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COLLABORATION BETWEEN ACOUSTICS AND HUMAN SCIENCES FO NOISE CONTROL REGULATIONS

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I – INTRODUCTION

Concerns for individual comfort and sustainable development for society strongly increased between 1960 and 1995. This phenomenon is not new and in France the concept of unhealthy establishments translating the efforts of public authorities to protect the the environment close to factories dates back to 1917. This law also addresses the problem of noise.

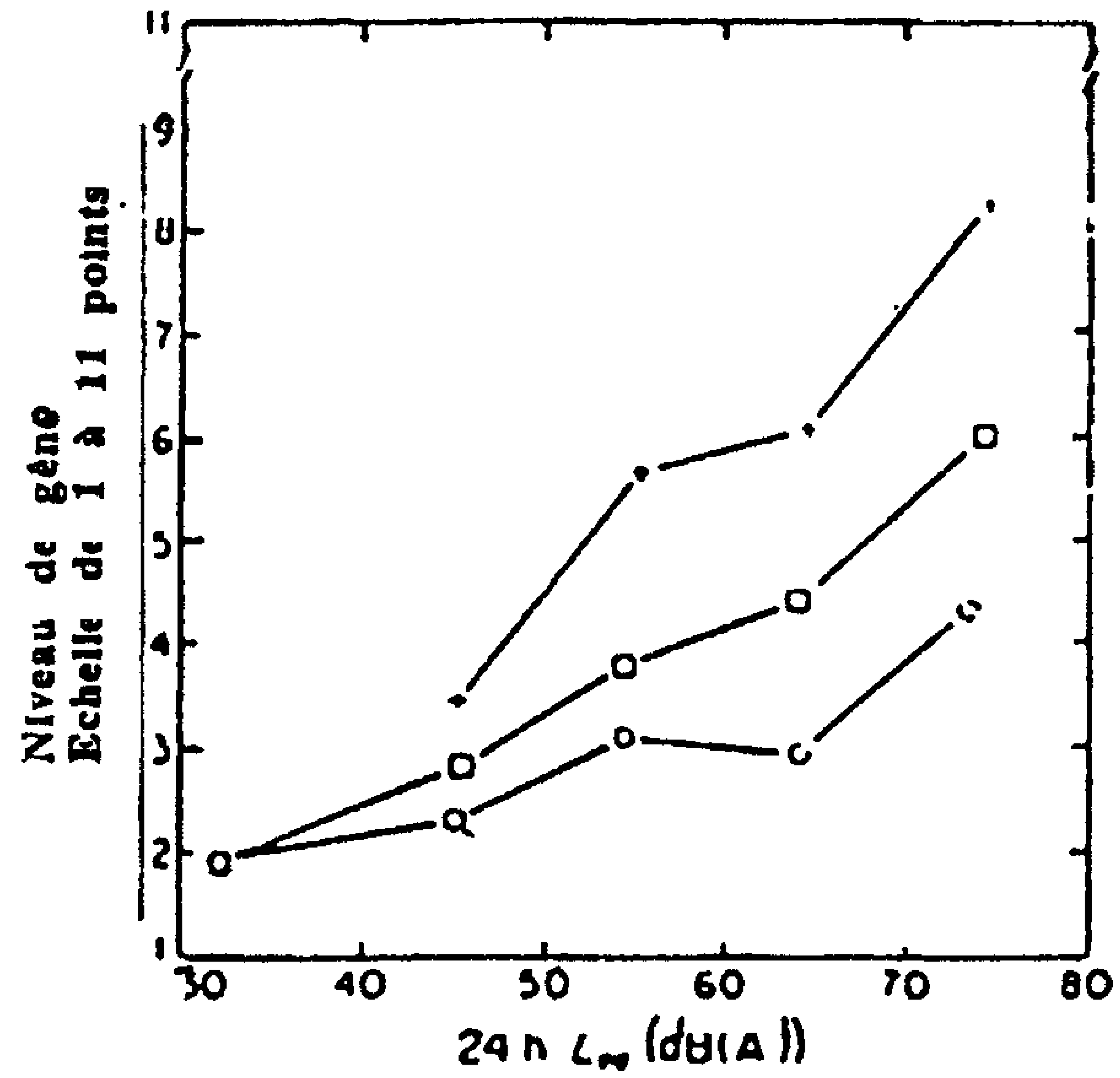
Since that time, human sciences and physical acoustics have collaborated to prepare noise control regulations. Before this new era, **the principle of protection**, guaranteed to citizens by the State was based on common sense and the observation of noise-related public health problems. However, it was more difficult to legislate for the second principle – **prevention**. Today prevention – prudence when knowledge about the effects of a physical agent is insufficient – is rare. Although this view is backed by the World Health Organisation, legislation and regulations are usually only introduced once problems have arisen.

Protecting the public from noise has an economic cost generated when reducing emissions from vehicles (cars, aircraft), improving acoustic insulation in homes, or refusing to develop land to distance noise sources from homes, schools, hospitals, etc. And life and human scientists are asked to prove the impact of noise on health and well-being (Mouret 1991, Rylander 1990).

To be credible, research by psychologists, doctors and epidemiologists must lead to general laws; such conclusions are acceptable as they apply to all populations exposed to noise.

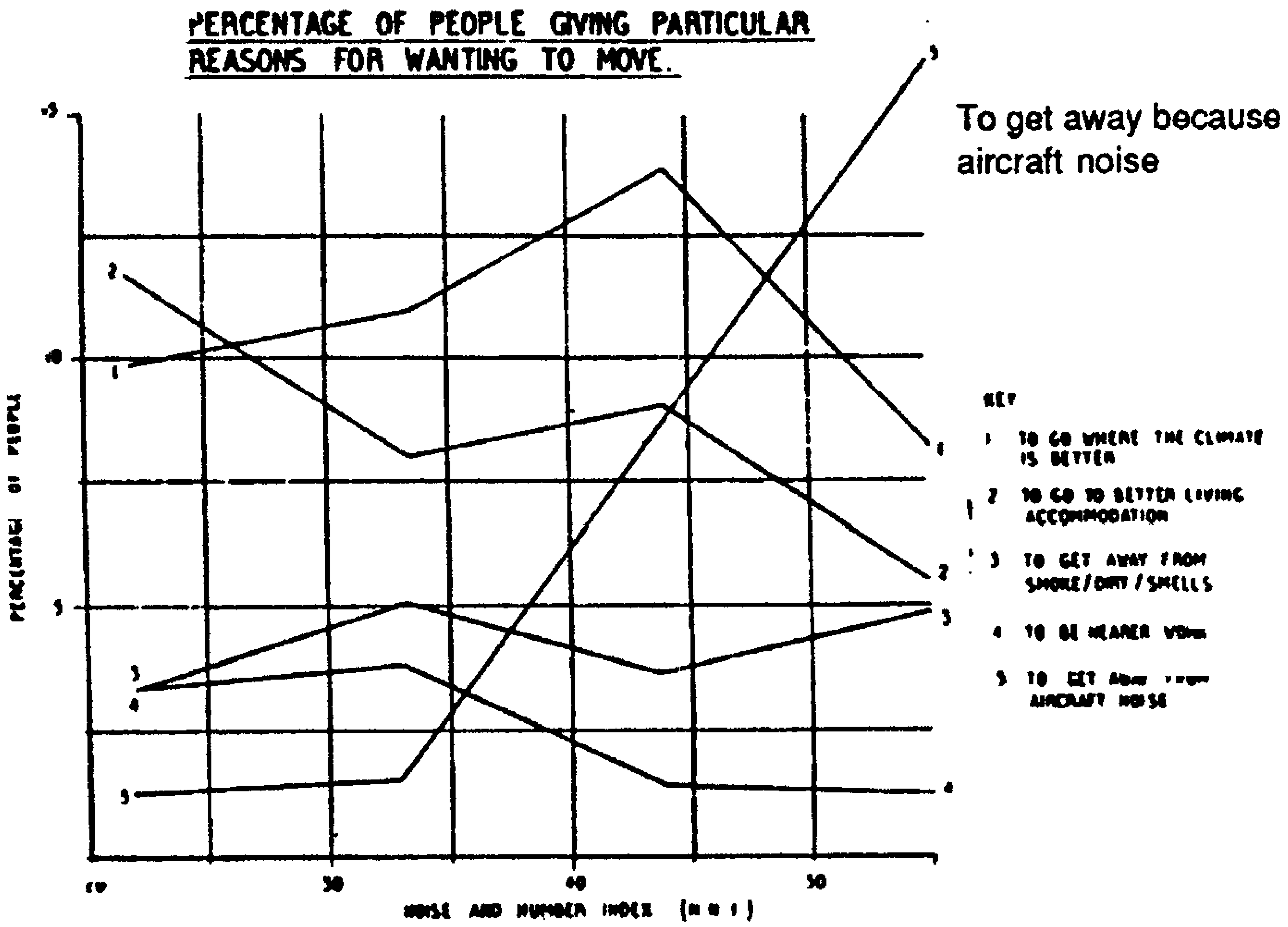
this demand can be observed in all industrialised nations and target values determined by standards or laws and regulations apply to all manufactured products and infrastructures.

However, other approaches to environmental protection exist. For example, ALARA (As Low As Reasonably Achievable) objectives proposed by the Specialist Commission of the National Council for Protection from Radiation in the USA (quoted by Plat 1995). This view of noise prevention is particularly important as the population believes «that it is possible to protect them from noise (here and now)». This has a high impact on expressed anoyance. Sometimes the part played by this feeling plays is as significant as the physical noise itself (Fields Walker 1982).



Interaction between preventability and noise level + noise could be reduced here,
□ intermediate preventability attitude, ○ no-one can do anything about noise

Another way to manage noise would be to determine the percentage of works devoted to soundproofing infrastructures and buildings. This principle would be difficult to adopt on a political level and just as difficult to respect in some circumstances – noise around airports, for example. But this approach is logical as whatever the measured environmental noise level, some people will always express annoyance or a experience noise-related disorders. Langdon (1976) observed that 10 to 15% of the population sleeps badly independent of noise.



NOISE and NUMBER INDEX (NNI)
Origine Mc kennel in Wilson Report 1962

This type of observation gives an initial indication for the selection of thresholds levels. It is not *essential* to propose noise level values which protect 100% of the population. However, it would not be sensible to choose noise levels which cause annoyance in 50% of the population exposed to noise. In this scenario, annoyance is observed but it is not politically correct to accept that half the population should be left to suffer.
WHO recommendations which often aim to permit sustained development within the meaning of the Rio convention are, in most cases at the low end of the scale with 10-15%/50% of the population annoyed.

II – PSYCHO-ACOUSTIC LABORATORY RESEARCH PROGRAMMES

The first programmes in this category in the XXth century (Fletcher Munson 1933) validated a noise comparison unit by establishing the correspondence between the physical aspects of the noise and the psychological impact of the noise on listeners. In fact, this research made it possible to resolve a particularly delicate programme – how to weight feelings caused by the different frequencies which make up a noise. Nowadays, there are a range of different spectral weightings based on equal sound impression graphs expressed in phones. Weighting curve A corresponds to the 40 phone scale, weighting B to 70 phones and weighting C to 100 phones. These graphs are included in ISO standards 131, 226 and 532 and IEC standards 537, 651 etc.
Curiously enough, as researchers resources increase – in this age of digital acoustics – the more they seem to simplify. Generalised use of dB(A) is under careful study in Holland (1997), which may lead to its adoption by the European Commission responsible for preparing a Directive applicable in every country (Green Book DG XI – Perera 1996).
The spectral weighting adopted in standards does not only depend on the capacities of the ear to discriminate or neurone connections in auditory centres; the type of noise, including the physical origin, is also considered. For aircraft noise, the psycho-physical investigations already mentioned above tend to show that dB(A), dB(B), dB(C) and dB(D) do not include sufficient information about annoyance or pollution and that frequency analysis is also necessary.
A perception level scale, called the Perceived Noise Decibel scale (PNdB), was determined in a laboratory research programme by Kryter (1959). The PNdB weighting gives more weight to medium and high frequencies in the 1000 to 10 000 Hz range than they have in other A, B graphs. These frequencies are extremely marked in the sound spectra from jet engines and cause the increase in annoyance induced by this source which is much greater than mere loudness. This method is extremely precise but also very complex. It was adopted by international authorities, and particularly by the International Civil Aviation Organisation (ICAO). It is obligatory in all countries for aircraft certification.
Acoustic laboratory work makes it possible to propose noise exposure indices, in addition to acoustic units.
It is also possible to vary noise assessment methods, to evaluate effects in psycho-acoustic terms and to uses electro-physiological methods.
Using psycho-acoustic methods, Fastl (1996) made possible laboratory tests of the effects of the future magnetic levitation Transrapid train between Berlin and Hamburg. A short 30 km track already exists and recorded noise patterns are used as stimuli for laboratory experiments.
The principle consists in composing two sessions with the noises of isolated train pass-bys, the first with three types of conventional trains – Intercit (134 kph), freight trains (93 kph) and express ICE trains (248 kph) and the second with the Transrapid.

Every session has the same 54 dB(A) LeqA. Subjects score results in 3 ways:

- on a 7 poin scale from very soft to very loud
- using a global loudness magnitude estimate
- line length to assess instantaneous loudness of a pass-by.

All the Tansrapid noises were recognised as train noises.

Moreover results show good annoyance equivalence at the same Leq between 2 types of train.

At INRETS, Champelovier and Philipps (1996) constructed an experiment designed to assist in the decision to adopt Leq as an aircraft noise indicator instead of the existing index which combines the average level of Lmax and the number of events. To check the importance of the number of events, 4 pairs of sessions were prepared with identical Leq levels 2 by 2:58.45, open Windows, leq 45, closed Windows, Leq 37. Every 20 minute session comprised 4 to 10 noises to correspond to the reality of high European airport traffic. The evaluation methods were subjective annoyance and cardiac rhythm.

The results for annoyance levels, expressed on a 4 point scale, are very similar for each pair of identical noise sessions. The relationship between heart rate response to identical Leq sessions is also convincing. The number of events has no effect.

Leq levels 20' dBA	57.9	57.6	44.7	45.5	45.5 windows open	45.7	37.2	37.8
number of events	4	10	4	10	4	10	4	10
annoyance rating	2.81	2.88	2.33	2.41	2.11	2.16	1.62	1.62

The second research programme turned out to be very useful for proposing an aircraft noise exposure index: the immediate conclusion is that Leq can describe aircraft noise, as soon as air traffic becomes dense with approximately 180 movements aircraft movements per day or more, during the daytime. This conclusion is not valid at night.

In the field of the masking communication by noise, extremely precise linguistic acoustic studies have demonstrated the optimum reverberation time for schools. This parameter, which obviously varies with the volume of the classroom, is now a legal obligation in France for the construction of schools and universities.

Laboratory experiments provide rather more qualitative information.

Psycho-acoustical methods are widely used by acoustic experts to define the acoustic properties of domestic appliances like washing machines, refrigerators, vacuum cleaners, etc, in which noise levels and frequencies undergo small variations (Kuwano 1994).

Practical applications have been extended to noises with greater fluctuations like those from bus (Kuwano 1993, Garcia 195, Parizet 1996) but limited for the moment to noise generated by a single source, although there are in fact several. Significant gains in the reduction of noise from cars, required by regulations over the last 20 years, cuts been achieved. Another aspect of this demand for quieter cars is that drivers now demand good acoustic quality inside vehicles. All car manufacturers now employ acoustic engineers whose mission is to reduce noises from engines, accessories, tyre/road contacts hum and even from door closing. This problem is not simple because some noises are useful, for example when changing gear or early detection of a mechanical incidental. Moreover, positive and negative psycho-acoustic characteristics – i.e. not neutral – can vary with the countries in which the car is sold. This was the case for high loudness (Blauert, 1986). More recently a study has shown that the Japanese are neutral to high bus loudness but Germans and Americans are negative. Shibuya (1993) underlines the differences in

sensitivity to car noise between Japanese and Europeans. Parizet (1993) established that the combination of feelings of loudness and sharpness is useful for describing car fan noises to which driver/purchasers are sensitive.
In a different field the psycho-acoustical characters of wind turbine noise have been analysed (Persson Waye, Chilman 1997).

III – THE CONTRIBUTION OF THE PSYCHO-SOCIOLOGICAL SURVEYS

Noise cannot be characterised by a single physical phenomenon. Both at work or at home, everyone, with their own specific biological make-up, is part of a psycho-social context which generates or modulates sound sources. In these conditions, any attempt to demonstrate cause and effect relationships between environmental factors and health is doomed to failure even though demonstrating relationships of this order would be particularly useful for the introduction of legislation.
Because individual factors modulate annoyance, people in a given acoustic situation express different degrees of annoyance. Psycho-sociological surveys using samples of exposed populations and the statistical treatment of results make it possible to compare annoyance in the same way as acoustic measurements compare different noises.

The concept of annoyance

In addition to «annoyances» which interrupt communications, leading to conflicts, slow learning and other easily measured consequences, «psychological» annoyance is a relatively loose concept defined by Vallet «psychological» annoyance is a relatively loose concept defined by Vallet (1983) as a «negative affective perceptive feeling expressed by the people who hear the noise».
This notion is therefore, in principle, different from the concept of «loudness» which only refers to the perception. Although there are many psycho-biosociological components of nanoyance, it is one of the most frequently used criteria in psycho-sociological surveyes and laboratory studies into the effects of noise.
Although, justifiably, annoyance is a frequently questioned criterion, it is nevertheless an extremely useful concept the quantification of which makes it possible to propose physical noise thresholds, particularly for road traffic and has the additional advantage of corresponding to complaints from people exposed to noise.
In this concept, the quantitative aspect of annoyance scales is simply an hypothesis, whereas the verbal expressions used to describe different degrees of annoyance provide a ranking. This provides an ordinal scale; the hypothesis is that the intervals on this scale are equal.

Annoyance surveys

The results of questionnaire surveys at the homes of local residents concerning noise sources provide most of the information required to legislate against noise.
Thousands of surveys have been carried out (Fields 1993) but it is still possible to break new ground as so many factors condition expressed annoyance.
Response to annoyance/noise level functions are used to define thresholds by identifying the inflection points of curves, by segmentation and by other methods. Another principle, more political, consists in considering that there will always be a percentage of people annoyed whatever the noise threshold and, for example, a noise threshold for a country could be defined as corresponding to 15% of extremely annoyed people.

In these surveys, it is essential to include noise characteristics in addition to the simple noise level expressed in decibels. In fact, when the noise level drops, the annoyance threshold notion depends much more on individual sensitivity than the actual acoustic level, particularly below a value of 65 dB(A) in daytime Leq. Remarkable stability of level and annoyance thresholds was observed (Vallet 1990) in four studies of people living near roads carried out in France between 1963 and 1988.

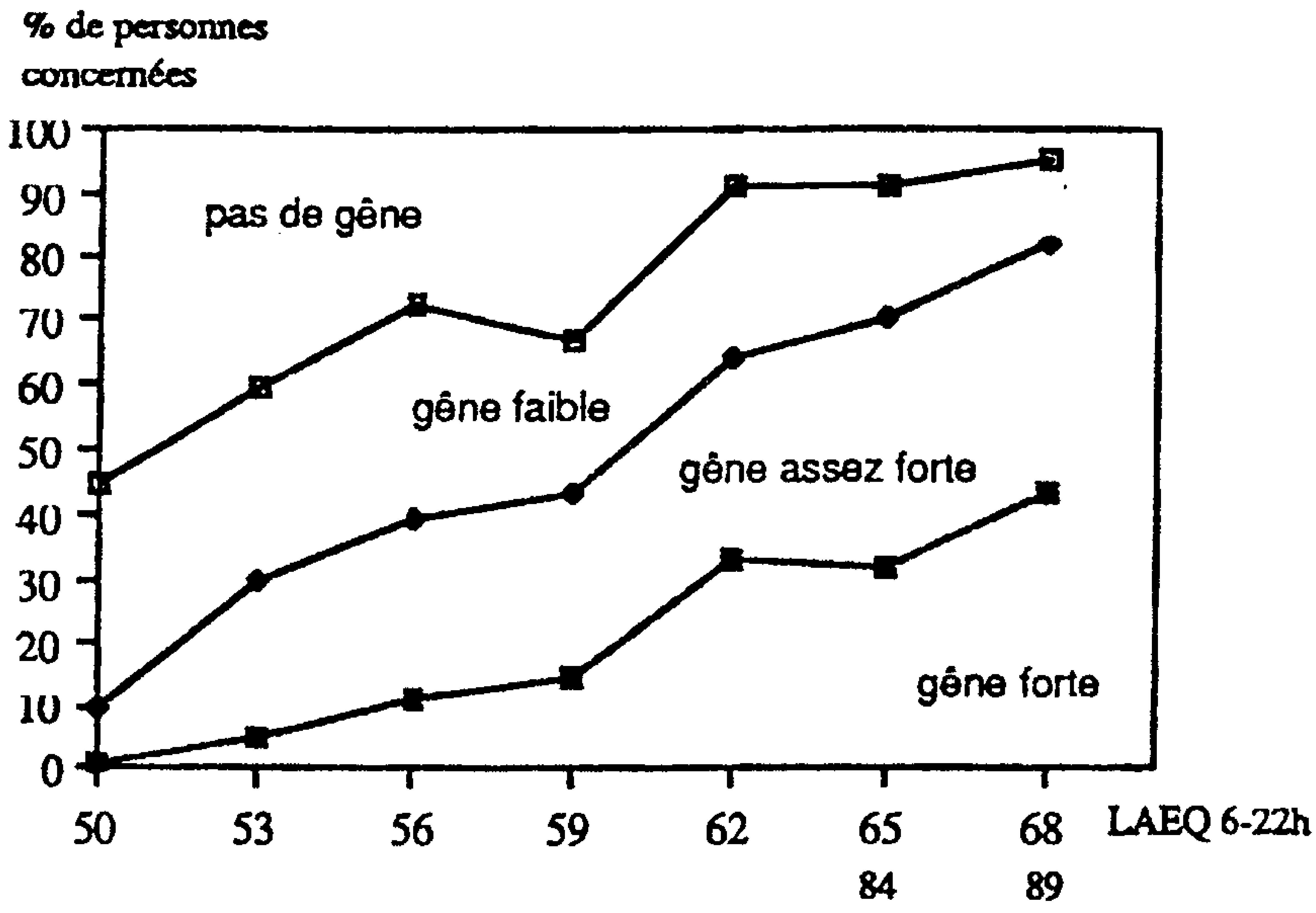
Here the threshold was 61+or–1 dB(A) in 8a.m.-8p.m. Leq.

Not all indices which exist today were defined by surveys but this is frequently the case. In fact, in Great Britain, aircraft noise led to legislation as early as the 1960s following the publication of the «Wilson report».

The graph shown in this report plots the different reasons expressed by the local residents who wanted to move away from the area and the variations in these responses as a functin of noise levels. Some reasons were totally independent of noise. The intention to move to a new home, which is a potential behaviour pattern, grows rapidly as soon as the Noise and Number Index (NNI) reaches 33-35 points. This type of noise-annoyance graph makes it possible to determine a threshold for legislative purposes. In Great Britain and Switzerland, this index has been used to determine noise footprints around airports and urban development in the future.

Statistical programmes can always be used – segmentation, for example – to obtain the best cut-off point, i.e. the threshold value, when the function is more monotonous with no obvious points of inflection. In sigmoid functions there are two threshold values.

Répartition des personnes selon l'exposition au bruit d'avion et l'intensité de la gêne



Origine Oliva 1993

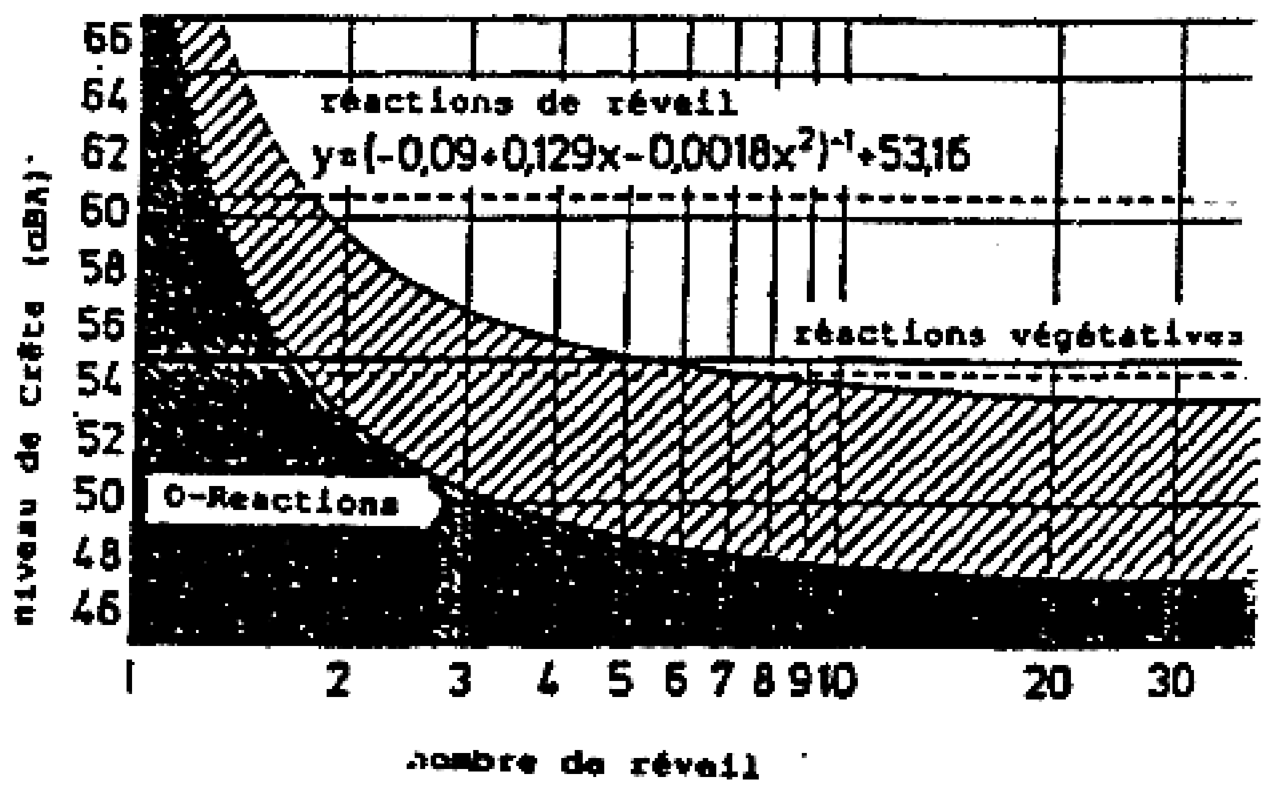
Psycho-sociological surveys carried out before and after the installation of noise prevention devices such as baffles and earthworks, which modify the levels of exposure of homes to noise, make it possible to define the minimal gain that must be obtained to reduce annoyance. Several, already old, surveys (Vallet 1979) show that noise has to be reduced by 6 dB(A)Leq to obtains any reduction in annoyance. If the reduction in loudness is less, the difference is perceived but annoyance does not change.

However, this observation was not included in French law.

IV – THE CONTRIBUTION OF SLEEP RESEARCH TO NOISE LEGISLATION

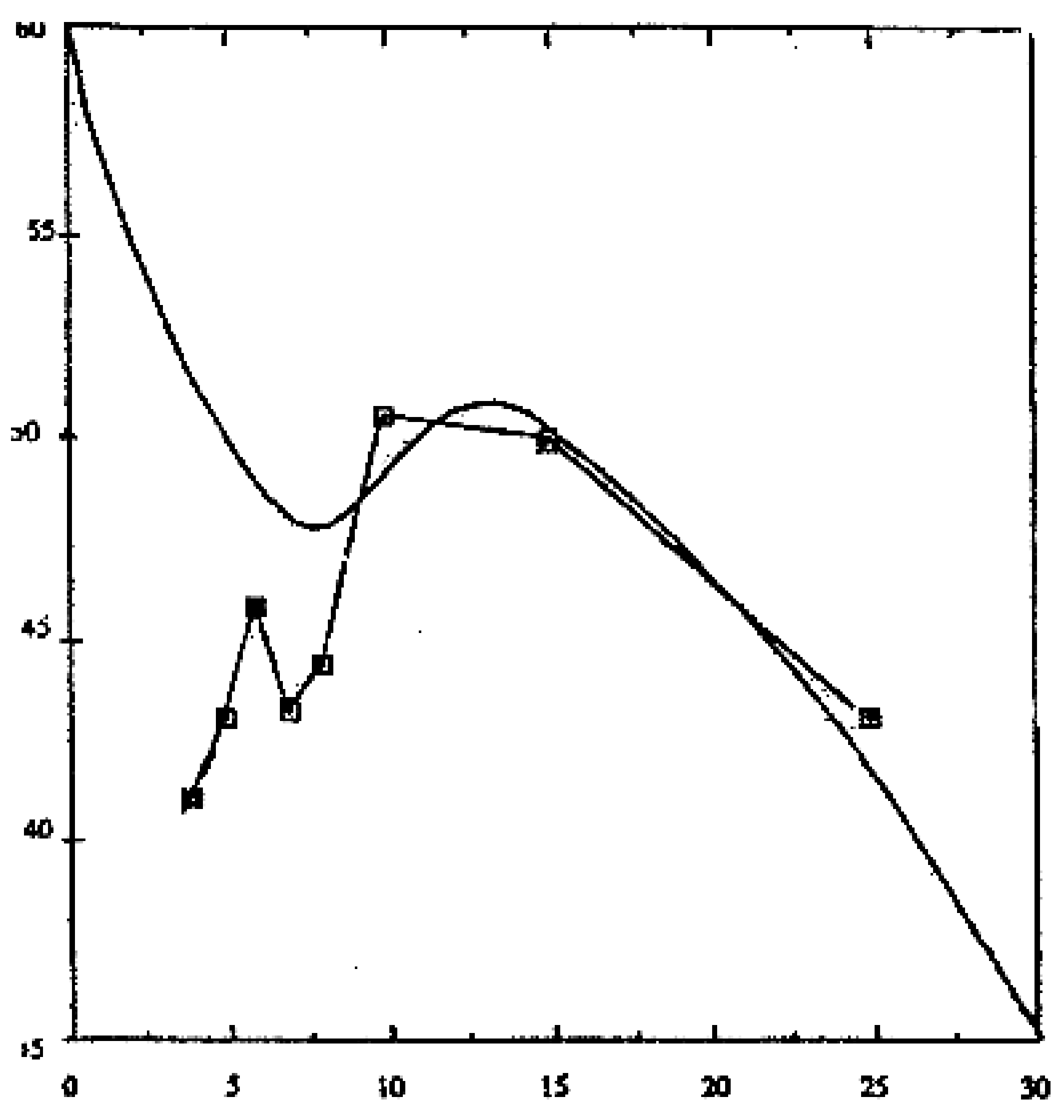
Most research work into sleep disturbance by noise is very interesting. Since the study into sonic bangs, surveys have progressed and initially resulted in a proposal to limit peak levels (Lmax).
Since 1996, aircraft using airports in London must not exceed outdoor noise levels of 87 dB(A) which, as windows provide 36 dB(A) acoustic insulation, leads to an indoor noise level of 51 dB(A). American and European research recommend a slightly lower level: Wilkinson notes that a reduction in noise from 60 dB to 47 dB(A) Lmax significantly improves sleep, based on changes in the electro-encephalograms of sleepers.
Very recently (Griefahn 1991), scientists began to use noise indices and Lmax levels simultaneously. The graph below includes many kinds of noise and, for example, it can be seen that for a situation with 10 noises at 54 dB(A), 90% of night-time awakenings are eliminated. With the same number of noises and a Lmax of 48 dB, all reactions are eliminated.
These results, together with those of Vallet (1993) have been included in a meta-analysis carried out by the Netherlands, which has led to legislation stating that indoor Leq levels in bedrooms must not exceed 26 dB(A).

Courbes dose-réponse en fonction du nombre d'evénements et de niveau de crête (Griefahn)



Rêveils en fonction du nombre de bruits par nuit

Niveaux de crête en dB(A) à l'intérieur



Nombre de bruits par nuit

This rule seems to be a good way to use the physiological results from sleep research. Another recent application is using night noise contours to forecast annoyance around airports so that urban planning is based on the most restrictive parameter.
Porter (1997) concluded that it is currently difficult to develop a tool of this kind. However; Paris Airport has been working on this idea and has prepared a map of zones from the duration for which Lmax exceeds a given threshold.

V - CONCLUSION

Collaboration between human and acoustic sciences is extremely fruitful, particularly when defining legislation for different means of transport.
The results which first addressed road noise at the beginning of the 1970s are encouraging. Research has now been extended to aircraft and trains, particularly high-speed trains.
A relatively promising field for co-operation between these two scientific sectors concerns the situation in which a noisy infrastructure is suddenly created – a new motorway, for example – in a formerly quiet area. In these conditions the hypothesis is that the noise level acceptable for a road on which traffic increases regularly is not true for a totally new noise. This now must be confirmed.

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