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STUDY OF ANNOYANCE DUE TO URBAN AUTOMOBILE TRAFFIC SCIENTIFIC REPORT

D. Aubree, S. Auzou, and J. M. Rapin

Translation of "Etude de la gene due au trafic urbain. Compte rendu scientifique", Centre Scientifique et Technique du Batiment, Paris, France, June 1971, pp 1-76.

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16. Abstract

Continuous traffic-noise measurements have been carried out over 48-hour periods in front of a hundred buildings in different types of streets in Paris and its suburbs.

Physical interpretation of the results provides a noise prediction formula for a traditional type of street.

The noise at each point was characterized by a limited number of parameters by means of factor analysis, and their effect on the degree of disturbance by 700 individuals questioned near the measurement stations was studied. It was found that many additional factors affect disturbance besides noise, and that the dispersion of replies for any given noise situation is very wide.

A disturbance index is proposed which takes into account the daylight level L_{50}, the position of rooms in the dwelling exposed to noise, and the individual degrees of satisfaction with the area.

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SUMMARY

Continuous traffic-noise measurements have been carried out over 48-hour periods in front of a hundred buildings in different types of streets in Paris and its suburbs.

Physical interpretation of the results provides a noise prediction formula for a traditional type of street.

The noise at each point was characterized by a limited number of parameters by means of factor analysis, and their effect on the degree of disturbance experienced by 700 individuals questioned near the measurement stations was studied. It was found that many additional factors affect disturbance besides noise, and that the dispersion of replies for any given noise situation is very wide.

A disturbance index is proposed which takes into account the daylight level L_{50}, the proportion of rooms in the dwelling exposed to noise, and individual degrees of satisfaction with the area.

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Historical Survey - References - Theory - Methodology

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STUDY OF ANNOYANCE DUE TO URBAN AUTOMOBILE TRAFFIC
SCIENTIFIC REPORT

D. Aubree, S. Auzou, and J. M. Rapin
Centre Scientifique et Technique du Batiment
Paris, France

I - INTRODUCTION (MOTIVATIONS AND OBJECTIVES) /7*

No one denies that the noise from automobile traffic is a cause of annoyance for people living along the traffic routes. However, between simple awareness of the noxiousness of the traffic noise and the evaluation of the resulting annoyance, there is a gap which thus far studies have not bridged, especially in regard to urban traffic noise.

Previous studies have dealt primarily with highway noise, and there are two reasons for this:

- many highways are built,
- while facilitating measurement, the statistical stability of highway noise permits of simple representation that favors research using noise indices.

The town planning authorities at the national level (D.A.F.U.) and the regional level (Prefecture of Paris) decided that it would be useful to complement these first studies with an on-site study in the urban area, in the proximity of thoroughfares such as the streets of Paris, those serving the Parisian suburbs, and the suburban service and delivery routes.

The C.S.T.B. was entrusted with this research because of the experience already acquired in this field by its personnel (acousticians and sociologists) and with its equipment (mobile measuring chains).

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* Numbers in the margin indicate pagination in the foreign text.

The purpose of this new on-site study is to immediate information on noise levels in urban areas and on the resulting annoyance. In particular this study will permit us to: /8

- situate the annoyance caused by these various urban routes in relation to that resulting from highways,

- see if the physical parameter taken (average level of acoustic pressure of noise, at the peak hour) to characterize the highway noise is sufficient in the case of the other urban routes,

- study the relationship between the characteristics of the traffic and that of the street, between the geometry of the environment and the physical properties of the noise.

Based on this study, we must be ready to:

- give the best physical parameters characterizing the urban traffic noise from the point of view of the annoyance expressed,

- define the limit noise levels that must not be exceeded near dwellings,

- predict the characteristics of the urban traffic noise from the cross sections of the streets and from the intensity and type of traffic on them.

The result of this study must be able to be used directly by the town planning authorities, architects and study bureaus entrusted with designing buildings, and the engineers who build the traffic routes.

II - CONDUCT OF THE RESEARCH /9

2.1. Choice of Sample of Streets

In determining the measuring sites, we sought to obtain the greatest possible variety of noise levels.

The Prefecture of the Paris region set as an objective 100 measuring points distributed so as to have 40 in Paris and 60 in the suburbs.

For the city of Paris, except for two service routes and two intersection, or 8 points, the criteria for choosing are the width and the fact that the street is two-way or one-way. The number of locations for each of the streets was set by the Prefecture of the Paris region at 4 and the sites were determined based on our knowledge of the streets of Paris. After some supplementary measurements, the number of points came to 43.

The collaboration of the Study and Planning Groups and especially that of the Departments of Essonne, Hauts-de-Seine, Seine-Saint-Denis and Val d'Oise was valuable for determining the suburban streets. From this there resulted especially the choice of the six main arteries RN3, RN7, RN10, RN20, RN186 and RN305 on which we had, in general, 4 points per street. There, too, some supplementary points brought the number of locations measured up to 28. Finally, the division, again set by the regional Prefection, at 20 delivery routes and 16 service routes, was brought to 22 and 18 for a total of 68 suburban sites.

Since in this study we are mainly interested in urban traffic noise, we have officially from our research the sites near railways and highways as well as those flown over by airplanes. The same precautions were taken hen a facade overlooked, foreseen or not, a playground, which is oftent the case in the large complexes. /10

Moreover, we did on-site verification of each location's proper conformity to the intended objective recorded on cards. There then began the tedious work of contacting the building managers, often followed by going from door to door in order to find someone who would allow us to place the measuring equipment in his home. This dependence on the good will of the tenants or co-owners did not permit us to do exactly what we wanted and sometimes caused delays.

2.2. Method of Measurement and Processing

At the beginning of the study, two methods of measurement were used concurrently. The first has been used by all those who have done similar studies and consists of recording noise level samples, more or less long and more or less frequent, and afterwards processing them in the laboratory. It is the sampling method.

The second method used by the C.S.T.B. is based on continuous analysis of noise level and is therefore *a priori* conducive to more precise results. Associated with this option is that more complicated equipment must be installed at each measuring point, since the statistical anaysis is done at the site; but a direct consequence of this choice is that processing in the laboratory is done away with, with a considerable gain in time.

After a series of comparisons of the results obtained by the two methods (see Annex 3), we retained the second, with statistical analysis during 48 consecutive hours and partial results for each hour, obtained by photography and the statistical analyser. The principle of this method is described in detail in Annex 3. The hourly results permit groupings or syntheses intended for the physical study and above all to permit correlation with the sociological survey. These are, besides the entire 48 hour period, early morning (0530 to 0730 hours), daytime (0730 to 2230 hours), bedtime (2230 to 0030 hours) and night (2230 to 0730 hours).

Because of the volume of data, we used a calculator to deal with the statistical analysis readings, and the photographs of the counters were reproduced on the statements and then on perforated cards. /11

There were several variants of the program and the reader is referred to Annex 3 for the details.

Our experience in the domain of automobile traffic noise and the simplicity of this model, caused us to take as our basic hypothesis that the distribution of the noise levels followed the Gaussian model. This choice can be criticized and we know that the real distribution differs from it for probabilities less than a hundredth, but what value can be attributed to such low percentages, inasmuch as we are seeking to generalize from results necessarily only bearing on a restricted number of measuring points? We have to be realistic and beware of a possibly illusory exactitude that risks losing sight of the fact that it is a question of physical measurements, of measurements of the level and occurrence of acoustic pressure. The influence of a certain number of parameters escapes us, such as atmos heric conditions for example.

If all of the physical experimentation was done on this hypothesis, the sociologists preferred a method of linear interpretation between the experimental points.

The recorder, and therefore the analyser, always worked on dynamics of 40 to 90 dB (A). The computer, which does not consider percentages greater than 99,95% or less than 0.5%, prints for each hour and for each of the 5 syntheses the level that is reached or exceeded for 1%, 10%, 50% and 90% of the time, as well as the standard deviation. It also gives the results of test showing the validity of the hypothesis using the Gaussian curve. It is a question of the ET value called standard deviation of the deviations between the experiment points and the line of regression, that is, the Henry line, the distribution occurring in cumulative form. The maximum deviation of a point and of this line is also printed; this is the value EM.

Two indices were also calculated only for the syntheses. The first is the TNI, or Traffic Noise Index, and it is obtained by applying the following formula: /12

$$TNI = \bar{L}_{90} + 4\ (\bar{L}_{10} - \bar{L}_{90}) - 30$$

in which $\bar{L}_{90}$ and $\bar{L}_{10}$ are respective the average of the 24 hourly values of acoustic pressure level reached or exceeded during 90% and 10% of the time.

The second index is the equivalent energy level. It is calculated according to two methods. One, by numerical integration of the values actually measured without hypothesis on the law of distribution of levels, leading to a value called L_{eq}. The other, purely mathematical integration with the aid of a formula which supposes that the distribution is Gaussian, leads to L_{moy}. All of this is developed at length in Annex 3.

2.3. Psycho-Sociological Survey

The survey that allowed us to obtain the results given in the present study was preceded by two other studies which we will now briefly describe, the details of each of them being given in annex (5.1.).

The first study permitted us to construct the instrument used for evaluating the annoyance; the second permitted a reasoned choice of the survey sites.

2.3.1. Study Prior to the Working Out of an Annoyance Index

In order to give at least a working definition of the notion of annoyance, we freely interviewed 10 persons. This lead us to include two types of questions in the questionnaire that was used in the extensive study.

The first type of question was aimed at evaluating the amount of interference of a noise level with certain behaviors (reading, sleep). The second type evaluated the annoyance more totally on bipolar scales of 7 points of which only the ends were labeled. /13

The questionnaire contained 61 questions in all, of which:

5 were on total annoyance

18 were on behavioral annoyance
4 were on attitudes toward the noise
2 for weighting (each behavior not being disturbed equally by the noise
22 on the variables other than noise that might have an influence on annoyance
10 others were descriptive questions, and filter or controle questions.

Once adjusted (on about twenty persons) the questionnaire was administered to a first sample of two hundred persons. The data thus obtained allowed study of the weighting systems the influence of variables other than noise on annoyance, and a system of composition of the different elementary annoyances, so as to have a graduated scale for each of them.

The questionnaire was then administered to a sample of 500 persons chosen so that there was a subject distribution covering all of the acoustic variables retained after factorial analysis.

2.3.2. Choice of Acoustic Variables

The number of acoustic variables describing the noise was very high. We in fact had for each period of early morning - daytime - bedtime - night - 24 hours, values L_1, L_{10}, L_{50}, L_{90} (level in dB (A) exceeded during 1%, 10%, 50%, 90% of the time): $(L_{10} - L_{50})$, $(L_{10} - L_{90})$ for a total of 35 different variables.

Since it was impossible for us to deal with 35 acoustic variables plus the annoyance variables at the same time, we did a factorial analysis on the first, which allowed us to retain as representative of all the others: L_{50} daytime, $(L_{10} - L_{90})$ night, $(L_{10} - L_{90})$ early morning. It was therefore in relation to these variables that we chose the survey sites, in the immediate vicinity of the acoustical measuring points. /14

2.4. Principal Collaborators

Robert Josse*, head of the Acoustic Division, was in charge of the research and in particular of the the physical part; Jacques Bietry** was responsible for the sociological part and the processing of the data.

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Jean Marie Rapin*

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III - ANALYSIS AND INTERPRETATION /15

3.1. Physical Aspects of the Phenomena

3.1.1. General Information on the Results of Measurements[1]

We measured the variations of acoustic pressure level in decibels (A) during 48 hours at a large number of sites in Paris and its suburbs. This was necessary for the most complete and most representative sampling possible of the phenomenon "urban site traffic noise".

Each measuring point is a special case for which a complete physical interpretation could be made. Viewed in this way, each measurement can be the object of a study, and we would undoubtedly discover that an exact description of the traffic noise at a given point depends on complex variables that may exceed the physical: the behavior of a driver in a certain place certainly has to do with psychology and sociology. Such a study would be of interest only only if it were practical. In fact, the interpretation of acoustic pressure level due to traffic noise, in terms of annoyance, remains inexact and does not allow interpreation of slight differences between two levels. It is therefore useless to seek methods of calculation that are too refined.

We therefore contented ourselves with trying to interpret some very simple cases, then to consider all of our results on a macroscopic scale in order to deduce simple laws.

3.1.2. Urban Site Traffic Noise Spectrum

We characterize the urban site traffic noise spectrum by means of an overall value in decibels (A). It was useful to verify whether a particular noise had a certain spectrum and if the geometrical characteristics of the street influenced the distribution. /16

We determined the distribution spectra by octaves of the acoustic

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1. N.B. - The results of the measurements dealt with in this chapter are to be found in Annex 4.

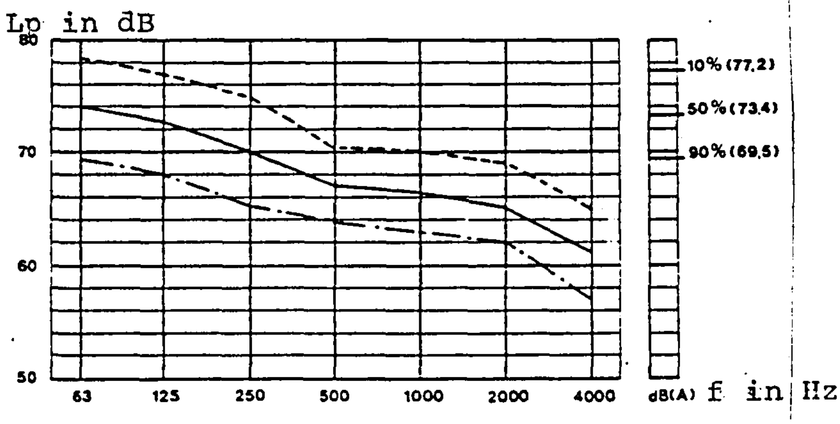
pressure levels exceeded during 90%, 50% and 10% of the time, at different points in the streets in U.* The analysis was done for the recordings on a tape recorder for a period of 20 minutes. Two samples were measured simultaneously in each street.

Rue de Rennes, in front of the 2nd floor and in front of the 6th floor (FIG. 1), May 6, 1969, between 1545 and 1605 hours.

Avenue de Versailles, in front of the 2nd floor and in front of the 8th floor, May 9, 1969, between 1507 and 1527 hours.

Boulevard Saint-Germain, one-way street, in front of the 2nd floor and the 6th floor, April 29, 1969, between 1508 and 1528 hours.

FIG. 2 shows an average spectrum deriving from these measurements. We do not see a very significant difference between this spectrum and those preveiously measured in the vicinity of highways without buildings along them (Ref. I). They are also quite comparable to the spectra presented in the different foreign studies that we have mentioned in the Annexes. The level of acoustic pressure in dB (A) therefore suffices to physically characterize a traffic noise.



/17

Fig. 1 - Distribution spectrum of noise level in Paris (rue de Rennes, 6th fl.)
----- L_{10}, ——— L_{50}, — · — L_{90}
Octave analysis

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* N.B. - We call a street with buildings along both sides a U street; one with buildings on one side is an L street.

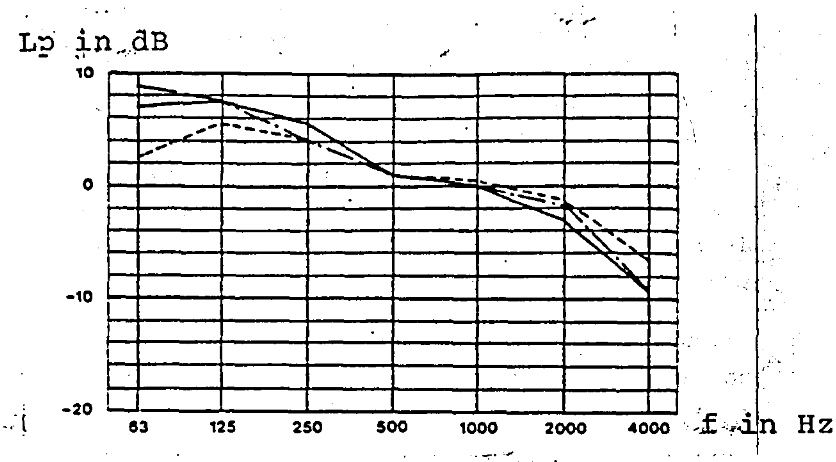


Fig. 2 - Distribution spectrum of traffic noise in relation to its level in 1,000 Hz octave

——— Average of 6 points in the streets of Paris

— · — 50 meters from Boulevard Peripherique, in Paris

----- Average in vicinity of highway (1964 LAMURE-AUZOU)

3.1.3. Influence of Traffic for a Given Street /18

In Annex 2 we have shown how the acoustic power of a street with traffic depended on the flow. We verified this for a large sampling of measuring points with information given by the measuring apparatus that we installed in the vicinity of the measuring points. These data were later complemented by the results of the systematic readings made by the Paris highways department.

For 24 hours of measuring in Paris, it was possible to determine a linear regression between the level exceeded 50% of the time each hour and the decimal logarithm of the flow of traffic during the same period of time.

For 90% of these points, the coefficient of correlation between L_{50} and the flow on the street is greater than 0.972, for 50% greater than 0.982, reaching 0.990 in the best cases.

The average error is on the order of a decibel; that is, of the same order as the precision of measurement that can be reached. It can be deduced from this that the correlation between the noise level and the flow on a street is very good.

Note that the 4 points for which the correlation seems least good (between 0.95 and 0.97) are points at the edge of the Cours de Vincennes, which actually carries two streams of traffic: traffic of the central street and traffic of the two lateral avenues. These two streams of traffic have different characteristics. The correlation was studied for the sum of the two flows. A weighting of the flow of the lateral avenue that took into account its greater proximity to the measuring points would no doubt have led to still better results.

Annex 4 gives the results of these regressions accompanied by plans and cross sections describing the position of each measuring point.

Note that the coefficients of regression have different values for each measuring point. /19

$\frac{d\ L_{50}}{d\ \log Q}$ varies between 10 and 20 as could be expected from the theory given in Annex 2.

However, our theory does not predict such a linear law of variation of L_{50} in relation to log Q. We have to think of a correlation of the effects of the variation of concentration and of the variation of speed.

If the present knowledge of the laws of traffic in a street is too weak to shed light on acoustic phenomena, the laws of acoustics can perhaps lead to better knowledge of the laws of traffic.

At the same time as the study of the correlation between L_{50} and log Q, we studied the correlation between σ, which was good. The coefficient of regression of σ in relation to log Q is negative.

FIG. 3 shows the relative variation of $\frac{d\sigma}{d\ \log Q}$ in relation to

$\frac{d\ L_{50}}{d\ \log Q}$. We ascertain that the absolute values of the coefficients of regression vary in the same way.

A rough interpretation permits us to write:

$$\frac{d\ L_{50}}{d\ \log Q} = -3.5\ \frac{d\ \sigma}{d\ \log Q}$$

which permits us to write that:

$L_{50} + 3.5\sigma$ is independent of Q.

For a normal distribution this means that the acoustic pressure level exceeded during 0.025% of the time is independent of the flow, which translates a very simple and logical fact: the maximum noise level points in a street, generally due to the passage of an isolated vehicle that is particularly noisy, is perfectly independent of the flow on the street.

/20

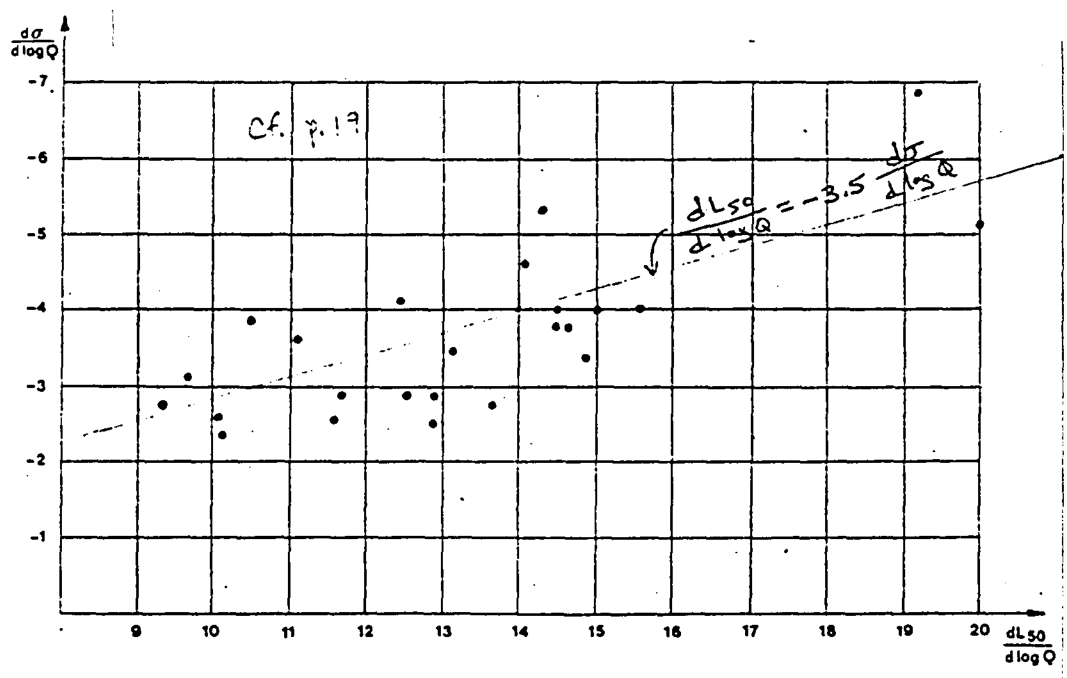


Fig. 3 - Relative variation of coefficients of regression L_{50} / log Q and σ / log Q

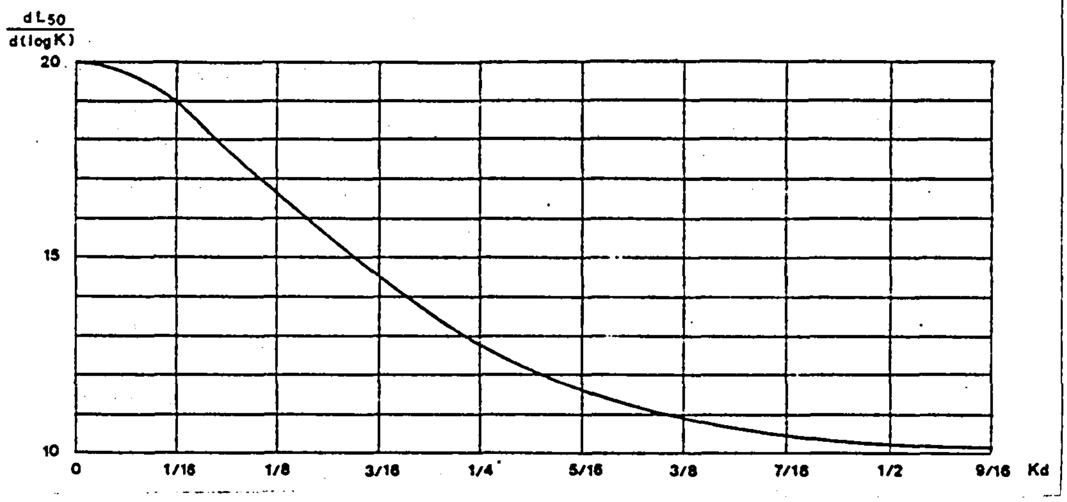


Fig. 4 - Variation of coefficient of regression of L_{50} in relation to log K as function of K for a line of independent sources of equal acoustic power and regularly spaced.
K is the concentration of vehicles per meter
d is the distance from the point of observation to the source line in meters.

This phenomenon is translated most precisely by the correlation between L_{50} and σ (Annex 4). /21

These different correlations show that knowledge of the flow can perfectly describe the noise in a street.

Similar work was done for the suburban points. If the correlation was as good for the main streets, it was not so good for certain service roads where the traffic flow was very low. In these latter cases the geometry of the streets and the atragnement of the buildings was more complex. Several flows of traffic could be mixed. Each of these cases had to be studied individually and could not be included in the general case.

For the main streets, $\frac{d\ L_{50}}{d\ \log\ Q}$ takes the average of the highest values, like Paris (between 15 and 16).

3.1.3. Mutual Influence of Traffic Density and Distance of Measuring Point to Street

In Annex 2 we have shown that $\frac{d\ L_{50}}{d\ \log\ Q}$ depended on the distance between the location of the microphones and the edge of the road. Two measurements made at the same time from two different heights on the Boulevard Saint-Germain translate this phenomenon. It is a question of points P 11 and P 12 (Annex 4). Point P 11 is on the 2nd floor, at about 12 meters from the 1st line of cars and 16 meters from the center of the road; at this point $\frac{d\ L_{50}}{d\ \log\ Q} = 14.8$.

Point P 12 is on the 6th floor, about 20 meters from the 1st line of cars; at this point $\frac{d\ L_{50}}{d\ \log\ Q} = 13$.

This difference is perfectly explained by FIG. 4. If it is allowed that P 11 is on the average 14 meters from the lines of cars and P 12 is 20 meters.

Application of FIG. 4 to the values of $\frac{d\ L_{50}}{d\ \log\ Q}$ leads, if it is allowed that L_{50} is independent of the speed, to average spacings be- /22
tween cars of about 80 meters, which is too much.

The Boulevard Saint-Germain has a flow of about 1,000 vehicles per hour. It would therefore be necessary for these vehicles to be traveling at 80 km/h. Cars travel on the Boulevard Saint-Germain in at least two lines, which indicates, for a line at a distance of 80 meters, a speed of 40 km/h, but that does not mean that the average distance between vehicles is 80 meters. If we observe the traffic on the Bulevard Saint-Germain, we ascertain that because of the traffic lights at the intersections the traffic consists mainly of clusters of cars. From which we must deduce that the average distance between clusters (consisting of 2 or 3 cars) is 80 meters? This explanation seems plausible to us. Note, however, that we have allowed that the variations of speed connected with the variations of flow are not accompanied by a systematic variation of noise emitted by each vehicle.

If we accept as valid this explanation of the variation of L_{50}

at P 11 and P 12, Boulevard Saint-Germain, we can see that the points P 16 - P 17 - P 18 and P 19 measured on the Rue de la Convention for flows similar to the Boulevard Saint-Germain, follow the same law and lead us to allow a spacing of about 80 meters between groups of vehicles. Points P 5 and P 6, Rue de Vaugirard, lead to the same results.

At point P 24, Avenue de Versailles, where the flow is about double that of the previous streets, the average spacing between groups of vehicles would be 50 meters.

On Rue de Douai, the average flow is about 600 vehicles per hour and $\frac{d\ L_{50}}{d\ \log Q}$ varies from 11.7 to 13.7 (P_1, P_2, P_3).

FIG. 4 can be applied to explain the variation of L_{50} if we allow that the speed of the vehicles is slow due to the narrowness of the street.

On Cours de Vincennes, where the points are far from the main artery and the flows are very high, $\frac{d\ L_{50}}{d\ \log Q}$ is about 10. It is 9 for the points nearest the lateral avenue where the traffic affects the variation of L_{50} with the main flow. In the case of the arteries it seems that the traffic is made up of larger clusters, with a high value of $\frac{d\ L_{50}}{d\ \log Q}$. /23

3.1.5. Influence of Height

In dealing with the effect of the distance on the variation of L_{50} with the flow, we dealt partially with the effect of the variation of height. Note that at a distance D from a line of vehicles, on a street whose sides are clear:

$$\frac{d\ L_{50}}{d\ \log D} = 20 - \frac{d\ L_{50}}{d\ \log K}$$

according to Annex 2.

Thus if $\frac{d\ L_{50}}{d\ \log K} > 10$ $\qquad$ $\frac{d\ L_{50}}{d\ \log D} < 10$

L_{50} will slowly decrease in relation to the distance.

We have shown in Annex 2 that the reflections on the facades and the presence of several lines of cars tends to diminish the decrease.

We cannot a priori determine what the variation of L_{50} will be with the height, since this variation depends on the flow. On the other hand, we know a little better how to control the average L variations. Points P 11 and P 12, Boulevard Saint-Germain, give us some indications: the variation of L_{50} is weak between the 2nd and the 6th floor. It depends on the period: decrease of about 3 dB daytime, 2 dB at night. σ decreases about 1 dB. Average L decreases 3.5 dB whatever the period of mesurement.

Boulevard Bourdon, the variation of L_{50} between a 3rd floor and a 9th floor is much weaker : from 1 to 2 decibels daytime, none at night. σ decreases about 1 dB, while average L decreases 3 decibels whatever the period of measurment; L_{10} gives a variation similar to average L, and L_1 decreases 5 dB. (Note that the presence of Boulevard de la Bastille contributes to the weak decrease of L_{50} (Annex 4). /24

We have some individual cases in order to study this variation more precisely. We have used sampling with the help of tape recorders. A fixed microphone was on the highest floor of the building, while a movable microphone could be placed successively on the various lower floors of the building. The successive samplings took 20 minutes. The time of day chosen for the measurements was such that the flow on the street was high and there were no great differences of flow between the samples.

At each point, we determined the differences in acoustic pressure level, at 90% of the time, 50% of the time, 10% of the time and 1% of the time; that is, ΔL_{90}, ΔL_{50}, ΔL_{10}, ΔL_1 between the point of reference and the movable point.

The results of these measurements are given in the annexes. We note a certain dispersion in the results of measurements at the different sites. This dispersion is undoubtedly connected to the differences between the traffic flows and to the differences in geometrical characteristics of the streets. The absolute values of the deviations is very weak and on an order in the vicinity of that of the precision of the measurements. It is not possible to conclude that there are significant differents between streets. The variation of L_{50} is very weak, and in practice it seems negligible. L_{10} and L_1 decrease more quickly with height. σ decreases with height. L_{90}, on the other hand, has a tendency to increase with height. This effect was already seen in the Korn measurements (Annex 2). When the height increases, the sources of noise are viewed from a higher solid angle. In certain individual cases, we thus ascertained that L_{50} increases slightly between the 2nd floor and the 3rd floor. Parked vehicles and various obstacels can slightly reduce the acoustic pressure at the 2nd floor

In FIG. 5 we have indicated a law of average variation at the facade of a 7 storey building in a U type street. If L_1 varies as the noise from a point at the center of the street, we can allow that L_{50} is practically constant. /25

FIG. 6 shows the measurement of the variation of acoustic pressure along the facade of a 26 storey tower, located near a suburban avenue. We note the screening effect of a ground floor extension. The level of acoustic pressure is reduced at the first floors and is maximal at the 10th; it decreases very slowly. The acoustic pressure is higher at the 26th floor than at the 2nd floor. It is useful to compare these results with those obtained by foreign writers (Ref. 2, 3, 4, 5, 6). σ is weaker at the 26th floor.

To sum up, we can neglect the variation of L_{50} with height. The variation of L_1 and average L can be calculated according to the theoretical methods.

The decrease of σ with the height is approximately one third that of L_1.

3.1.6. Variations Along the Same Street

For Boulevard Saint-Germain we note variations in the coefficient of regression connecting L_{50} and the flow. Points P 13 and P 10 do not come under the general laws that we stated previously. At P 13, a point on the 4th floor, $\frac{d\,L_{50}}{d\,\log Q} = 11.6$; on the other hand, at P 10, a point on the 5th floor, it equals 15. We see that the proximity of the large intersection of Maubert creates an increase in the concentration of vehicles at P 13 and that on the other hand the noise from other streets at this intersection interferes with that of the Boulevard Saint-Germain. We can also allow that at point P 10, far from any large intersection, the speed of the vehicles is greater and the concentration is less. /26

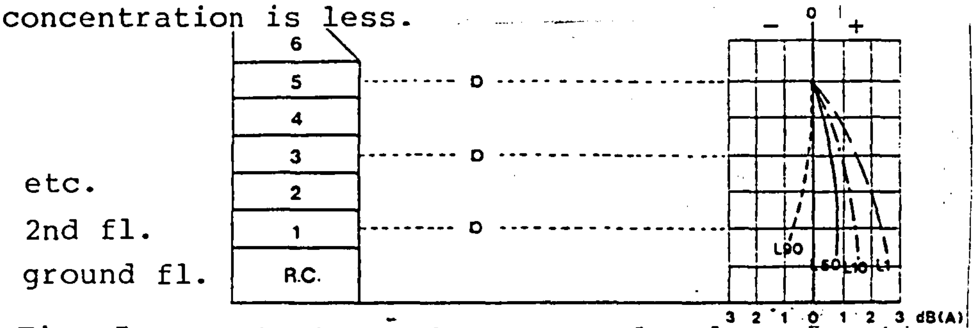


Fig. 5 - Variations of pressure level as function of height. Average of 5 Paris streets for L_1, L_{10}, L_{50}, and L_{90}. Ref. : 6th fl. level

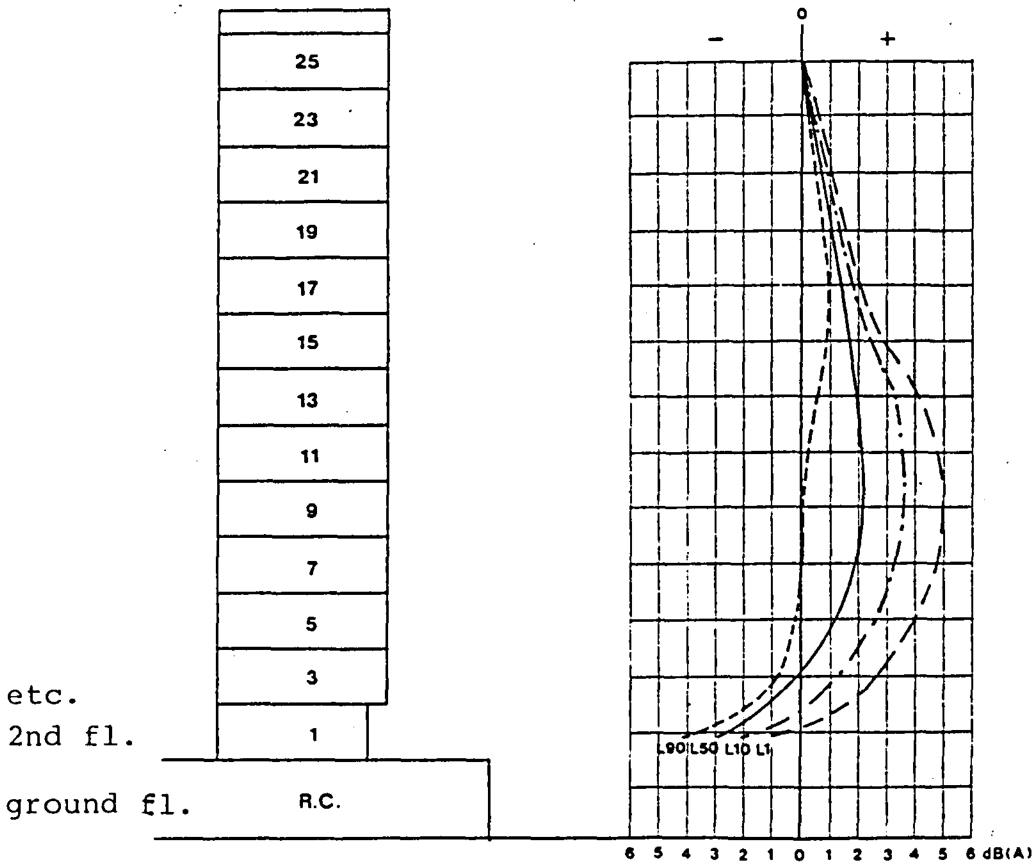


Fig. 6 - Variation of pressure along a 26 floor tower.
Place : 25, av. du General Leclerq -LA CORNEUVE
Ref. : 26th fl. levels

We also note that point P 18, Rue de Vaugirard, differs from the other points on this street: the measurement was made on a day when the flow was higher than usual, with increase in the concentration. /27

Points P 9 and P13, Boulevard Saint-Germain, near traffic lights, have an L_{50} level about 2 dB higher than that measured at the other points. The differences between the L_{90} levels are greater (close to 5 dB), while L_{10} and average L are not affected by the proximity of intersections.

Despite the existence of a traffic light near P 8, there is no significant difference between the points on Rue de Vaugirard. The same observation can be made for Rue de la Convention.

Point P 28, Boulevard de Batignolles, near Place de Clichy, gives an abnormally weak σ, without L_{50} being especially changed.

It is difficult to give a law of variation of noise along the length of a street. We have grouped the values of L_{50} for all of the Paris points near an intersection traffic light: most do not differ significantly from the other points.

We note significant differences when the street meeting the intersection is a street with a flow that is much less than that of the streets it meets.

Moreover, point P 37 on Rue Emile Duclaux, located 26 meters from Rue de Vaugirard, has an L_{50} level greater by 5 dB than point P 36 of this street, located 60 meters from Rue de Vaugierard. (The L_{50} level for Rue de Vaugirard is about 6 dB greater than that measured at point P 37). The flow on Rue Emile Duclaux is about 20 times weaker than that on Rue de Vaugirard.

The problem of traffic noise at an intersection must be approached taking into account the sum of the flows of the different streets that enter it.

An intersection like Gobelins, for example, ((P 42 and P 43) has /28
a high flow; we ascertain that the L_{50} level measured is in proportion to this flow, while the dimensions of this intersection are such that the effect of reflection by the facades is less than in an ordinary street.

3.1.7. Variation with Time of Year

We measured the acoustic pressure at the facades of different buildings along streets of Paris and its area at different times of the year. It was useful to know if a measurement of acoustic pressure made on a certain day could be representative of the noise on the street during the course of the year.

We decided to measure the acoustic pressure regularly at the same point. For reasons of convenience we chose the C.S.T.B. headquarters building on Avenue du Recteur Poincare. It is a secondary street susceptible to great fluctuations of flow. The measurement was made each month from the third Tuesday to the following Thursday. The values retained for employment of the data were the daytime and night syntheses. These values were calculated according to two methods: (FIG. 7a and FIG. 7b).

- line of the Gauss passing closest to the measured values (Gauss)
- linear interpolation among the measured values (BIL)

We can also verify the validity of the hypothesis of a normal distribution for the entire year. The results obtained by these methods have very significant differences. These differences are negligible as long as the acoustic pressure level is greater than 60 dB (A). We may conclude that the hypothesis of a normal distribution is very valid.

For levels greater than 60 dB (A) the annual variation of the daily statistical levels is weak. It is on the same order as that of the precision of the measurements or the variation in relation to the height. We can deduce from this that the traffic noise levels greater than 60 dB (A) that we measured at each point during 48 hour periods are representative of a yearly average.

/29

	Period	Method	Annual quadratic mean	Diff. betw. daily av. and annual av.	Maximum lower difference
L 1 %	DAY	Gauss	75,2	+ 2,5	- 1
		BIL	75,4	+ 2,4	- 1
L 10 %		Gauss	69,5	+ 2,4	- 1
		BIL	69,1	+ 2,4	- 1
L 50 %		Gauss	62,5	+ 2,3	- 1,6
		BIL	62.6	+ 2,5	- 1,7
L 1 %	NIGHT	Gauss	70,7	+ 1,2	- 1,6
		BIL	70,8	+ 2,3	- 0,9
L 10 %		Gauss	61,6	+ 2,1	- 1,3
		BIL	61,9	+ 2,2	- 1,5

The variation of levels less than 60 dB (A) is a little greater and becomes appreciable with the precision of the measurement.

	Period	Method	Average	Maximum upper difference	Maximum lower difference
L 90 %	DAY	Gauss	55,6	+ 2,1	- 3
		BIL	56,2	+ 2,6	- 3,6
L 50 %	NIGHT	Gauss	50,5	+ 3,2	- 3,4
		BIL	49,9	+ 2	- 2,6
L 90 %		Gauss	39,4	+ 3,1	- 5,5
		BIL	39,2	+ 4,8	- 8,8

These levels thus have a limited significance. It does not seem to be of interest to know such weak levels with great precision.

MONTHLY VARIATIONS AT C.S.T.B. HEADQUARTERS

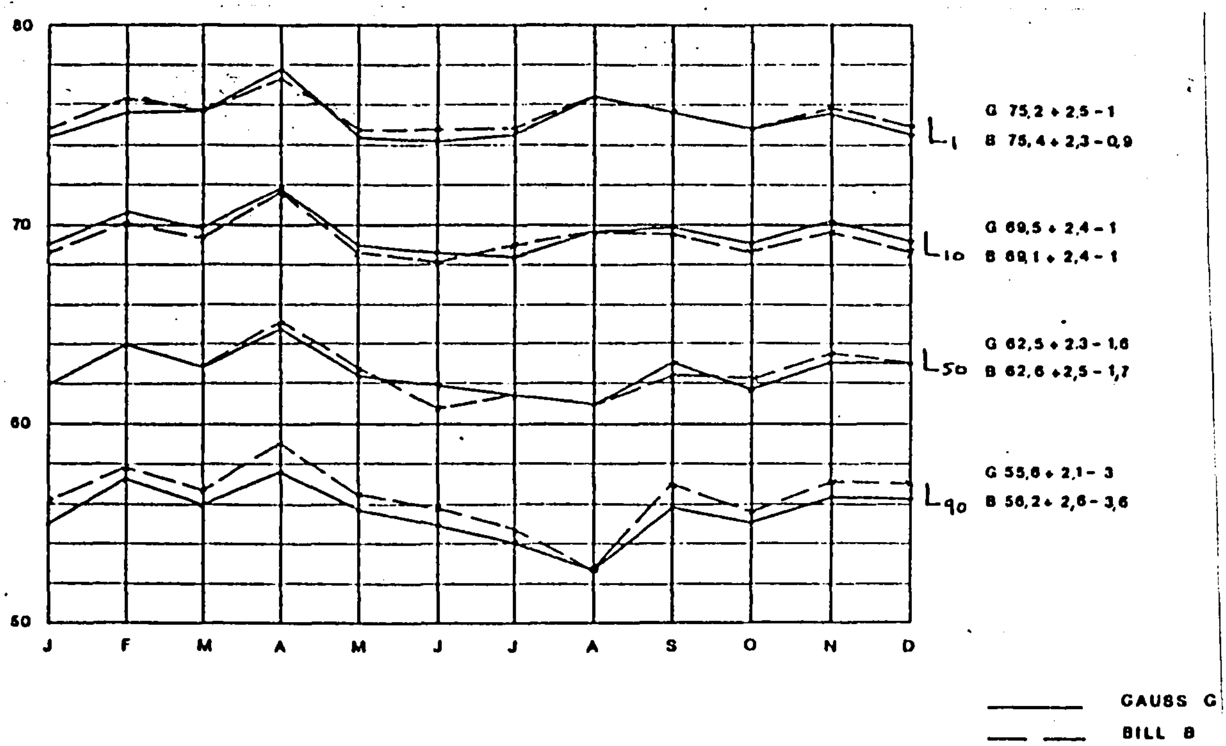


Fig. 7a - Daytime synthesis

MONTHLY VARIATIONS AT C.S.T.B. HEADQUARTERS

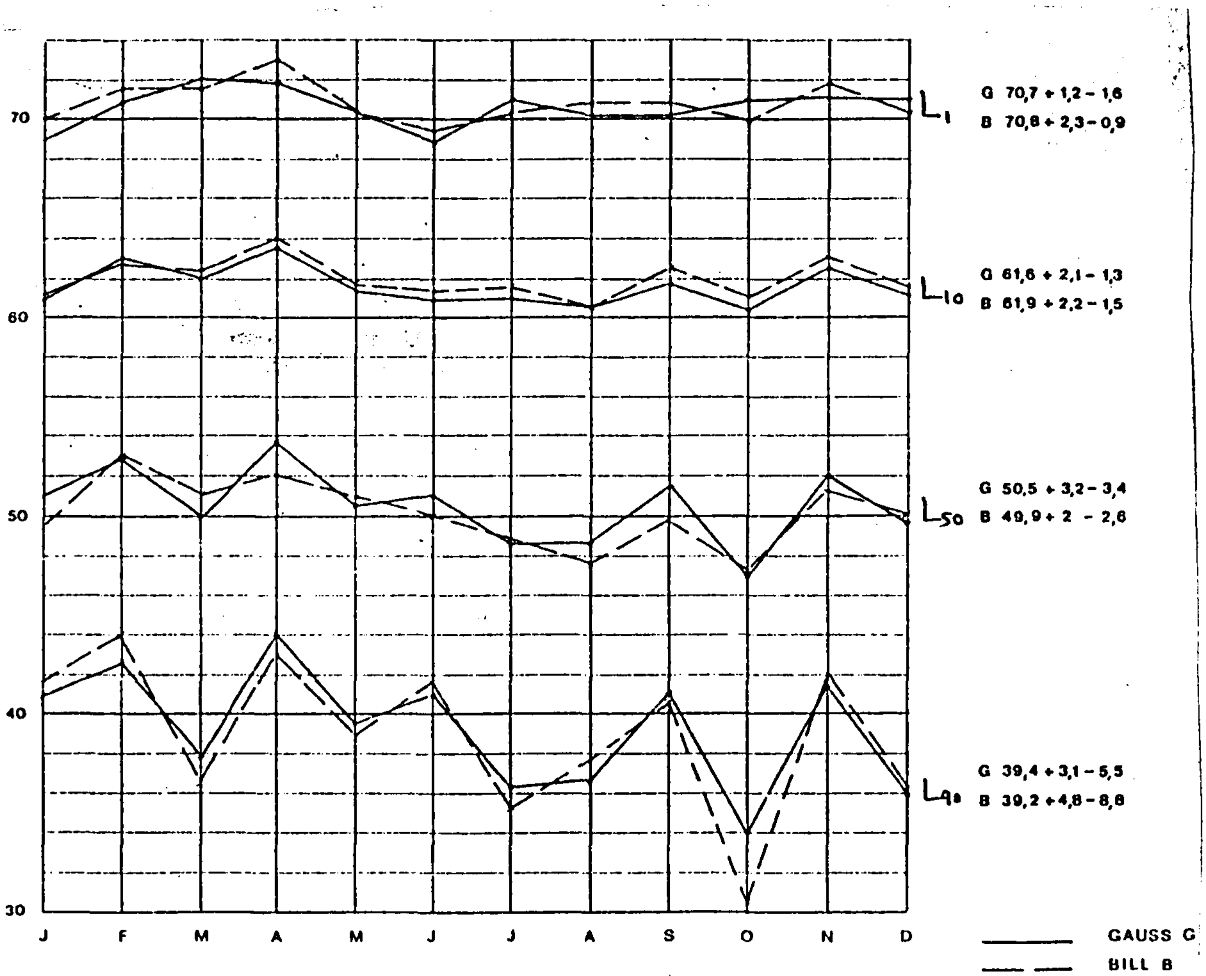


Fig. 7b - Night synthesis

The month of August shows a drop in the level at 90%, which is especially noticeable in the daytime: when L_{90} is very weak it contains only traffic noise. /32

The study of the different measuring points permits other remarks on variations during the course of the year. For points P 5 and P 6 on Rue de Vaugirard likewise, the traffic is less in the morning in April (slack period between 0500 and 0700 hours) than in January; the measurements were made on the same days of the seek (Tuesday and Wednesday).

As we stated above, the difference is noticeable mostly for L_{90} (6 dB between 0500 and 0700 hours)). For L_{50} the difference is only 3 dB.

We have spoken (Annex 2) of the effect of rain on the noise emitted by an isolated vehicle. This effect is much less pronounced when it is a matter of traffic noise: the cars move more slowly when the roadway is wet. Several measurements were made of this at point P 6 at the time of the preliminary measurements. The last measurement was made on an especially rainy day. The roadway consists of mosaic paving. No significant variation of L_{50} was ascertained. On the other hand σ is a little higher for the 24 hour period (2 dB).

There is no significant difference between the points B 11 and B 13, measured during good weather, and the points B 10 and B 12, measured during rain and snow.

An Austrian study published in 1949 shows a slight effect caused by the foliage of trees (decrease with the height more rapid) on the noise at the facade at the time of passage of a light vehicle and a heavy one. The measurements were made by the Institute of Physical Chemistry of the University of Vienna. There is a row of very thick trees on each side of the street, the foliage of which intermingles and appraches the facades.

The greatest reduction (3 to 4 dB) is at the floor (4th floor) closest to the tops of the trees. This measurement, mentioned in the book of Moles (Ref. 7 and 8), shows that the trees mainly effect the field reverberated by the street. The attenuation of the sound by the vegetation is in fact very slight. Wooded areas several dozens of meters wide are required to achieve an appreciable reduction of noise in an open field. In the case of a street, there must be multiple reflections from the facades in order for the trees to have any effect. /33

The measurements of variation of noise at the facades of buildings on Boulevard Saint-Germain that we mentioned above show a decrease in sound with the height, which is slow and similar to that measured in streets without trees. We note that there is no common measurement between the trees of the Boulevard Saint-Germain, which are spaced and regularly pruned, and those of the Institute of Physical Chemistry of Vienna. We know of no cases of Parisian streets where falling leaves can cause a significant seasonal variation in the level of acoustic pressure.

3.1.8. Difference Between a U Street and an L Street. Effect of Reflection by Facades

The sampling of measurements that we have for Paris does not permit us to make good comparisons between a street lined on both sides by buildings (U street) and a street lined by buildings on one side and whose opposite side is perfectly clear.

The case of a small square on Rue de Vaugirard at P 6 cannot be considered a clear side because the results at this point are not different from the results at the other points on the street.

This lead us to compare the Paris points with the suburban points, in spite of the noticeably different conditions of traffic flow.

If we compare, for example, the results of measurement at point B 7 near National 7 to those at a point such as P 24 on Avenue de

Versailles, we ascertain that with equal flow the L_{50} leve at P 24 is from 5 to 6 dB greater than L_{50} at B 7. We note that similar differences exist between most of the Paris points and suburban points. /34

It seems possible to use the values given for FIG. 8, taking $\alpha = 0.1$ for the calculation of L_{50} and on condition that the flow is high. (FIG. 8 corresponds more closely to a calculation of average L.)

3.1.9. Evaluation of the Acoustic Pressure in a U-Street in Relation to the Flow and the to the Width of the Street

We successively eliminated variable differences that might act on the noise in a street, retaining only two: the traffic flow and the geometry of the street.

The flow being the most important variable, we sought a correlation between the daytime L_{50} level, the night L_{50} level at each Paris point, and the flow corresponding to the same periods at each of these points. The values of the flows came either from simultaneous counting or from countings made by the Paris highway department, made public when they were old.

In the case of intersections, 4 measuring points, the sum of the flows was determined.

The study had to do with 39 points in the streets of Paris, or 78 daytime and night synthesis values. FIG. 9 shows the statistical distribution of the values of L_{50} and of the equivalent level (L_{eq}). We ascertained that our sample was quite representative of the different situations.

The equation for the line of regression (daytime and night together) is:

$$L_{50} = 11.9 \log Q + 31.4$$

The correlation factor is 0.887. The average deviation of the L_{50} values measured in relation to this law is 2.4 dB and the maximum deviation is 5.7 dB.

/35

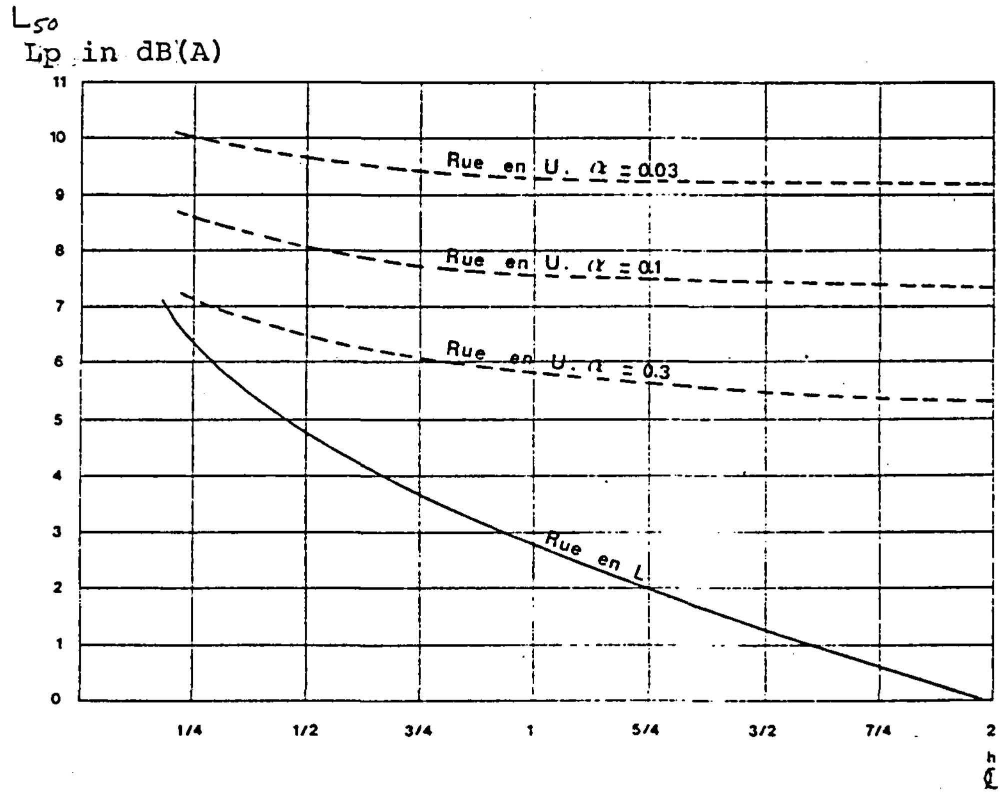


Fig. 8 - Variation of the level of acoustic pressure as function of the height h of a measuring point at the facade of a building located on a street with a width l and of infinite length, completely covered with sources of noise. The width of the sidewalk is not considered. Reference level zero is that which would be measured at a distance l from an identical street with no buildings.

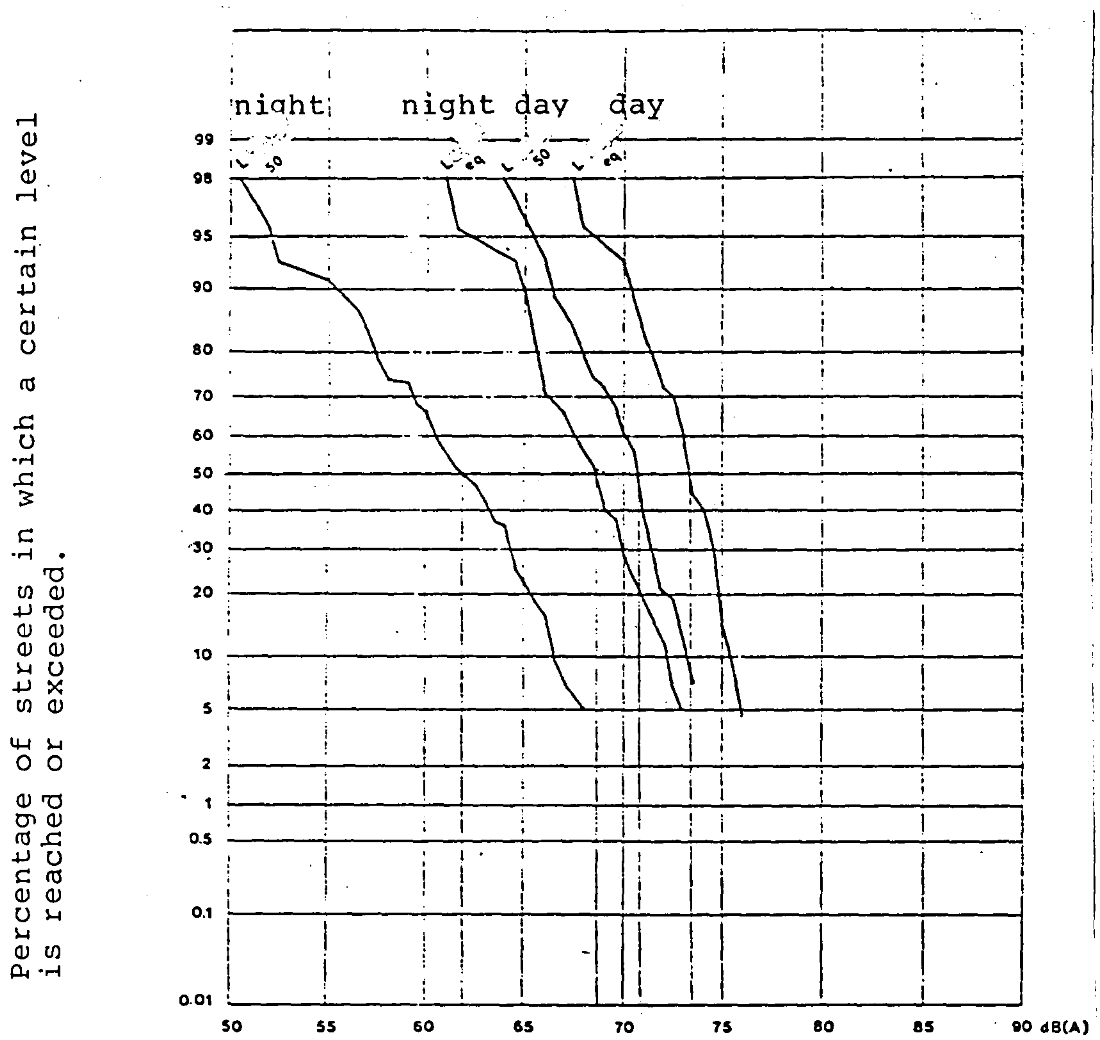


Fig. 9 - Distribution obtained for 43 Paris streets as function of L_{50} and L_{eq} levels of traffic noise, day and night.

We ascertained that for a Paris street, merely knowing the flow allows us to calculate an approximate value of L_{50}. /37

Seeking the correlation between L_{50} and σ lead to the equation:

$$L_{50} = - 2.43\sigma + 80.3$$

The corelation factor is 0.909. The average deviation of the L_{50} values measured in relation to this law is 2.2 dB, or about 1 dB error on σ and the maxium deviation is 4.8, or about 2 dB error on σ.

The approximate value of σ as it can be deduced from this law from a knowledge of L_{50} permits calculation of L_{10} or L_{90}, for example. The precision will not be as good for the calculation of average L since σ intervenes in the square. σ can also be calculated directly from log Q by means of the formula:

$$\sigma = - 4.38 \log Q + 18.6$$

The correlation factor for this regression is 0.87.

We sought to improve the precision of the calculation of L_{50} by taking into account the geometry of the street. For which we included the <u>width of the street</u>, using the law given theoretically: in a U street, when the buildings are practically at the edge of the roadway, the square of the acoustic pressure is practically inversely proportional to its width.

We therefore have, for a U street, sought a formula with the form:

$$L_{50} = A \log Q + B - 10 \log 1$$

We found: /38

$$L_{50} = 15.5 \log Q + 22.8 - 10 \log \frac{1}{20}$$

which leads to a correlation factor of 0.96 between

$$L_{50} + 10 \log \frac{1}{20} \text{ and } \log Q$$

the average error on L_{50} is 1.7 dB. It is on the same order as the precision of measurement or the variations due to height.

Therefore, for a U street we can apply the formula

$$L_{50} = 15.5 \log Q + 36 - 10 \log l \qquad \text{(FIG. 10)}$$

which can be complemented by the formula that we gave above for the calculation of σ. Using the graph of FIG. 8 permits us to apply this law to a street lined with buildings on one side, by applying the correction factor corresponding to the value of h/l at this point.

We note that in FIG. 9 there is a linear relationship between L_{50} and the equivalent energy level (L_{eq}).

We found for the night

$$L_{eq} = 0.62\, L_{50} + 30$$

and for the day

$$L_{eq} = 0.7\, L_{50} + 24$$

These two relationships differ little; they can be given a single value

$$L_{eq} = 0.65\, L_{50} + 28$$

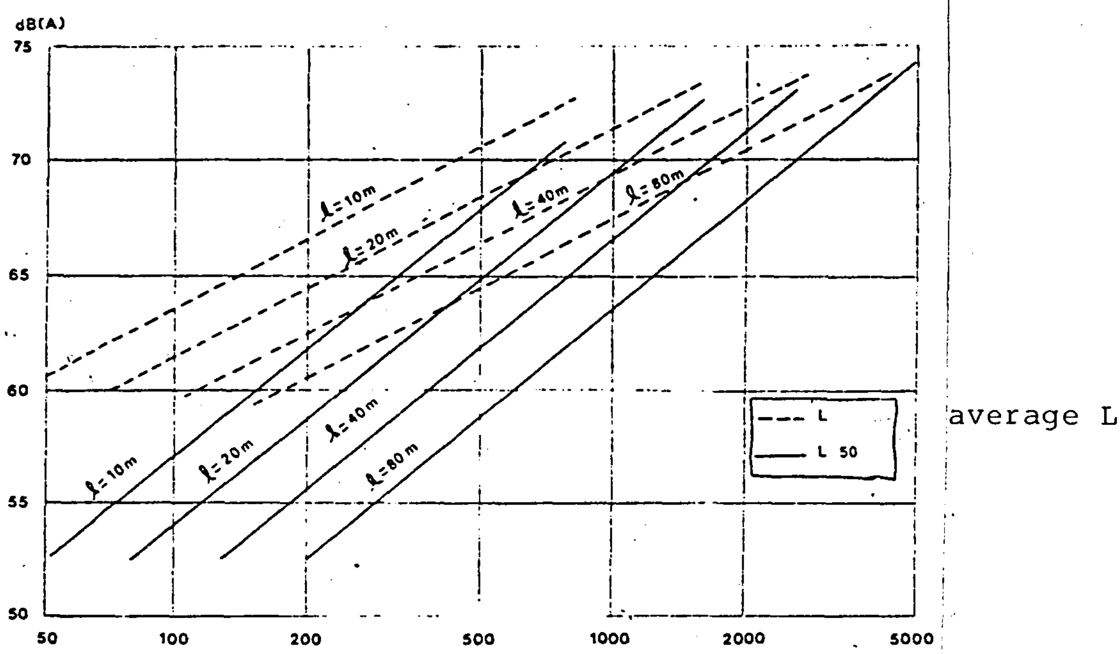
which allows us to write

$$L_{eq} = 10 \log Q + 51 - 6.5 \log l$$

We have shown that for the totality of our measuring points,

L_{eq} was greater than average L by one decibel (L_{eq} and L_{moy} differ only by method of calculation. See Annex 3.)

/39



Average flow in vehicles/hour

Fig. 10 - Level of traffic noise in the streets of Paris as function of traffic and width of street.

$$\text{average } L = 10 \log Q + 50 - 6.5 \log l \qquad \text{(FIG. 10)}$$ /40

This expression agrees with our theory that showed that the average energy emitted by a street with traffic is proportional to the density of the flow of vehicles K, and therefore proportional to Q if U, the average speed of the vehicles varying little, or if the variations do not correspond to significant changes in the noise emitted by an individual vehicle, which seems to be the case in ordinary streets.

We thus have a tool permitting us to predict with sufficient precision the acoustic pressure due to traffic noise in standard urbanized areas. Of course, all of the cases cannot be put in the form of equations. Suburban areas in particular lend themselves less to general laws and the problem is complex when the there is little traffic. These special cases are of little interest since they correspond to weak levels of acoustic pressure.

The very important catalog of results of measurement that we have compiled corresponds to a range of cases sufficiently wide to bear on points of comparison for most of the complex cases that may occur (Annex 4).

3.2 Sociological Aspects

3.2.1. Non-Parametric Analysis

We have noted in Annex 5.1 that if annoyance varied in relation to the intensity of the sound to which the subject is subjected, it was possible for its expression to be modified by factors that would increase it or diminish it. In our study these variables are called "correction variables" since they "correct" the obtained results, with their parasitic influence, in order to obtain comparable statements of annoyance.

It was therefore necessary to control above all the biases that /41 that might come from the following factors:

- age
- sex
- profession
- possession and frequency of use of an automobile
- period of habitation in the present dwelling
- presence of other sources of noise
- place where radio and television are listened to (street side or back)
- time spent in the dwelling: day, night
- location of the bedroom: street side, or back)
- occupancy rate (number of persons in relation to number of rooms)
- whether or not sleep inducerssare taken
- evaluation by the subject of the noise in his previous dwelling in comparison with the present noise
- satisfaction in regard to the section of town
- rate of exposure of the dwelling (number of rooms on the street side in relation to total number of rooms)

No value other than that accorded in this study must be attributed to these variables.

The occupancy rate, for example, is merely the ratio of the number of persons habitually inhabiting the dwelling to the number of habitable rooms (living room + bedrooms).

On the other hand, in order to calculate the rate of exposure of the dwelling, we devise a ratio dimilar to the preceding one but adding the kitchen to the total number of habitable rooms.

Finally, satisfaction with the section of town is given the working definition of the number of positive responses to the question; the most satisfied being those who answered yes to all of the items (that is, to each part of the question).

The correction variables that we have just listed do not all have

total effect. Certain ones influence only a particular behavior. /42
Thus, the place where the radio and television are listened to was studied only in relation to the corresponding activity.

In order to study the possible influence of the correction variables on annoyance, we basically used the Friedman variance analysis*.

This analysis of variance, as well as other statistical tests used in this first part of the analysis of the data (χ^2 Test, Sign Test, Spearman correlation coefficient) is statistically non-parametric. Other names for it, independent distribution methods and order statistics, indicate that the only measurement used here is a sequence.

The Friedman variance analysis lead us to eliminate the following correction variables as having no effect on expression of annoyance:

- age
- profession
- possession and frequency of use of an automobile
- period of habitation in the present dwelling
- place where radio and television are listened to
- location of the bedroom, on the street side or in back
- occupancy rate of the dwelling

For all of these variables the probability of error in case of rejection of the "zero hypothesis" — the correction variable is without effect on the expression of annoyance — is very high (most often greater than 20% or even 30%).

Table I gives the correction variables having an effect and the annoyance on which they have a bearing.

The first column of the table carries the score corresponding to the value (simple or combined) of the annoyance under consideration.

* See Annex 5.4.

Table I - Friedman Variance Analysis

N = number of subjects
NF = Friedman number
dl = degree of freedom

Score	Parameter	Controlled variables	S	N.F.	dl	Probability
a.* reading combined	sex	L_{10} J $L_{10} - L_{90}$ J	340	7,623	1	$0,001 < p <$ 0,0
a. reading combined	presence day	L_{10} J $L_{10} - L_{90}$ J	330	3,787	1	$p = 0,055$
a. reading combined	presence day	sex $L_{10} - L_{90}$ J L_{10} J	184	6,260	1	$0,01 < p <$ 0,0
a. going to sleep	medicines	exposed room L_{10} C $L_{10} - L_{90}$ C	196	13,969	1	$p < 0,001$
a. overall 7 points	S.Q.	L_{10} 24 h $L_{10} - L_{90}$ 24h	128	11,165	3	$p = 0,01$
a. day 7 points	S.Q. rectified	L_{10} J $L_{10} - L_{90}$ J	240	9,806	2	$0,001 < p <$ 0,0
a. night 7 points	B.L.P. night	L_{10} N $L_{10} - L_{90}$ N	350	17,285	1	$p < 0,001$
a. day 7 points	B.L.P. day	L_{10} J $L_{10} - L_{90}$ J	398	10,175	1	$p < 0,01$
a. day 7 points	B.L.P. day	L_{10} J $L_{10} - L_{90}$ J	418	12,937	1	$p < 0,001$
a. night	B.L.P. night	L_{10} N $L_{10} - L_{90}$ N	424	17,551	1	$p < 0,001$
a. sleep combined	B.L.P. night	L_{10} N $L_{10} - L_{90}$ N	206	20,543	1	$p < 0,001$
a. guests, meals combined	B.L.P. day	L_{10} C $L_{10} - L_{90}$ C	414	4,347	1	$0,02 < p <$ 0,05

*a = annoyance

In the second column (parameter) there is the variable whose effect on the score was studied. /44

The third column contains the list of of matching variables*. These are the variables which may interfere with the parameter by changing the value of the score, and which must be controlled in order to obtain an unbiased result.

The fourth column contains the number of subjects undergoing the analysis.

The fifth column (N.F.) contains the Friedman number; the distribution of this number is approximately that of a χ^2.

The sixth column contains the number of degrees of freedom of χ^2.

Finally, in the seventh column there is the probability of error for the rejection of the zero hypothesis.

We note first of all that for reading, annoyance differs according to sex. Men are more annoyed than women. On the other hand, the annoyance varies according to the time spent in the home. The ones who are most annoyed are those who are not there (or are there very little) during the day. The graph of FIG. 11 shows that women are there longest, during the day. The second result therefore confirms the first.

A final calculation shows the preponderance of the time of presence. If in fact we study the effect of the time of presence during the day for reading, eliminating the male population, we ascertain that it is the women who spend the least time in the house who are most annoyed, and this is shown very clearly ($0.01 < p < 0.02$).

It can also be seen that annoyance in regard to sleeping is different depending on whether or not medicines are taken. The effect

* See Annex 5.4.

of other calculations whose results we will study later, besides the fact of taking medicines, does not diminish the annoyance, but indicates that the medicines are taken because of annoyance. That is why /45
the analysis of variance as well as the correlation coefficient reveal that those who are most annoyed take the most sleeping medicines (r_s = 0.3544, which is higly significant since p 0.0005). Note that annoyance in regard to sleeping used in this calculation was not caused solely by traffic noise. It can also be due to personal cares or poor health.

If we now consider satisfaction with the section of town, we ascertain that when satisfaction increases, annoyance decreases. In the first variance analyses, satisfaction with the section of town, evaluated by means of question 5 in the questionnaire, included an item bearing on satisfaction in regard to noise. It later seemed to us that inclusion of this item could introduce a bias and did not allow using this variable for correcting the effect of noise since it was included in the result. It seemed more normal to evaluate the influence of satisfaction with the section of town on the annoyance due to noise by excluding the noise from the question. As it was not possible to do the questionnaires themselves again, we proceeded to use perforated cards. We considered question 5 and question 6 at the same time. If the rank of noise for question 6 was less than or equal to the total of the satisfying elements of question 5, we woudl consider that the noise was part of the satisfying elements and take away one point from the total of question 5.

For example, if someone said he was satisfied with 7 items out of 10 in question 5, and he he put street noise in the 5th position in question 6, we would consider the noise as part of the 7 satisfying items and take away one point from the total of question 5 (7 - 1 = 6).

If a subject was satisfied with everything (10 in question 5), we counted 9 since the noise was necessarily included in the result.

In the other cases, if the rank of the noise for question 6 was greater than the total for question 5, we took the total for the question as it was.

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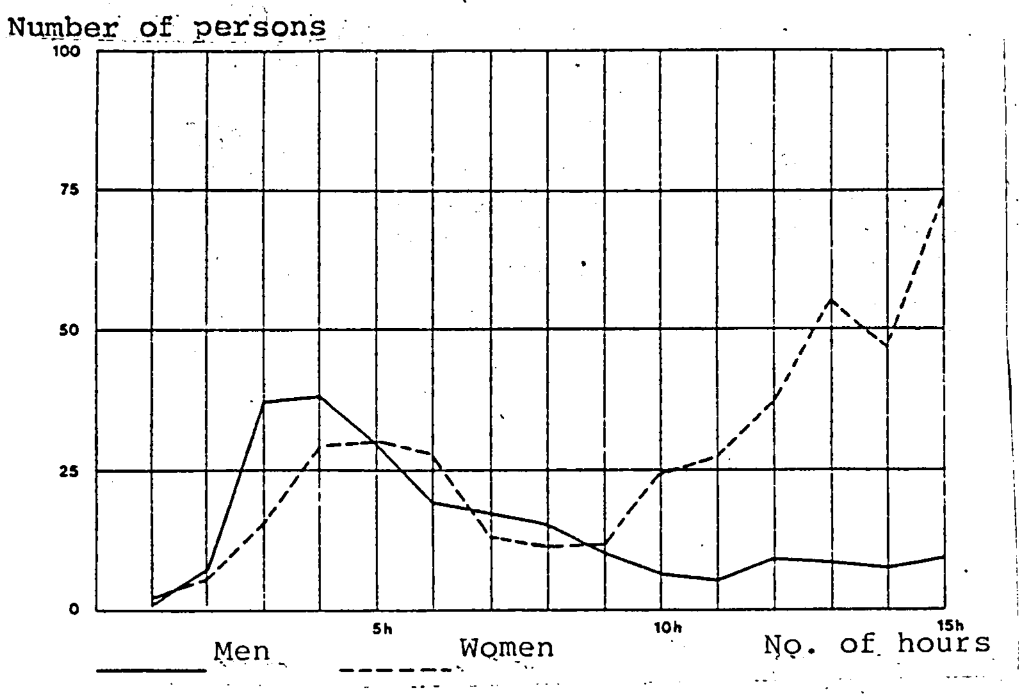

Fig. 11 - Histogram of number of hours present daytime

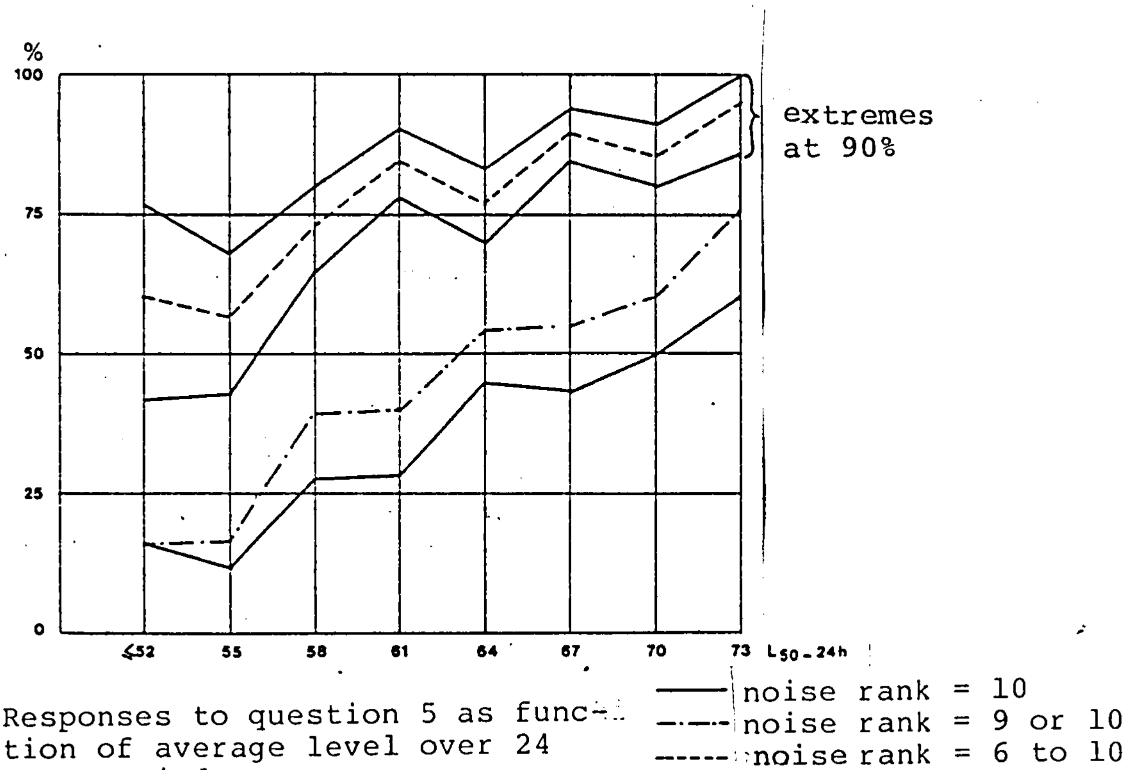

Fig. 12 - Responses to question 5 as function of average level over 24 hour period

This "rectification" of the satisfaction in regard to the section of town shows that there are in Table I the results of two calculations concerning the S.Q. The second concerns the rectified S.Q. and is also improved in relation to the first. /47

Another result, while significant, does not appear in Table I. It is the analysis of variance between satisfaction with the section of town and annoyance at night evaluated on a 7-point scale. In fact, order obtained is aberrant or, to be more precise, there is no order.

On the other hand the correlation coefficients calculated on the same variables, satisfaction with the section of town on the one hand and daytime and night time annoyance in 7 points on the other, are both highly significant.

- day $r_s = -0.1305$ $p < 0.0005$
- night $r_s = -0.0915$ $0.005 < p < 0.01$

An indication of the annoyance caused by noise can also be provided by the rank accorded noise in question 6, in relation to different noise levels. We reporduce here the results obtained with the average level measured over 24 hours (FIG. 12).

If we consider the noise to be disagreeable only when it is in the last position (rank 10), it has to reach a level of 70 dB for 50% of the population to declare that they are annoyed, but only 57 dB for 25%.

If we consider the noise disagreeable when it is given rank 10 or rank 9, 50% of the population is annoyed at 63 dB (A).

Finally, if we consider not only big annoyances but average ones as well (ranks 6 to 10), 60% of the population classifies the noise in these ranks from level L_{50}, the lowest recorded being 52 dB (A). We must say, however, that although we see a regular increase from weak levels (52 dB (A)) to strong levels (73 dB (A)), that the ranking here only indicates relative annoyance since the noise is classified in /48 comparaison with other elements of the question. It is therefore in fact possible to be very annoyed with the noise but classify it in the first ranks if the section of town is very run down or spoiled. It is also possible not to be annoyed at all but still classify the noise last simply because the section of town is one lacking nothing and in spite of that there is always a little noise.

The same classification according to types of streets yielded no further information.

Let us now consider the evaluation of the noise in the previous dwelling compared with the noise in the present dwelling (BLP). At the beginning of the study the two evaluations of day and night were dissociated.

A calculation of correlation convinced us that this distinction was a useless refinement. In fact, the correlation coefficient of Spearman between day BLP and night BLP is: $r_s = 0.87$. The probability of this correlation being due to chance is much less than 5 per 10,000 ($t = 44.504$ or $p \ll 0.0005$).

The influence of this correction variable is felt not only in the evaluation of a general annoyance, but also for specific annoyances such as in regard to sleep or family mealtime or guests. This means that if one thinks he had more noise in his previous dwelling, he considers himself less annoyed overall, but also for conversations at table, and finally he considers himself woken up less at night by traffic noise.

This last correction variable is in fact rather ambiguous. If the Friedman variance analysis indicates that there is a relationship between two variables - BLP and daytime annoyance in 7 points for example - it does not give the meaning of the relationship, that is, if it is because there was less noise before and one is therefore more annoyed, or because one is very annoyed now and therefore thinks there was less noise before.

At this stage of the study we considered that the noise in the previous dwelling was in fact a correction variable, intending to make the required verifications that we did not yet have the means to accomplish. /49

The combined indirect annoyance is calculated by means of two questions by which we try to determine if the street nose is perceived by opening a window that is not directly exposed. We ascertain that there is a relationship between the total noise and the combined indirect noise. The most annoyed overall are those who are most annoyed indirectly. This is of course entirely to be expected since if there is much noise on the street side, it can also be heard in the back of the building and the people are annoyed or very annoyed.

This first series of variance analyses permitted us to isolate the correction variables having an effect on annoyance. Their limited number allows them to be introduced in the following analyses as matching variables and in this way to neutralize their effects and to obtain the effect of the noise alone on annoyance. Table II, constructed on the same model as Table I, lists the significant influences. We see immediately that of all the possible independent acoustic variables (L_{10} and $L_{10} - L_{90}$), L_{10} almost the only one to have an influence.

We ascertain, in fact, that when daytime L_{10} increases, daytime annoyance being evaluated on a 7-point scale, the combined radio-television annoyance and the combined mealtime annoyance increase significantly.

We also see that when L_{10} for bedtime increases, the combined mealtime annoyance and the radio-television annoyance also increase. It is necessary to remember here that the bedtime period is from 2130 to 0030 hours and that it thus covers the entire evening when people may occupy themselves with watching television, listenting to the radio, or having dinner.

Table II - Friedman Variance Analysis /50

S = number of subjects
NF = Friedman number
dl = degree of freedom

Score	Parameter	Controlled variables	S	N.F.	dl	Probability
a.* day	L_{10} J	sex S.Q.	120	13,435	5	p 0,02
a. combined radio, TV	L_{10} J	sex S.Q. B.L.A. J L_{10} - L_{90} J	108	8,847	2	0,001 $<$ p $<$ 0,01
a. combined guests, meals	L_{10} J	sex S.Q. B.L.A. J L_{10} - L_{90} J	318	37,674	2	p $<$ 0,001
a. combined guests, meals	L_{10} C	sex S.Q. L_{10} - L_{90} C	55	10,018	4	0,02 $<$ p $<$ 0,05
a. combined guests, etc.	L_{10} C	S.Q. (no noise) L_{10} - L_{90} C	55	9,636	4	0,02 $<$ p $<$ 0,05
a. combined radio, TV	L_{10} C	S.Q. (no noise) L_{10} - L_{90} C	240	4,408	1	0,02 $<$ p $<$ 0,05
a. combined reading	L_{50} J	sex S.Q. B.L.A. J L_{10} - L_{90} J	140	12,634	3	0,001 $<$ p $<$ 0,01
a. combined reading	L_{10}-L_{90} J	sex S.Q. B.L.A. J L_{10} J	264	10,744	2	0,001 $<$ p $<$ 0,01
a. combined guests, etc.	L_{10}-L_{90} J	sex S.Q. B.L.A. J L_{10} J	315	6,019	2	0,02 $<$ p $<$ 0,05
a. combined indirect	L_{10} 24 h	sex S.Q. L_{10} - L_{90} 24h	327	14,729	2	p $<$ 0,001

* a = annoyance

The annoyance in regard to reading increases with the daytime L_{50} as well as with the daytime (L_{10} - L_{90}), which also seems to influence annoyance in regard to meals and guests. /51

The table does not show the results of the analysis of variance for night time annoyance in 7 points in relation to night time L_{10}. In fact, while it is significant ($0.01 < p < 0.02$), the result is not ordered. Those that are subjected to the most noise are not the most annoyed. The correction variables being neutralized, it is difficult to explain this result.

Certain effects that did not appear in the Friedman variance analysis were revealed by a Spearman non-parametric correlation test (r_s). Thus we note a weak but nevertheless significatn correlation between the bedtime L_{10} and annoyance in regard to going to sleep. The coefficient $r_s = 0.126$ is not in fact very high but corresponds to a probability of $0.005 < p < 0.01$.

In regard to the evaluation of noise in the previous dwelling compared with present noise, we must not a significant difference ($X^2 = 6.69$ ddl = 1), or: 0.001 p 0.01) depending on whether one has lived in the present dwelling for a short time ($\leq$ 2 years) or a long time (> 2 years). Those there for more than 2 years think, most oftent, that there was less noise in the previous dwelling.

It is necessary to state here that there is a relationship (of which we do not know the meaning) between the noise in the previous dwelling and the annoyance expressed, but the length of time in the dwelling has no influence on the annoyance. The relationships between these various factors are not easy to explain. In fact, the difference in evaluation according to whether one has lived in his dwelling for a long or short time may also be due to actual increase of noise over the years, or to forgetting of the noise experienced in the previous dwelling.

If we now consider the results of two correlations, we can try

to envisage the problem from another angle. In fact, in correlation with the rate of exposure of the place or the 24-hour L_{50}, the evaluation of the noise in the previous dwelling correlates negatively in both cases: $r_s = -0.23$, or $p < 0.0005$ and $r_s = -0.13$, or $p < 0.0005$. /52
We may therefore wonder if the evaluation of the noise in the previous dwelling is not more of an indicator of annoyance - if I am presently very annoyed, looking back I evaluate the past noise as weaker than the present. We must nevertheless mistrust such reasoning since we must not forget that the stronger and closer to maximum the present noise, the less probable is that the previous noise was moreso.

We also tried to see what relationship existed between satisfac- with the section of town and noise. We give here the results obtained with L_{10} and L_{50} for 24 hours. The result for L_{10} is highly significant, $X^2 = 28.43$, or a probability of $p \ll 0.001$, and with L_{50}, $X^2 = 17.98$, or $0.001 < p < 0.01$. The two calculations are therefore very significant. It is interesting to note that when the noise increases, the satisfaction in regard to the section of town also increases.

These results are confirmed by a Spearman correlation calculation. The coefficient is such that $r_s = 0.20$, or a probability of $p < 0.0005$. People are therefore more satisfied with their section of town when there is more noise.

If we consider the categories of streets rather than the noise, we get the following results: by grouping on the one hand the main arteries of Paris and the suburbs, and on the other hand the service routes of Paris and the suburbs, and making two degrees of satisfaction (not so satisfied $\leqslant 6$, and very satisfied > 6), we obtain if we put the delivery routes (suburbs only) with the service routes, a $X^2 = 8.29$, which with a degree of freedom gives a probability of p 0.01, and with the main arteries a $X^2 = 8.31$, or a probability of $p < 0.01$, or a very significant difference.

The conclusion to be drawn from such a test is the following:

The most satisfied live on the main arteries. This is in accord with the preceding results. In fact we have seen that the noisiest streets were the main arteries. But if we consider the components /53 of the satisfaction (public transport, schools, doctors, etc.) we see that the results mentioned above are not so paradoxical, since the main arteries are also those that have most of the conveniences that are the components of satisfaction with the section of town.

We shall also mention a statistical study bearing on the 7-point scales alone. At the beginning and end of the questionnaire (question 2 and 48, 3 and 49) we presented the subjects, in similar terms, with a 7-point scale for day and night annoyance evaluation. The sign test showed that the results obtained on the scale at the end of the questionnaire were different from those from the scale at the beginning. We obtained:

$z = -8.82$, or a probability of $p \ll 0.00003$ for the day, and
$z = -2.72$, or $p = 0.0033$ for the night

These two results are therefore highly significant and we may say that people consider themselves more satisfied at the end of the questionnaire than at the beginning.

Here again we must exercise great prudence in tyring to explain the result. We may in fact think that the questionnaire made the subjects more conscious of the annoyance they felt and after the impulsive response given at the beginning of the questionnaire, they gave a more "objective" response at the end. There is, however, another possible explanation, which we prefer in spite of the absence of formal proofs.

AT the beginning we ask the subjects to situate themselves on a 7-point scale of which only the ends are labeled: very satisfied - very unhappy. At the end, the scale is the same but the labels are: very tolerable - completely intolerable, and we may think that, for these subjects, there is a semantic difference between very unhappy and completely intolerable, the latter expressing extreme unhappiness.

Table III - Spearman Correlation Coefficient Among Annoyances /54

number of subjects = number of degree of freedom + 2

Correlation		r	τ	Probability	dl
a*. day 7 points (1)	a. overall total 7 points	0,688	20,911	$p \ll 0,0005$	486
a. overall total 7 points	a. night 7 points (1)	0,634	18,193	$p \ll 0,0005$	493
a. day 7 points (1)	a. night 7 points (1)	0,638	21,706	$p \ll 0,0005$	688
a. day 7 points (2)	a. day 7 points (2)	0,605	19,932	$p \ll 0,0005$	689
a. night 7 points (1)	a. sleep corrected	0,199	5,330	$p < 0,0005$	690
a. night 7 points (1)	a. retiring corrected	0,285	7,823	$p < 0,0005$	691
a. night 7 points (1)	a. rising corrected	0,176	4,689	$p < 0,0005$	689
a. retiring corrected	a. rising corrected	0,263	7,143	$p < 0,0005$	686
a. retiring corrected	a. sleep corrected	0,453	13,342	$p \ll 0,0005$	690
a. sleep corrected	a. rising corrected	0,363	10.208	$p \ll 0,0005$	685
a. day 7 points (1)	a. day 7 points (2)	0,721	27,226	$p \ll 0,0005$	683
a. night 7 points (1)	a. night 7 points (2)	0,715	26,839	$p \ll 0,0005$	690
a. radio, TV combined	a. guests, meals combined	0,532	11,120	$p \ll 0,0005$	313
a. reading combined	a. guests, meals combined	0,238	5,641	$p < 0,0005$	526
a. reading combined	a. radio, TV combined	0,342	6,059	$p < 0,0005$	277

* a = annoyance

In Table III we give as an illustration the value of the correla- calculated on the ranks among the different annoyances. We ascertain that they are all highly significant. /55

We have seen in this chapter that the annoyance expressed by the subjects depended at the same time on the noise, L_{10} and L_{50} essentially, and certain variables able to modify the effect of the noise, satis faction with the section of town and rate of exposure; while these results are very interesting they have a limited bearing since they permit of no prediction. This is why, after formulating a certain number of hypotheses, we did another analysis of the survey data, using this time parametrical statistics, which is the subject of the following section.

3.2.2 Parametric Analysis

3.2.2.1. Standardization of the Annoyance Statements

Like most variables in pyschology, the annoyance statements, whether resulting directly from the questionnaire or indirectly by construction of ordered scales from hierarchized questions, are variables with simply ordered values. Each of the states taken by a given variable is generally marked by its rank in the ordered totality of the possible states. But we know that any other system of marking that respects this order can be used, for example any increasing sequence of whole numbers.

Thus, the four possible responses to a question (for example: very often, often, rarely, never) can be marked by the sequence of whole numbers 1, 2, 3, 4 which define the rank of each response according to a decreasing order of "frequency", or even by the sequence 3, 7, 12, 25, which respects this order.

Under these conditions, it is not possible to apply current statistical methods to these variables. The notion of average, for example has no meaning: the calculation of an average would lead to as many values as methods of marking the variable.

If the methods of non-parametric statistics (for example, the Friedman variance analysis, the Spearman correlation coefficient, etc.) are usable, they do not generally have the "power" and the "finesse" of the methods of "standard" statistics. /56

On the other hand, if they can show the existence of relationships among several variables, they do not permit quantitative description of these relationships, that is, prediction.

For example, non-parametric statistics permits conclusions on the influence of exposure of the dwelling on the annoyance felt by the occupants, but it does not permit an estimation of the size of this influence.

Under these conditions, we are lead to make a further hypothesis which gives, on a simply ordered scale, an "interval scale" structure.

Standardization Hypotheses

The interval scale has the following supplementary property, in relation to the simply ordered scale: it permits expression of the notion of "distance" between two categories of the scale and consequently comparison of the distances with each other. It is defined only as a near linear transformation; that is, the origin of the scale and the unit of distance are arbitrarily chosen.

Has this notion of distance a meaning in the present case of annoyance statements?

It is not possible to demonstrate it. It is a first hypothesis that is not unreasonable. It is also accepted, implicitly or explicitly by all of the writers who construct an "annoyance index" and study its variation with a physical parameter such as noise.

The notion of distance being accepted, it remains to estimate the distance separating neighboring categories of the ordered scale. /57

There are several procedures for this; we have used the "method of successive intervals", (44), the principle of which is briefly described here.

The response that a person gives to a question posed to him depends on many parameters, only certain of which are controlled (noise, for example); on the other hand, each of the possible responses corresponds to an interval of an underlying scale of psychological measurement (in the present case, the scale of annoyance provided with a metric, of which the existence is accepted.)

We also allow that the responses of a group of persons under the same conditions (here, living in identical places from the point of view of noise levels), have a Gaussian distribution of the scale of psychological measurement (the annoyance scale).

Based on these hypotheses, the method of successive intervals then consists of establishing the experiential curve of distribution of the responses of a group of persons placed under the same noise conditions; then deducing from this this the value of the reduced Gauss variable corresponding to each of the responses. The operation can be carried out on many groups of persons (in the present case a total of about 200 persons divided into 4 groups). Based on the scales thus obtained, we can calculate an average annoyance scale.

Remeber that the unit and orgine of this scale are arbitrary. We have chosen to make the origine of each scale coincide with the response corresponding to the absence of annoyance. For example, the value 0 was attributed to the response "never" of the question "Do you have difficulty falling asleep?"

We find: /58

	Number of the question	Standardized value of the points of the scale							
7-Point scale	2	0	0,7	1,3	1,8	2,3	2,7	3,8	
	3	0	0,7	1,2	1,5	1,9	2,3	2,8	
	48	0	0,8	1,4	2,0	2,5	3,0	3,7	
	49	0	0,8	1,3	1,7	2,0	2,4	3,1	
	50	0	0,8	1,5	2,1	2,6	3,2	3,9	
Daytime activities	8 - 9	0	0,8	1,5	2,2	3,0			
	12-13-16	0	0,6	1,6	2,6	3,3			
	17								
	18 et 19	0	0,9	1,5					
Indirect annoyance	22 - 23	0	1,0	1,6	2,6				
Night time activities	29	0	0,9	1,5	2,3				
	31	0	1,0	1,7	2,7				
	39	0	0,9	1,5	2,2				
Opinions	45	0	0,8	1,3	1,8	2,3	2,8	3,3	4,1
	47	0	0,0	0,5	0,8	1,2	1,6	2,1	2,9

For daytime activities the rules of composition of the questions for evaluating annoyance are described in Annex 5.1.

It is possible to verify that the annoyance scale determined in this way accounts well for the distribution of the observed responses (44). We have not found any significant differences between the observed frequencies and the frequencies predicted by means of the annoyance scale. But of course, like all statistical tests, this test does not prove that the accepted hypotheses (existence of an interval scale, existence of the Gaussian model used in the method of successive intervals) are effectively verifed.

It shows only that the experimental data do not disagree with /59
the proposed theory; in other words, it permits temporary acceptance

of this theory; that is, until observation demonstrates that it is not acceptable.

3.2.2.2. Construction of a Single Annoyance Index

a) Factorial Analysis of the Standardized Annoyance Statements

The methods of analysis and of graphic representation are the same as those used for noise, which are described in Annex 5.2.

The two axes represent two independent factors. The position of the annoyances in relation to these factors tells something about the meaning to be given to the factors.

In a first factorial analysis, we introduced the annoyances evaluated on the 7-point scales and the annoyances for the day and night activities. In FIG. 13 we directly ascertain that the different annoyances are distributed in two groups one of which coincides with the factor I and the other, clearly separate, is much closer to factor II. The first group contains all of the 7-point scales and the annoyances for the daytime activities. The second group contains the annoyances for the night time activities; its position on the graph indicates that it is not entirely independent of factor I. However, factor II represents it best. This first analysis provides us with two factors, therefore, a "night annoyance" factor and a "general annoyance" factor, the daytime activities being included in the latter.

FIG. 14 and FIG. 15 reproduce the results of another factorial analysis where, besides the already mentioned annoyances, there are the results from questions intended more for studying the attitudes of the subjects towards noise rather than the annoyance itself. We thought that these attitudes might be influenced by the sound level to which the people were subjected and could consequently be used for evaluating annoaynce. FIG. 14 gives the same representation as FIG. 13, for overall and behavioral annoyances. The attitudes seem to be rather independent of factors I and II (they are both rather close to the origin of the axes.

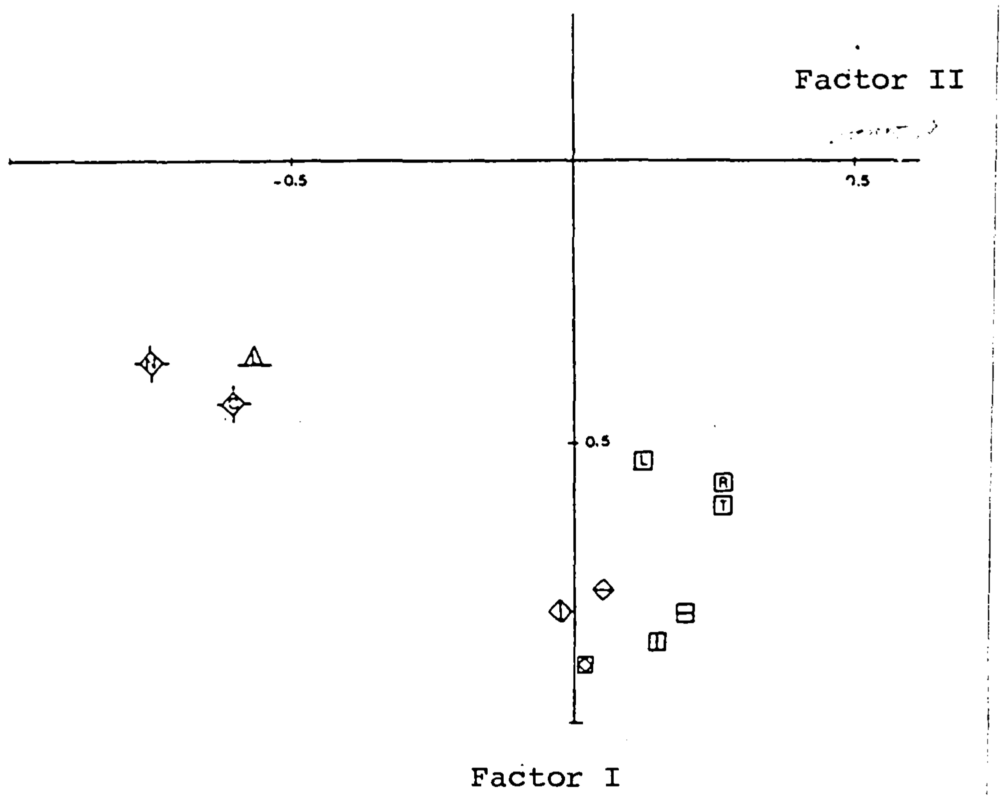

Fig.13 - Factorial analysis of annoyance

- Day annoyance 7 points (beginning of questionnaire)
- Night annoyance 7 points (" " ")
- Day annoyance 7 points (end of questionnaire)
- Night annoyance 7 points (" " ")

Overall annoyance total 7 points
Reading annoyance combined
Radio-TV annoyance combined
Guests-mealtime annoyance combined
Indirect annoyance combined

Retiring annoyance corrected
Sleep annoyance corrected
Rising annoyance corrected
Annoyance, opinion = action on noise
Annoyance, opinion = effect on health

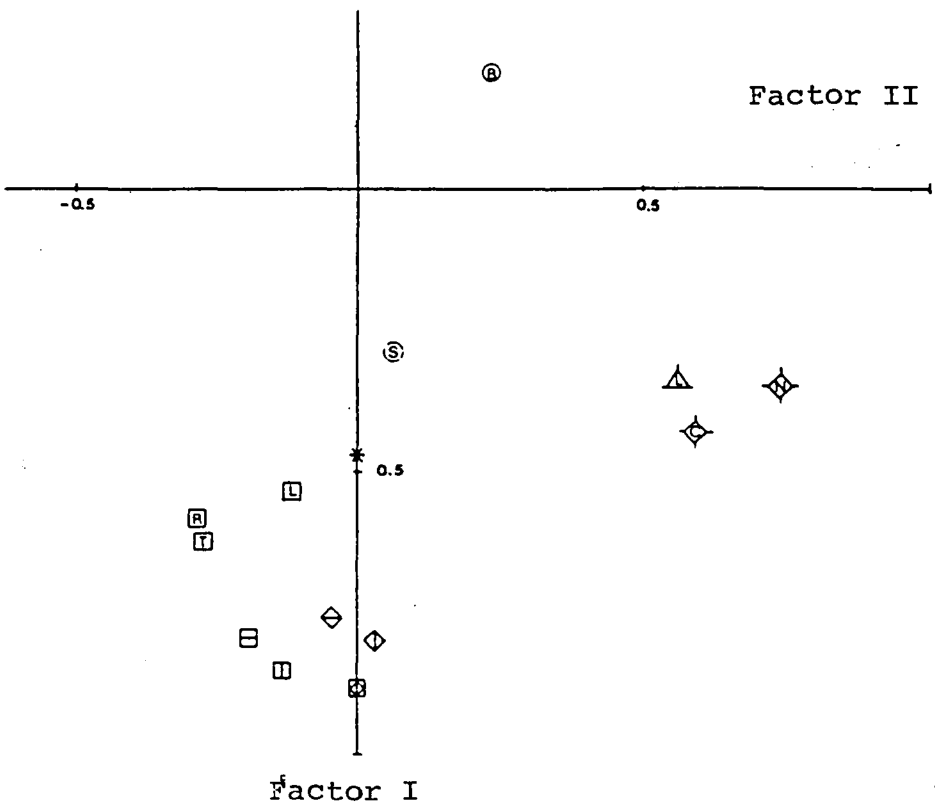

Fig. 14 - Factorial analysis of annoyance

Day annoyance 7 points (beginning of questionnaire)

Night annoyance 7 points (" " ")

Day annoyance 7 points (end of questionnaire)

Night annoyance 7 points (" " ")

Overall annoyance total 7 points

Reading annoyance combined

Radio-TV annoyance combined

Guests-mealtime annoyance combined

Indirect annoyance combined

Retiring annoyance corrected

Sleep annoyance corrected

Rising annoyance corrected

Annoyance, opinion = action on noise

Annoyance, opinion = effect on health

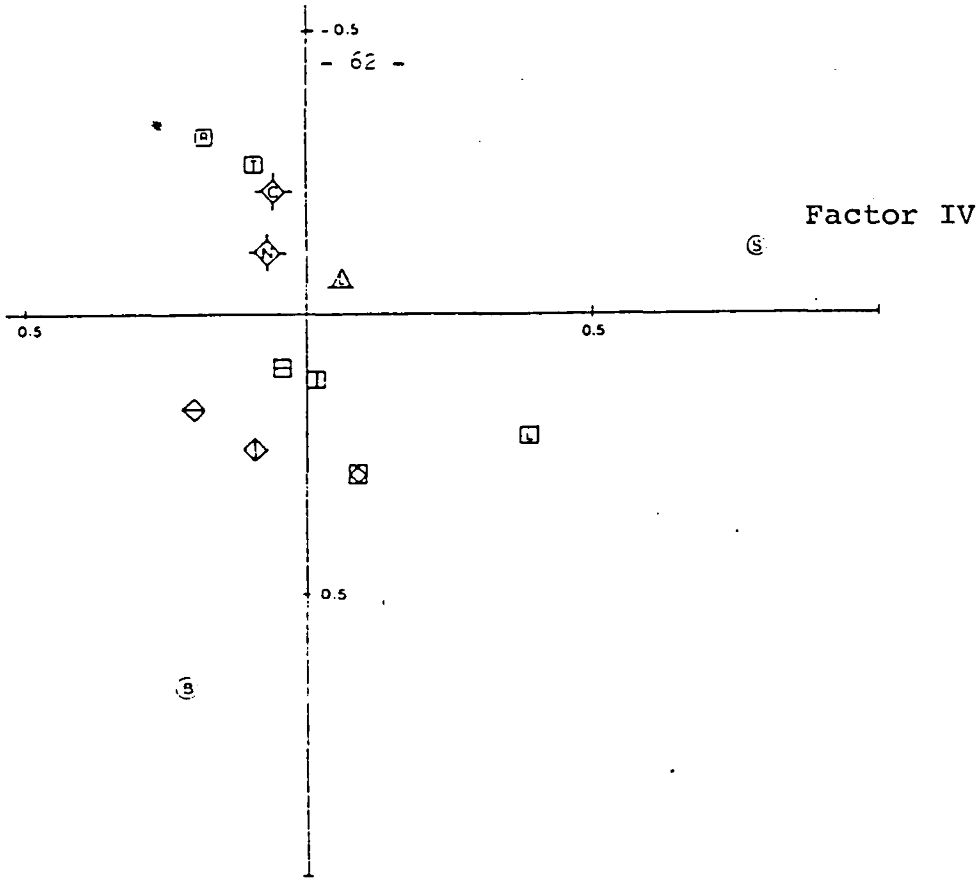

Fig. 15- Factorial analysis of annoyance

Day annoyance 7 points (beginning of questionnaire)
Night annoyance 7 points (" " ")
Day annoyance 7 points (end of questionnaire)
Night annoyance 7 points (" " ")

Overall annoyance total 7 points
Reading annoyance combined
Radio-TV annoyance combined
Guests-mealtime annoyance combined
Indirect annoyance combined

Retiring annoyance corrected
Sleep annoyance corrected
Rising annoyance corrected
Annoyance, opinion = action on noise
Annoyance, opinion = effect on health

This is confirmed by FIG. 15, in which the two evaluations of the attitudes are rather close to factors III and IV, independent of each other and independent of factors I and II. Consequently, the attitudes evaluated by the bias of the questions bearing of the supposed effects of noise on helath, or on the means of protecting oneself from noise, cannot be included in a scale for evaluating annoyance as defined at the beginning of this study (also see Annex 5). The attitudes toward noise are in fact independent of the annoyance felt. /63

With two "factors", one for night time annoyance and the other for general annoyance, we introduced into two factorial analyses the components of each of them (annoyances for activities at night, on the one hand; and for general annoyances and daytime annoyances, on the other hand).

The factorial analyses provide the coefficients of correlation of the different annoyances that compose the factor, with the factor itself, and thus allow us to characterize it.

For example, we find for general annoyances and for daytime activities the following correlation coefficients:

7-point scale	- daytime annoyance,	beginning of questionnaire	0.82
	night		0.77
	daytime	end of questionnaire	0.87
	night		0.80
	overall		0.89
Daytime activities	- reading		0.56
	radio-TV		0.64
	meals-guests		0.60

In a last analysis we also introduced independent acoustic variables representing all of the others (L_{10} and $(L_{10} - L_{90})$ for 24 hours).

The principal result of this analysis is the ascertaining of total independence between annoyance for night time activities and noise, the highest correlation coefficient being on the order of 0.05. /64

We may be all the more astonished with this result since in the survey interviews the people questioned frequently mentioned that noise at night was the most annoying.

In fact it was found that, when they respond to exact questions about their sleep, the subjects give reasons other than noise for their disturbed sleep. It may be that once the subject is awakened he decides that the noise he perceives is very annoying, whereas it is not the noise that he considers responsible for waking him.

On the other hand, we see a rather strong correlation between L_{10} and the 7-point scales, and likewise with the daytime activities.

		L_{10} 24 hours
7-point Scales	- Beginning of questionnaire	
	day	0.20
	night	0.21
	- End of questionnaire	
	day	0.20
	night	0.18
	overall	0.16
	- Daytime activities	
	reading	0.03
	radio-TV	0.20
	mealtime-guests	0.42

Solely the factor grouping the overall annoyance and the annoyance in regard to the daytime activities that constitutes our index of annoyance.

b) Analysis of the Regression : Composition of the Index /65

The annoyance index is a weighted linear combination of all of the overall and behavioral annoyances for the daytime composing the factor. This combination was obtained by a multiple linear regression (it could also have been obtained directly, from the results of the factorial analysis). By introducing into the analysis of the regression the common factor in the form of correlation coefficients of each of the annoyances with it, we obtain the coefficients of regression of these annoyances which, after standardization, give the relative weight of each of the partial annoyances in the factor. This annoyance index varies from 0 to 10.

The index is 0 when there is a total absence of annoyance for each of the scales of partial annoyances; it is 10 when the annoyance is the maximum for all of the partial scales simultaneously.

The coefficients whose standardized partial annoyances are suitable for constituting the annoyance index (I G) are the following:

7-point scales	Beginning of questionnaire	day	0.20
		night	0.20
	End " "	day	0.17
		night	0.21
		overall	0.17
	Daytime activities	reading	0.16
		radio-TV	0.15
		mealtime-guests	0.25

The annoyance index for each subject is then calculated for each subject by using the formula found in this way.

c) Analysis of the Regression : Seeking a Formula to Express Annoyance as a Function of Noise and the Correction Variables /66

First of all we studied the influence of the correction variables on the annoyance index calculated as above in order to verify that this influence is not felt only on the partial annoyances but also on the common factor. By studying the influence of satisfaction with section of town on the annoyance index, for 548 subjects, we obtained by Friedman variance analysis a Friedman number of NF = 5.55, which with a degree of freedom number equal to 1 gives a probability of occurrence of $0.01 < p < 0.02$. With the rate of exposure of the dwelling, we obtain for 462 subjects a Friedman number of NF = 4.16, or, with a degree of freedom number equal to 1, a probability of $0.02 < p < 0.05$. These two correction variables therefore influence expression of annoyance. The importance of this influence is given to us by an analysis of the regression. The best results, as expected from the non-parametric analysis of the data, were obtained with L_{10} and L_{50}. Finally, we propose to retain a formula expressing the annoyance as a function of daytime L_{50}, which is the parameter that the acousticians can most surely predict.

The correction variables are introduced into the analysis of the regression in dichotomic form. It has been verified that finer cutting is useless, since betterment of the resulting precision is illusory.

Satisfaction in regard to the section of town (SQ) can then take two values:

0 if the number of items with which the subject is satisfied is less than or equal to 6 out of a total of 9.

1 if this number is greater than 6.

The rate of exposure of the dwelling (EXPO) takes the following values:

0 if one room out of two at the most overlooks the street.

1 if more than one room out of two overlooks the street.

Finally, we obtain the following formula: /67
(1) annoyance index = $0.13\ L_{50} - 0.62\ SQ + 0.61\ EXPO - 3.74$, a formula which reduces, in the case where the subject is little exposed to the noise of the street (EXPO = 0) and is satisfied with his section of town (SQ = 1) to
(2) annoyance index = $0.13\ L_{50} - 4.36$.

But we can also establish an equivalency between the correction variables and the noise with a constant annoyance index. Formula (1) can in fact be stated as:
(3) annoyance index = $0.13\ (L_{50} - \frac{0.62}{0.13}\ SQ + \frac{0.61}{0.13}\ EXPO) - 3.74$

or even:

(3) annoyance index = $0.13\ (L_{50} - 4.77\ SQ + 4.69\ EXPO) - 3.74$

This writing shows that non-satisfaction with the section of town and a high degree of exposure of the dwelling are each equivalent to about 5 dB (A) of average level L_{50}.

That is why we propose to use formula (2)

(2) annoyance index = $0.13\ L_{50} - 4.36$

when the subject is little exposed to the noise of the street and is also satisfied with his section of town. The same formula applies to the other cases, on the condition of increasing the average level L_{50} by 5 dB (A) if there is a high degree of exposure of the dwelling or if satisfaction with the section is low (according to the conventions described above) and by 10 dB (A) if two conditions are fulfilled at the same time.

FIG. 16 and FIG. 17 are a representation of the preceding results, FIG. 16 showing the distribution of the annoaynce statements as a function of L_{50}, and FIG. 17 showing the results of applying the dB (A) correction described above. These figures show the line of regression, the upper and lower quartiles, and the median.

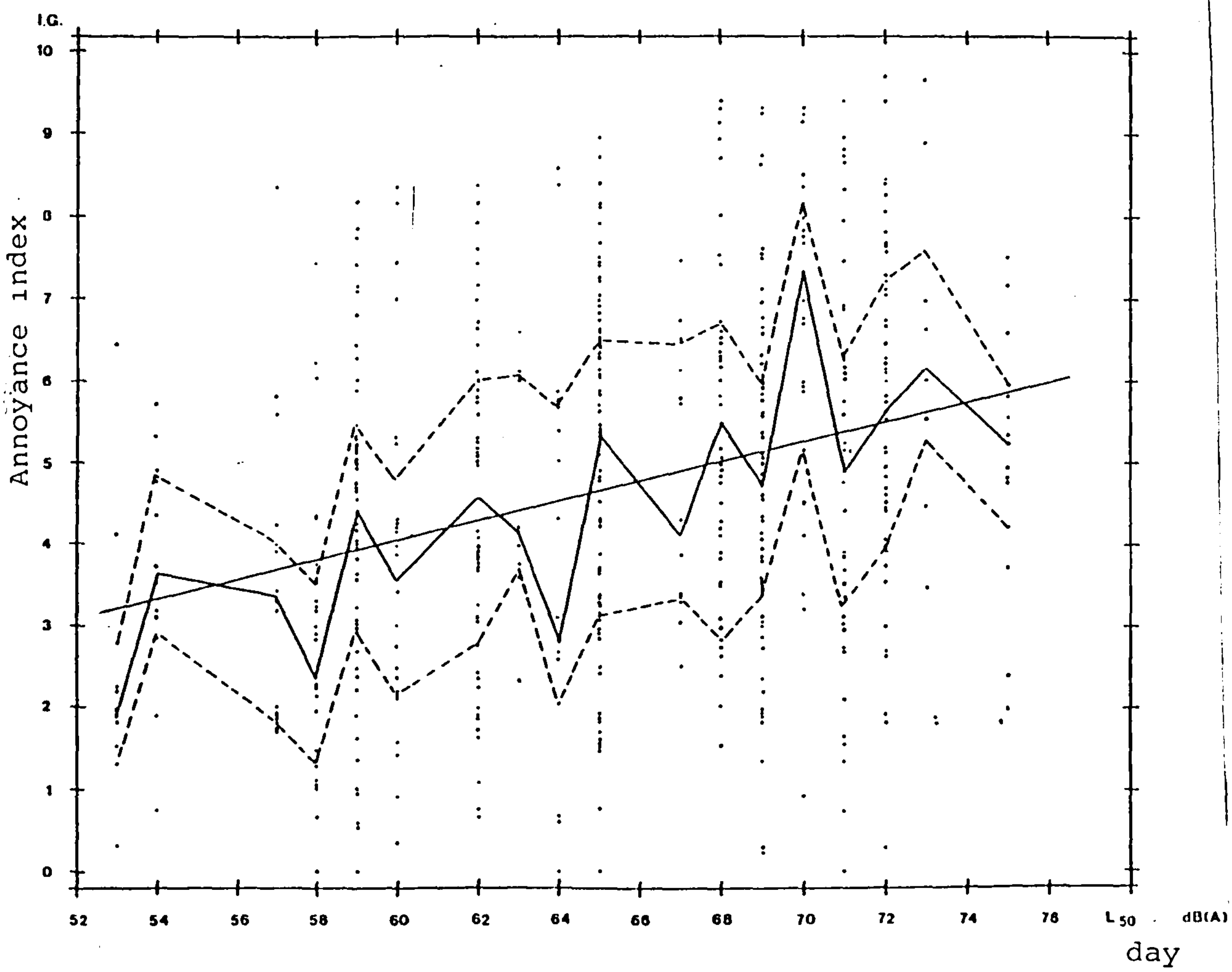

Fig. 16 - Distribution of annoyance statements as a function of L_{50}

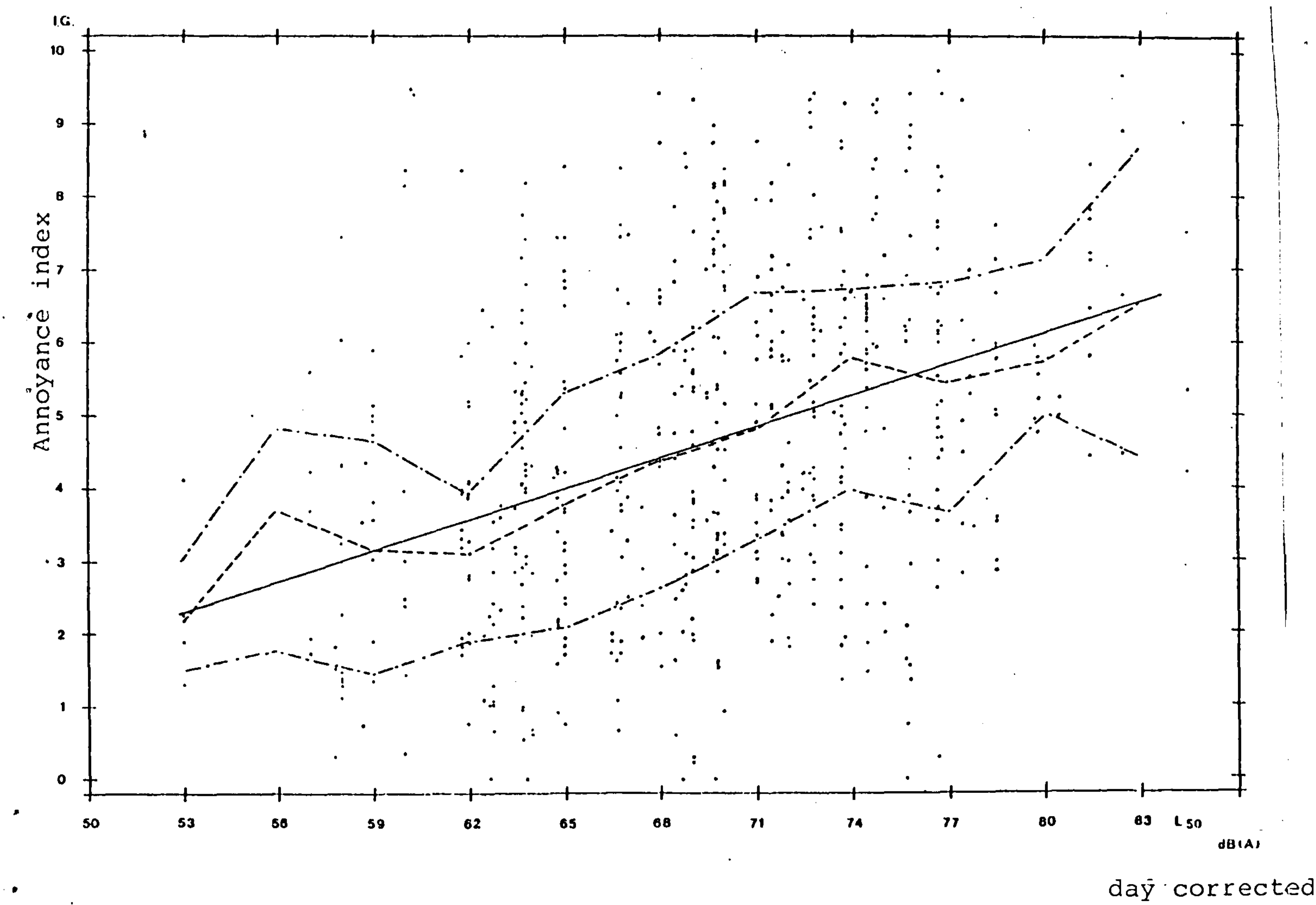

Fig. 17 - Distribution of annoyance statements as a function of L_{50} corrected

The correlation coefficient between the annoyance index and the corrected L_{50} is 0.37. This value, which may seem rather low, is in fact highly significant. It is also a completely satisfying coefficient if we think of the dispersion generally observed in the social sciences and of which FIG. 16 and FIG. 17 give an idea. /70

3.2.3. Comparison with Other Studies

We can try to compare the results obtained in our study with other similar studies done in England in in Sweden, as well as with the one done by the C.S.T.B. in 1967 (Ref. 9, 10, 11).

The table below gives the value of the correlation coefficients obtained in each of these studies between annoyance and noise level.

Great Britain	r_s	=	0.88	(a)
Sweden	r	=	0.91	(b)
C.S.T.B. 1967	r	=	0.61	(c)
C.S.T.B. 1970	r	=	0.37	(d)

At first glance the abovementioned results are clearly better than ours, but we must guard against a hastily comparing these results with each other. In fact, the first three were obtained by considering the average or the median of the annoyance statements by noise class while our coefficient (d) was calculated on the totality of the subjects; that is, contrary to what was done in the other studies, we did not artificially suppress the influence of the dispersion of the responses. It is necessary, however, to note that the Swedish researchers weighted the medians by taking into account the amount on which they were calculated. If that gives the medians a more exact value, it remains that at the time calculation of the correlation coeffecient all of the values of a particular noise class are found to be concentrated at one point and the variance is thus zero in that class. Such a procedure, not very defensible statistically, considerably improves the correlation coefficient. As a proof we will give the results obtained on our own data.

Correlation coefficient /71

On all subjects : $r = 0.37$

On the medians by noise class : $r = 0.97$

We see that in this way we obtain a higher coefficient than that of the Swedes, but in fact without value.

In England, I. D. Griffiths and F. J. Langdon of the B.R. mentioned in their study the coefficient obtained by using the individual results; it is equal to $r_s = 0.29$. With them, too, the difference is very important. It is possible that if their coefficient is lower than ours, it is due to the fact that in our study we controlled two variables having an influence on the expression of annoyance. By diminishing the variance, this control improved the correlation. We must also note that the acoustic variables used in these different studies were not the same.

The English study recommends the TNI (Ref. 9), the Swedish study the average energy level, and the C.S.T.B. in 1967, like this time, retained the L_{50} (level exceeded during 50% of the time). We recall here that this choice of the C.S.T.B. acousticians was motivated by the fact that it is L_{50} that they can most surely predict. The results obtained with L_{50} can easily be compared with those obtained with L_{10} or the average energy level; these last two parameters are nearly identical ($r = 0.97$) and both strongly correlate with L_{50}:

$r = 0.84$ for L_{10} and $r = 0.86$ for the average energy level.

If we finally seek the multiple correlation coefficient between the annoyance index and, on the one hand correction variables and on the other hand each of these parameters ($L_{10} - L_{50} - L_{eq}$), the result is still more convincing. In fact, we obtain the same coefficient with each of the abovementioned parameters: $r = 0.37$. We may therefore consider them to be measuring the same thing and having the same predictive value.

The results obtained with the TNI are, on the other hand, a bit /72 different. This parameter does not measure an average level or a peak but the difference between a slight noise and a loud one with a slight predominance of the level at 10% in the formula. If this parameter is used to characterize the noise measured in Paris and which is correlated with the annoyance index, we obtain, with a TNI calculated solely on the daytime hours, a coefficient of $r = 0.24$, which goes to $r = 0.27$ if calculated on 24 hours. In our study, the corresponding correlation coefficient, without introduction of the correction variables, that may be calculated with L_{10} or L_{50} for the daytime hours only or for all 24, is 0.32. There is therefore an improvement with relation to the TNI. Perhaps it is possible to find an explanation for this in the fact that the TNI was worked out to describe a noise which, after description of the sites studied by the English, is closer to highway traffic. L_{50} seems more representative of urban traffic noise, which we have studied. The improvement ascertained in relation to the TNI by using L_{50} may appear not sufficient to reject the index developed by the B.R.S. researchers, but it must be known that that is difficult to foresee when L_{50} can easily be it. These two arguments on the better correlation with the annoyance index and greater predictability therefore encourage us to prefer L_{50} which also has the advantage of being much more simple to calculate.

IV - CONCLUSION /73

The aims of this study were ambitious, since the subject is vast. We proposed to study, on the one hand, the physical laws of propagation of sound in a city, and on the other hand the reactions of annoyance of the individuals living in the rban sound environment. Never has a study been able to resolve entirely such problems, and we had to content ouselves with improving on previous studies.

The problem was approached on a macroscopic scale. Modern methods of statistical analysis permitted us to retain only parameters that are significant for characterizing the noise and the annoyance in town.

The originality of the acoustical measurements that we made resides in the size of the samples: 48 hours of continuous measurements permitted us to define a veritable "climate" of daily noise for each point. The description of the noise was limited to dB (A), because we showed that the traditional spectrum analysis of traffic noise in the streets did not bear on the description of parameters with significant variations. The study of the variation of levels in dB (A) can still be deepened. The statistical description used contented itself with making an evaluation of the noise levels existing at each moment. New methods of of analysis are required to described, for example, the instantaneous variations of the noise levels: the new parameters obtained could show great differences between two traffic noises whose statistical distributions are similar.

Thanks to this study we were able to determine the general laws of traffic noise in an ordinary street. Such laws cannot be extended to cover discontinuous urban areas, such as may be encountered in the suburbs and in recently urbanized areas. Here we are dealing with a great number of cases of kinds that must be the object of special /74 studies for which the measurements that we have made provide a catalog of standard solutions.

The results of the sociological survey show the complexity of the notion of annoyance. The slope of variation of the median of the annoyance indices with the level of acoustic pressure is weaker than what was ascertained at the time of the survey on highway levels. The annoyance due to traffic noise is expressed in a more ambiguous way. The dispersion of the responses of the individuals is great. Some individuals are annoyed when the noise level is low; other individuals can live in noisy areas without being annoyed.

We ascertain that it is preferable for dwellings to be only partially exposed to traffic noise, such as along an expressway: from this point of view a good solution is the building parallel to the street with the appartments doubly exposed.

The study shows that the annoyance due to traffic noise dissociates itself badly from a general state of annoyance due to many other factors. The influence, of the satisfaction of a person with his section of town, on the annoyance attributed to noise, is clearly evaluated here. It seems to be something new.

Despite the complexity of annoyance, it is possible for the legislator to take a position. It is evident that when the daytime L_{50} level is less than 60 dB (A), the number of persons who are annoyed is low. When it is greater than 70 dB (A), a large part of the population is annoyed.

Must legislation be the same for urban streets and highways? Here it is necessary to make reservations. The method used for analysing annoyance is different from the one used for the highway survey. In fact, urban traffic noise is more complex than highway noise. At present it does not seem possible to compare these two types of annoyance. A further study may perhaps solve this problem.

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