure which is based solely on physics rather than ergonomics – which is practiced when applying the equal energy principle, i.e., the 3-dB-exchange rate, to assess short duration continuous and impulse noise.

Risks in Occupational Safety and Health by the Application of the Equal Energy Hypothesis

Drawing inferences about the reported theoretical considerations on the one hand (which are presented by Strasser and Hesse [1993] and Strasser [1995] in much more detail), and regarding the results of several experimental investigations into the physiological costs of noise on the other hand (see Hesse el al. 1994; Irle et al. 2000), it should become evident that real risks exist in occupational safety and health rules which are based on the equal energy hypothesis or the principle of equal work. When, e.g., thinking about the fact that the prick of a needle into a finger, always is one and only one singular event of a mechanical irritation which causes pain, that cannot be converted into the caressing of this very point over a longer period, the inevitable issue raised is whether our sensory organ “ear” may represent an exception in the case of impulse noise. Can the ear actually be expected to tolerate 160 dB for 1 ms or 100 noise events of 140 dB / 1 ms in the same way as it tolerates continuous noise of 85 dB for 8 hours, which is what the principle of equal energy suggests (cp. Fig. 8)?

When considering the density of energy acting on the ear, impulse noise simply cannot be compared with continuous noise. Equalizing 160 dB / 1 ms or 1000 noise impulses with a level of 130 dB and a duration of 1 ms, each, with, e.g., 85 dB for 8 hours according to the 3-dB-exchange rate is in accordance with the energy equivalence principle. However, this does not mean that the term “dose” as a datum level is in fact acceptable in this case. During continuous noise, the sound energy acting on the ear is distributed over the 28 800 s of an 8-h-working day. However, in the case of impulse noise, the total sound energy is forced on the human sensory organ in extremely high doses within a fraction of a second. Just as a drug which in a small dosage over a longer period of time can induce healing and one single "overdose" of that drug can be lethal, the impacts of impulse and continuous noise simply are not identical. An impulse noise event is comparable, for example, with a hurricane in the inner ear which can hardly pass the carpet of hair cells without any adverse effect, just as a short gust blowing over a cornfield or being caught in a sail cannot have the same effect as a light wind over a longer period of time.

Conclusions

In the context of the energy equivalence principle in rating the physical environment (cp., e.g., Martin 1976; Strasser and Irle 2000), one must not forget a mechanical analogue where deformations of materials are the intended aim of an energy concentration. Fast, energetic manufacturing operations, such as, e.g., beating, bumping, or punching, are the essential presuppositions for deformations of materials (cp. Fig. 10).

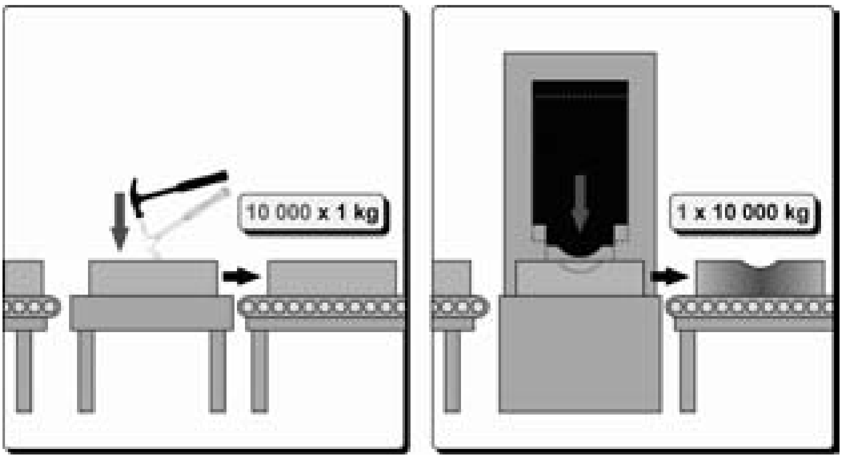

Fig. 10: *Energy concentration by a fast impact of a large mass (1 x 10 00 kg) enabling deformation of materials*

Therefore, it is only a stringent consequence that short but intensive events of environmental stress must involve a greater potentiality of health hazards for man. So, the validity of acceptable equivalences of environmental stress to guarantee health protection must be called into question. There should be no doubts that the effect of a dose which is dispensed within two different time intervals is more striking within the shorter one. Also, unquestionably, in the case of increasing density of energy or concentrations of harmful agents, the exceeding of physiological barriers with simultaneous intensifications of the effects becomes much more probable. This is especially true when the organism does not possess effective potentialities of temporal and/or spatial buffers. Therefore, the well-known endeavour for simplification and standardization which drives attempts to squeeze the rating of complex environmental situations into simple models or integrated measures as is done, e.g., also for ultra-violet radiation, mechanical vibrations, and carbon monoxide, cannot be adopted by ergonomics. Via this procedure, multidimensional connections get lost. In this context, a simple but slightly meditative comparison may be convincing for sceptics: The levelling of short lasting high intensity stress, based on physical rudiments, indeed seems to be as trustworthy as the statement that nobody can drown in a river with a statistical average depth of 50 cm (cp. Fig. 11).

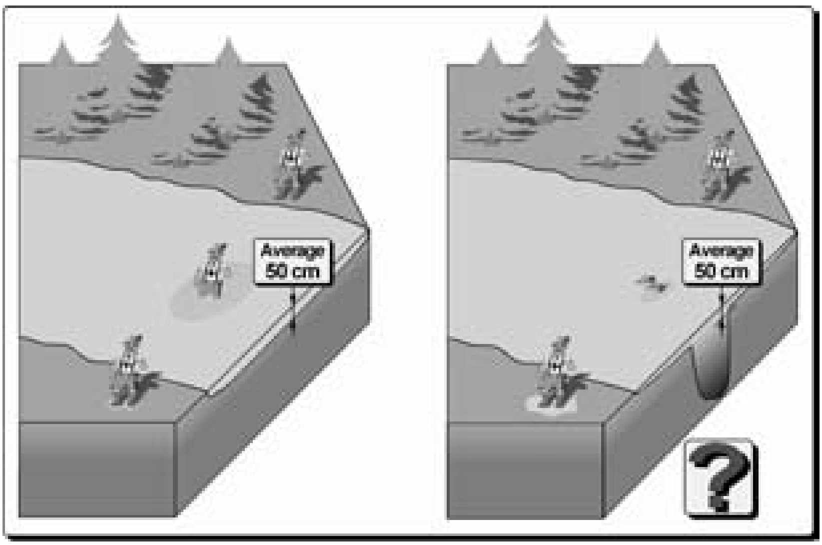

Fig. 11: *Safe crossing of a river with an average depth of 50 cm?*

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