increase in both traffic volume and speed on one thoroughfare that was changed from two-way to one-way operation and an increase in volume, but not in speed on another street from which an elevated structure was meanwhile removed. When no changes had been made in physical conditions or in traffic regulations, volumes increased only slightly while traffic speeds were nearly the same in 1951 as in 1939.

(7) The runs studied with the statistical instruments for measuring speed, gasoline consumption, braking, engine torque, and throttle opening showed that on congested streets, the vehicle was either standing still or travelling at less than 5 mph. for 50 percent of the time, and that during this time 26 percent of the gasoline was consumed. On the other hand, little time was lost while driving on the expressway routes outside the downtown area. The instruments also showed that for city and expressway driving the higher ranges of available torque in the automobile are actually used for only a small percentage of the time that the vehicle is being operated.

(8) This paper has discussed only two direct benefits to city drivers, savings in time and in gasoline consumption. The construction of the central artery will accomplish much more than that. For the first time the heart of the city will be made accessible to large volumes of highway traffic. Changes in travel habits are certain to result which will have a marked effect on the economic life of the downtown area. Before-and-after studies of land use, property valuation, volume of business, and public transit riding are contemplated at some future date to appraise some of the other and broader influences of this new expressway.

ACKNOWLEDGEMENTS

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TRUCK-NOISE MEASUREMENT

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SYNOPSIS

The problem of evaluating truck noise has been studied by engineers of the University of California's Institute of Transportation and Traffic Engineering for the past two years. In recent years the highway has become a serious source of disturbing noise. In many instances the level of the noise has increased to a critical value and has provoked action by local groups and state legislatures. This discussion deals entirely with the problems of measurement, first with specific equipment and techniques for measuring and recording and secondly with equipment and techniques for evaluating the measurements.

Instrumentation is described in which noise measurements may be made either by integrating (total-noise) devices or by instruments which divide the noise into frequency bands and give a reading for each band.

Field and laboratory tests have been made on noises produced by large trucks equipped with different mufflers. Field tests were conducted on three occasions in 1950 in conjunction with the California Motor Transport Associations and the California Highway Patrol. Analyses have been made of the tests to determine the correlation between measurements on 16 different mufflers and jury evaluations of the noise. The results of the analyses indicate that the American Standards Association sound-level meter can be used as a satisfactory instrument to indicate the annoyance value of truck noise, if used on the proper scale and set up in the proper manner.

●THE PROBLEM of evaluating truck noises has been a subject of study by the Institute of Transportation and Traffic Engineering, University of California, for two years. The highway has become a serious source of disturbing noise. The size of truck, bus, and automobile engines has increased greatly so that, together with the large increase in total number of units, the over-all effect of their noise is often very annoying. In many instances the level of the noise has increased to a critical value and has provoked action by local groups and state legislatures

It is recognized that there are several phases to the over-all problem, including measuring techniques; establishment of limiting specifications; exhaust system, engine, vehicle, and tire design; driver education in vehicle operation; highway surfacing for lowest tire-noise levels; and roadside and building treatment for sound absorption.

This discussion will deal entirely with the problems of measurement, first with specific equipment and techniques for measuring and recording, and second with equipment and techniques for evaluating the measurements.

INSTRUMENTATION

The instruments used for measuring noise are of two types: (1) integrating, or total-noise, measurement, and (2) instruments which divide the noise into frequency bands and give a reading for each band.

An integrating instrument always has a particular characteristic, and its reading has no meaning unless this characteristic is known. An equal response for all frequencies from 5 cycles per second to 20,000 cps. would be extremely good for some purposes, but not for noise measurements, because frequencies near 5 cps. or near 20,000 cps. are not audible and yet would give as large readings as frequencies which are audible. Even a meter with a flat response restricted to the audible range of frequencies would have no practical value in noise work except for measuring very loud noises or for use as an amplifier for analysis. The readings of a meter with a flat response are called *intensity levels* if expressed in decibels above a reference sound pressure of 0.0002 dynes per sq. cm. The intensity level is not an indication of the loudness of ordinary sounds, because the human ear is selective and responds more to high frequencies than to low frequencies. This selectivity is only slight for very loud sounds but is very great for sounds of low intensity. The response characteristic of the ear is given quantitatively by the well-known Fletcher-Munson curves (*7*). The change of response with intensity means that an integrating meter must have several different response characteristics available for measuring sounds of various intensities. The usual type of meter (*5*) built to American Standards Association specifications provides these characteristics by means of three weighting networks which may be selected by a switch whose positions are marked *A*, *B*, and *C*, or *40 db* , *70 db.*, and *90 db.*, or *flat*. These networks are designed to give a response characteristic similar to that of the average human ear when listening to sounds of corresponding intensity. The readings of an integrating meter when using a weighting network appropriate to the sound being measured are called *sound levels* when they are expressed in decibels above a reference sound pressure of 0.0002 dynes per sq. cm. (*5*)

Other instruments give a more-detailed description of a sound than that of the sound-level meter This is done by dividing the sound into two or more frequency bands and giving a reading for each band. Such instruments are generally not frequency weighted, so in interpreting their readings an appropriate weighting factor must be applied to the reading in each band to determine the total-sound level. The amount of detail provided by a meter depends on the number of bands, *i.e.*, the band width. Two- and three-band meters have been used, but more common are the octave-band meters and the so-called continuous-band analyzers. An octave-band meter has a ratio of 2:1 for the high and low frequencies in each band and has about 8 bands to cover the audible range from 37.5 to 9600 cps. A typical continuous-spectrum meter has a band width of about 3 percent of the frequency The output of such a meter may be fed to a recorder to graph the intensity level as a function of frequency.

The sound of a passing truck cannot be measured directly with an octave-band or continuous-spectrum meter because the sound intensity is not constant enough to permit scanning of the whole range of frequencies during the time of passing. To analyze such a noise it is necessary to first record it and then reproduce repeatedly the part which is of most interest. In our work this was done with a magnetic-tape recorder (*10*). A loop of the tape was then prepared containing between one and two seconds of the noise. With an extra idling pulley attached to the recorder the sound on this loop was reproduced continuously as many times as needed for analysis.

In order to reproduce each noise at a level corresponding to its original intensity, a calibrating signal was recorded on the tape just ahead of each noise. This was a 60-cycle signal derived from a voltage-regulated power supply and introduced into the recorder circuit ahead of the gain control. By recording each noise with the gain adjusted to give the same reference reading on the recorder volume meter for the calibrating signal and by analyzing each with the reproducing amplifier and analyzer gains adjusted to give a predetermined chart reading for the recorded 60-cycle signal, the proper intensity relationship between the noises could be maintained.

Truck noises were also reproduced in the laboratory for jury judgement purposes. The tape recordings used for this purpose were all made on trucks running on a dynamometer. Since there was an ample length of magnetic tape for each noise the loop technique was not needed. To reproduce the truck noise the output of a 75-watt amplifier was fed to a high-fidelity dual-speaker system of 25 watts capacity. Since sound-level readings were made of the original noises it was possible to adjust the amplifier to give the original sound-level reading at a chosen listening position.

FIELD AND LABORATORY TESTS

Both integrating and continuous-spectrum measurements have been made on noises produced by a truck operated at three different speeds on a dynamometer. On three occasions in 1950 the California Motor Transport Associations made tests on mufflers to determine which types and models were most effective (*2*, *3*, *4*). This work was witnessed and recorded by engineers of the University of California in cooperation with the technical-research unit of the California Highway Patrol. In the latest tests (*4*) a 275-horsepower diesel truck tractor was operated on a dynamometer at three different speeds and loads. A group of impartial observers rated the noises on a subjective scale having 10 values. Sixteen different mufflers were tested in this way. The jury and the microphones for sound-level readings and tape recordings were placed 50 ft. from the truck. The instruments used were a General Radio Type 759-B sound-level meter and a Magnecord Type PT6-J tape recorder. The sound-levels ran from 88 to 98 db. for the slowest speed (1,500 rpm.) and from 91.5 to 101 for the highest speed (2,100 rpm.).

The tape recordings were later analyzed with a General Radio Type 760-A sound analyzer and a Model FR frequency-response recorder made by the Sound Apparatus Company of New York. An expander had to be used to change the linear output of the analyzer to a logarithmic input needed for the recorder (*10*). With this arrangement the band width of the recorder was 2 percent of the frequency of any component. The band width is defined as the frequency range included between the frequencies at which the response of the recorder drops to one-half the major component (minus 3 db.).

Examples of the analyses of truck noises are shown in Figure 1. All of those analyzed had certain features in common. With very few exceptions the strongest single component had a frequency equal to that of the cylinder explosions. A component at half this frequency was often present at the higher engine speeds but not at 1,500 rpm. When present, this subharmonic was generally at least 10 db. below the fundamental. The second harmonic was generally 3 to 10 db. below the fundamental. A frequency of 1.5 times the fundamental was almost always present and usually slightly weaker than the second harmonic. Practically all the sound at frequencies below 250 cps. was harmonically related to the explosion frequency. Above 250 cps. the sound was composed of many components either too numerous or too fluctuating to be separated by the analysis. The strongest of these components was generally at least 12 db. below the fundamental.

We may conclude that the noises had almost all of their energy in a few harmonically-related low-frequency components and that the higher frequencies were numerous and not harmonically related.

APPRAISAL OF NOISES

To take the next step and go from the various kinds of meter readings and analyses to a specification of our subjective experience of the noise is like getting from one canoe to another in midstream: there is no known method which always works.

The American Standards Association has defined a term *loudness level* (*5*). For pure tones this is the intensity level of a 1000-cycle tone which sounds as loud when compared by an average human ear. For complex tones the loudness level is equal to the sum of the intensity levels of the 1000-cycle equivalents of all the components.

If the sound-level meter adds the components of a noise with proper weighting for each frequency it will read the loudness level. In other words, for an *ideal* meter the sound level and the loudness level are theoretically the same. But the subjective loudness heard by a person is something else, because the human ear adds the components of a complex sound in a different way. This can be understood in terms of the construction of the ear.

The ear drum reacts to sound pressure in much the same way that a microphone diaphragm does. A linkage of small bones transmits the motion to an inner diaphragm to which is connected the basilar membrane. The auditory nerves are distributed along the basilar membrane which runs down the center of a tapered duct which is coiled like a snail. The nerves at any particular position are used to hear sounds of a particular frequency, but each nerve responds to a considerable band of frequencies. The ear acts somewhat as a continuous-spectrum analyzer with rather broad band-pass characteristics. The electrical potentials produced by the nerves when sound is heard are proportional to the sound pressure

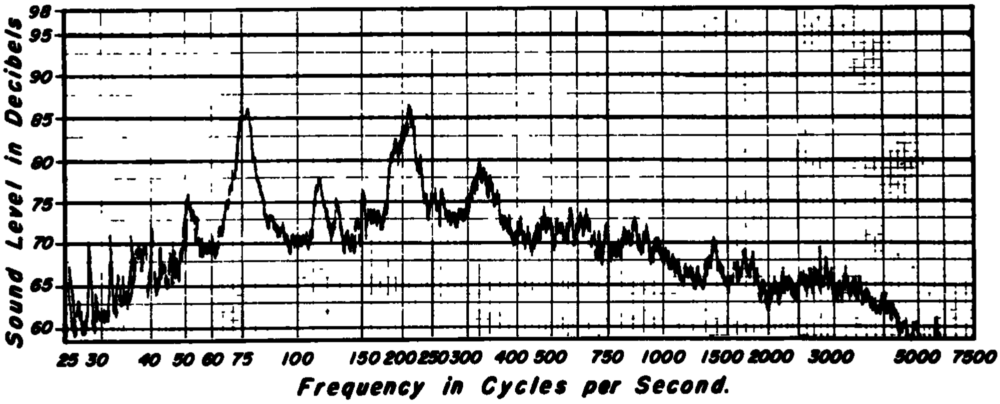

Figure 1(a). The noise of a truck with a straight exhaust pipe.

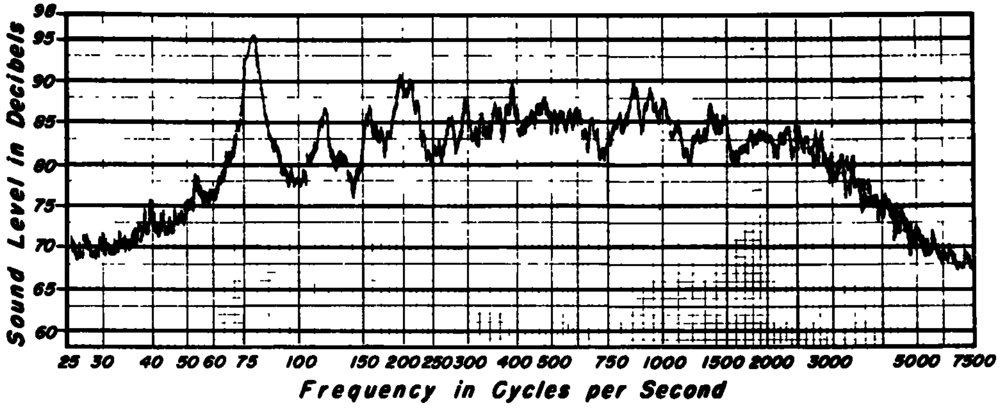

Figure 1(b). Same truck as in Figure 1(a) with an ordinary muffler.

up to a certain degree and thereafter show distortion of increasing degree (*6*). In addition to exciting some nerves more strongly, a louder sound will excite the nerves in a longer section of the basilar membrane. If one sound component partly saturates the nerve response in a section of the basilar membrane the ear will be less sensitive to other components which excite some of the nerves in this section. The result is that two simultaneous tones loud enough to cause some saturation will not be as loud if they are of almost the same frequency as they will be if they are far apart on the frequency scale. This phenomenon is called masking and is something which the sound-level meter does not take into account.

The fact that the ear distorts the sound before it reaches the auditory nerves also has a considerable effect on our hearing of certain kinds of sounds, for it results in the introduction of harmonics which are not present in the sound external to the ear. If the external sound also contains harmonics these may interfere either constructively or destructively with the subjective harmonics (*13*). This again is something which a sound-level meter cannot evaluate.

It seems then that the loudness of a tone is affected by the presence of other tones, that tones of different frequency do not add in the same way as do tones of the same frequency, and that, in fact, we cannot specify just how the components of a complex sound are added in the human ear.

Yet it is known that for many kinds of sound, whether simple or complex, the sound-level-meter readings can be converted to loudness values with a fair degree of accuracy (*8, 9*). The important question to consider here is whether or not this is true for truck noises. The largest discrepancies between subjective loudness and meter readings have been found where there were important sound components below 300 cps. and where the sounds were predominantly harmonic (*14*). Unfortunately, truck noises meet both these conditions.

Part of our recent research has been the comparison of sound-level-meter readings with loudness values obtained by comparing the noise aurally with a 1000-cycle tone. As no "dead" room was available this work was done in an open field. The acoustic conditions were very good when the wind speed was sufficiently low, but unfortunately this condition is rather rare in the locality in which the tests were conducted. Data were obtained with four different observers. The results corroborate the findings of other experimenters (*11*) to the effect that individuals vary from the average by as much as 4 or 5 db. Each of our observers made 10 readings which had a standard deviation around their mean of about 0.9 db. The loudness values thus determined were all below the meter readings by 3 to 6 db. It is evident that much more data would be required to establish any definite conclusions about the relation between A.S.A. loudness values and sound-level readings for truck noises.

When the 1000-cycle tone was adjusted to give the same reading as the noise (80 to 90 db.) on the sound-level meter, it was very piercing and much more displeasing, to some observers at least, than was the truck noise. The 1000-cycle tone affects the nerves on only a small section of the basilar membrane of the ear while a noise of comparable loudness stimulates a larger part of the membrane because of the wide frequency distribution of its components. The result is that the distortion level is reached at a much lower sound-level for a pure tone than for a complex sound having less than half its energy at any one frequency. Although the 1000-cycle comparison method has been used by other researchers to 110 db. above 0.0002 dynes per sq. cm. (110 phons) it would seem that for noise measurements the limit of its applicability is well below 110 phons and perhaps as low as 75 phons. When the discomfort level of the 1000-cycle tone is reached, the observer is strongly inclined to match discomfort rather than loudness, whatever that term may mean. In any case, the kind of sensation being matched becomes different when the discomfort level is reached. If this happens at a different intensity level for one sound than for the other, readings are not comparable. This leaves us without a standard method of measuring the loudness of very loud noises.

But fortunately, or unfortunately, it is not simply loudness that needs to be measured in the evaluation of truck noises. Loudness is only one of many conscious and subconscious subjective elements in the effects of noises on human beings.

WHAT WE WANT TO MEASURE

Our interest in this subject stems from the fact that people are annoyed by passing trucks. It is desirable to determine the factors which affect the amount of annoyance and to evaluate those factors which may readily be measured.

The annoyance caused by a given truck is largely dependent on the length of time that it is heard and the variations of loudness during this time. These factors are determined by the grade of the road, the necessity for stops, the speed of the truck, gear changes, and similar factors. These conditions are different for each location and are influenced by the design of the highway and adjoining structures. A great deal can be done to reduce noise if the problem is considered seriously when the original designs are made, but this is beyond the scope of this paper. Satisfactory minimization of annoyance for a large proportion of the actual operating conditions can be obtained by setting limits of noise production for some standardized measuring conditions. Specifications for such conditions have been suggested by the Automotive Traffic Noise Subcommittee of the SAE (*1*). We are therefore concerned here only with those factors of annoyance which are a function of the kind and amount of noise which a truck produces under a given set of operating conditions.

From the comments included in a large number of complaints and from people who have listened to truck noises reproduced in our laboratory, we have concluded that the most important factors in annoyance are the loudness and the relative proportions of high and low frequency components

ASA SOUND-LEVEL-METER READINGS AND ANNOYANCE

As was indicated above, there is considerable doubt as to the efficacy of the sound-level meter in measuring the loudness of truck noises. There is even more doubt as to its value as an index of annoyance effect (*1*). To determine whether or not it is possible to use a standard ASA meter to evaluate annoyance, the field and laboratory data have been analysed.

Standard methods of statistical analysis have been used to determine the correlation between people's judgment of annoyance value and sound levels. The results of this analysis are given in Table 1. The correlation coefficient is a measure of the degree to which the two variables may be said to be linearly related. A coefficient of 0.0 would indicate that no linear function could be found which would relate the sound level to the annoyance value even approximately. A correlation coefficient of 1.0 would indicate that there is a linear function which would enable us to compute the annoyance value exactly if the sound level is known. Intermediate values indicate that there is some best linear function which fits the data more or less exactly. Such a linear function is represented graphically by the regression line.

TABLE 1

JURY CORRELATIONS WITH SOUND-LEVEL METER—C SCALE

Date	Number in Jury	Number of Noises	Truck rpm.	Correlation Coefficient
January 16–17, 1950	10 to 13	26	2100	80
March 16–17, 1950	5 to 10	49	2100	.87
September 18, 1950	10	16	1500	.44
September 18, 1950	10	16	1800	.61
September 18, 1950	10	16	2100	.64
August, 1951	25	23		.52

The results in Table 1 are based on the data obtained at the muffler tests of the California Motor Transport Associations (*2, 3, 4*) described previously, except for the last line which is from data obtained in our laboratory. While the January and March results show reasonable correlation between jury ratings and sound-level-meter readings, those of September do not. The subsequent work in our laboratory corroborates the low correlations rather than the high. The instructions given to the jury were oral and may not have been entirely clear. It may be that on the first two occasions the juries were judging mainly on the basis of loudness rather than annoyance. If this were the case, the jury ratings might be expected to correlate fairly well with sound levels, which are more closely associated with loudness than annoyance, since the meter reading is almost entirely dependent upon the low-frequency components.

The noises recorded on magnetic tape at the September muffler tests have been reproduced in the laboratory with high-fidelity equipment and at approximately the same sound levels heard by the original jury. A sound tape with 23 different truck noises was prepared. Spliced in ahead of each noise was two seconds of a particular truck noise chosen as a reference. The tape began with the following instructions:

> You are asked to listen to the noises made by a truck with various kinds of mufflers attached and to evaluate these noises on a relative scale. The scale runs from a value of one, which is quite inoffensive, to a value of ten, which is quite annoying. The basis of rating is objectionableness rather than loudness. Each noise will be preceded by the same reference noise which will be rated five. Some of the noises will be worse than this reference and some better. We are particularly interested to know if you find some noises more obnoxious than others even though they are no louder.

The timing of the tape was as follows: for each of the 23 noises there were 2 seconds of reference noise, 2 seconds of silence, 10 seconds of the noise to be evaluated, and 4 seconds of silence.

The observers listened in groups of one to three. They were seated 54 ft. from the speakers in an area where the sound level was found to be uniform within ±1 db. The gain of the amplifier was adjusted to give a sound level of 96 db. for the reference noise and this reading was checked for each group of observers. Of the 25 observers, 20 were men and 5 women. All but 7 or 8 were college graduates. So far as is known none of them had had extensive experience with sound measurement or sound reproduction.

For each noise the average of the observers' ratings was computed. The correlation coefficient for these averages and the sound levels (C scale of ASA sound-level meter) was found to be 0.52. This low value corroborates the work of other investigators who have found poor correlation between jury judgement and sound-level readings. It also agrees well with the correlation of the 10-man jury which listened to the original noises during the September tests.

During the listening tests the most frequent comment volunteered by the listeners was that they found the high-pitched sounds more disagreeable than the low. Other investigators have found that high pitches are inherently more objectionable than low (*9*). In truck noises we have an additional effect of harmonic low frequencies but nonharmonic highs. The expected result of this would be a greater preference for the low tones.

Just as frequency weighting is necessary in measuring most sounds in order to match the response of the human ear, so is it necessary in order to obtain a meter reading having a close relationship to annoyance. The jury judgements obtained in our laboratory and some of those obtained by the California Motor Transport Associations were accompanied by readings on the A and B scales of the ASA sound-level meter. These scales weight the sounds by attenuating the lower frequencies in accordance with the Fletcher-Munson curves as previously mentioned. The A and B scales are not ordinarily used for sound levels above 85 db., because at these intensities the response of the ear is nearly uniform for all frequencies with which we are concerned. The characteristics of these weighting networks are given by curves A and B in Figure 2, which gives the attenuation in decibels as a function of frequency.

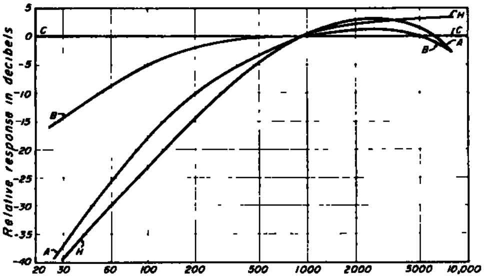

Figure 2. Response of weighting networks.

TABLE 2
JURY CORRELATIONS WITH A- AND B-SCALE READINGS

Date	Number in Jury	Number of Noises	Meter Scale	Correlation Coefficient
January, 1950	10 to 13	26	B	.83
January, 1950	10 to 13	26	A	.85
January, 1950	10 to 13	24	A	.81
March, 1950	5 to 10	49	A	.92
August, 1951	25	22	A	.83
August, 1951	25	23	B	.75

The correlations obtained between all the A- and B-scale readings and the corresponding jury values are given in Table 2. It is evident that the A-scale readings of the sound-level meter come very close to measuring the relative-annoyance values which people assign to various truck noises. Of the 23 noises reproduced in our laboratory, only one with an A-scale reading higher than that of the reference noise was rated less annoying than the reference by the jury of 25 persons, and only one noise with an A-scale reading lower than the reference was rated more annoying by the jury.

A scatter diagram for the A-scale readings and the jury values is given in Figure 3. The solid line is the regression line of the jury values on the meter readings. As defined in works on statistics, the regression line is the straight line that fits the data best. If x is the A-scale reading and y is the jury value, the equation of the regression line shown in Figure 2 is:

$$y = .555x - 45$$

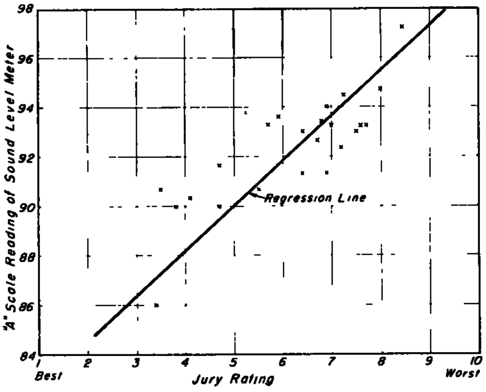

Figure 3. Sound-level-meter readings (A scale) versus jury ratings.

The significance of the correlation coefficients computed depends partly on whether or not the jury was large enough to average out the idiosyncracies of the listeners. To determine if a jury of 25 was sufficiently large, the correlation coefficients were computed for juries of 1, 2, 5, 10, and 25 persons. The results of this computation are shown in Figure 4. A curve is plotted through points for the sizes of juries mentioned above. Each such point represents the average correlation coefficient for 5 or more nonoverlapping juries except that for juries of 10 persons there was necessarily overlapping and for the top point there was only one jury. It appears that a very large jury would have given a correlation of at least .85 and perhaps as high as 0.90 whereas a jury much smaller than 25 would be insufficient to average out the individual differences.

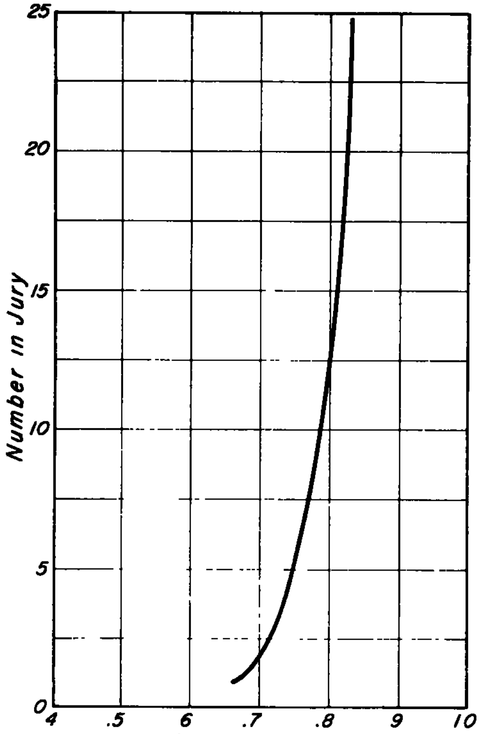

Figure 4. Effect of jury size.

The points in Figure 3 which are farthest from the regression line are for noises affected most by annoyance factors not sufficiently accounted for by the method of measurement. Those points farthest above the line are for noises rated less annoying than is indicated by their meter readings, while those below the line were rated relatively more annoying. By studying the analyses of these noises, it was found that the preferred noises had predominant low-frequency components while the noises rated relatively more annoying had a higher proportion of the higher frequencies. This indicated that for correlation with a jury even more attenuation of the low frequencies is needed than that provided by the A scale.

The sounds were reproduced in the laboratory through separate high- and low-frequency speakers. The network which divided the output of the amplifier between the two speakers had a crossover frequency of 800 cycles. At this frequency half of the energy went to each speaker. For each noise reproduced, voltage readings were taken across the terminals of the two speakers. The correlation between the jury values and the input to the low-frequency speaker was practically zero, indicating that readings of low-frequency components alone are not significant of annoyance value. On the other hand, the voltages across the high-frequency speaker gave a correlation coefficient of 0.85.

The weighting obtained by using the high-frequency-speaker voltage as a measure of the noise is indicated by curve H in Figure 2. It is evident that this provides an attenuation of the low frequencies more drastic than that of the A scale of the sound-level meter. Since it also produces better correlation it is evident that the weighting of the A scale is not excessive.

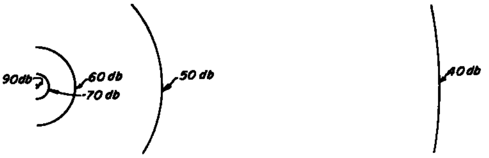

Figure 5. Relation between sound level and distance from a noise source.

Even though better correlation with a jury might be obtained by greater attenuation of the low frequencies than that of the A scale of the sound-level meter, the results might be undesirable because the reading would be almost independent of the low-frequency energy. Some people might be bothered more by the low frequencies than by the highs and for them a noise might be quite intolerable, though it gave a low reading on a meter which practically ignored the low frequencies. Some present or future trucks might produce a much higher proportion of low frequency noise than the trucks used for this research. The annoyance for such sources would be more closely related to the sound level.

It must also be realized that the jury method of measuring annoyance has its limitations. What a person thinks more annoying is not necessarily that which, over a period of time, would have the worst effect on his nervous condition, his sleep, his digestion, or his ease of communication by voice. Some of these effects are very likely to be more closely related to loudness than is the annoyance value determined by a jury. Therefore, it seems inadvisable to depart too far from loudness measurements.

A definite advantage in the use of the A scale of the sound-level meter to evaluate truck noises lies in the fact that such readings come as close as any reading yet devised to indicating the relative number of people who will hear a sound and how loud and annoying it will be to most of them. If we assume unobstructed transmission of the noise and an even distribution of population about the noise source, the number of people for whom the noise will be noticeable among the ordinary sounds in a home or office will be approximately proportional to the antilogarithm of the A-scale reading. This is true because the meter reads in decibels, which are logarithmic units and because the people at the limits of the area of audibility will hear the noise with an ear response which is approximately that of the A (or 40-db. weighting) scale. Normal sound levels in a home or office are in the order of 40 db. or more. Figure 5 illustrates the distances at which a noise has a given sound level.

It might be true that only those people should be considered for whom the noise is quite loud. But on the other hand, it has been found that noises as low as 60 db. have a bad effect on digestion. The A-scale reading would seem to be better than a C-scale reading for indicating the number of people likely to be affected by a noise, even though the C scale comes much closer to indicating the loudness at positions near the source.

CONCLUSIONS

Instruments are available to measure most of the physical attributes of vehicular-noise energy, including total noise and noise energy as a function of frequency.

Reproducing and analyzing equipment is available for making many special studies of vehicular noise that may be required.

The studies made on large trucks show that most of the sound energy is emitted in the low-frequency range between 70 and 250 cycles per second. In this range the sound consists very largely of harmonically related components.

The components of truck noise having frequencies over 250 cps. are numerous and have no appreciable harmonic relationship.

Sound energy, loudness, and annoyance are interdependent quantities but are not simple functions of each other.

Noises of low frequency are generally less annoying than those of higher frequency, considering the range from 50 to 2,500 cps., and this effect is increased in the case of truck noises by the harmonic nature of the low frequencies as opposed to the nonharmonic nature of the higher frequencies.

The sound level of a noise is not a good measure of the annoyance it may cause, because the frequency distribution of the components greatly affects the annoyance value.

The optimum frequency weighting for correlation of meter readings with a jury rating for truck noises between 90 and 103 phons is somewhat more in favor of the high frequencies than that provided by the A (40-db.-weighting) scale of the sound-level meter designed to the specifications of the American Standards Association.

For truck noises between 90 and 103 phons, good correlation exists between the annoyance evaluation of a jury and the indications of a totalizing meter using a network that suppresses the low frequencies in accordance with the ASA specifications for the A scale (40-db.-weighting scale) of a sound-level meter

The method of measurement given above is the best way of estimating by a meter reading the relative number of people who will be affected by a given noise.

The ASA sound-level meter operated on the A scale is a practical and satisfactory instrument for evaluating loud truck noises.

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