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SUBJECTIVE RESPONSE TO THE NOISE INSIDE CARS

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Introduction

There is a need during the development of a vehicle for a simple and reliable method of assessment of the degree of acoustic refinement that has been achieved.

This need is most frequently met by the measurement of Sound Level dBA but there is an awareness, shared by MIRA and vehicle manufacturers, of the shortcomings of Sound Level dBA for rating the noise inside vehicles. This led to an interest in alternative methods of measurement and, therefore, an investigation was undertaken with the following aims: 1) to acquire reliable subjective scales of preference for the noise inside mid-market cars, 2) to understand the objective bases of these scales and 3) to define a simple objective method of measurement which correlates better with subjective appraisal than existing methods.

Method of Obtaining Subjective Scales

Subjective experiments were conducted in a laboratory facility where very high quality stereophonic tape recordings, made at constant speeds in the front and rear of five cars, were reproduced accurately over the area in which four subjects sat during each session.

Seven pair comparison experiments were carried out and, with only a few exceptions, the subjects made judgements of preference that were consistent at the 95% confidence level and values of the coefficient of agreement between subjects were satisfactory. For each experiment the aggregate preference matrix was used to obtain a scale of Total Expressed Preferences, namely the number of times each stimulus was preferred to any other by the group of subjects, and this was taken as the subjective rating scale of the stimuli.

Correlation of Subjective Scales with Standard Objective Measurements

In four of the experiments the stimuli were presented exactly as recorded and in each case the product-moment correlation coefficient between the subjective scale and the following objective scales was calculated (the values of the coefficients, averaged via the z - transform over the four experiments, are shown in brackets); Zwicker Loudness (-0.92), Sound Level dBA (-0.87), Stevens Mk 6 (-0.86), Sound Level dBD (-0.82), Sound Level dBC (-0.79), Sound Pressure (-0.78) and Sound Level dBB (-0.76).

Zwicker Loudness provides the best correlation of all and Sound Level dBA provides the best correlation of the Sound Levels.

The values of the coefficients, which are negative because preference decreases as level increases, show that Zwicker Loudness accounts for 85%, and Sound Level dBA 76%, of the variance in the subjective scales. The possibility of finding a method of measurement which provides a better correlation with subjective preference depends on the nature of the residue of the variance, unaccounted for by the best of the standard measurements.

Two explanations of the residual variance can be offered. The first is that in reality the subjects' preferences are based on Zwicker Loudness or Sound Level dBA and failings in the experimental method prevent the subjects from reporting this fact accurately. The second is that other criteria, as well as loudness, exist as bases for preference and these criteria, if identified and measured, could reduce the residual variance and therefore increase the correlation coefficient.

The Existence of Other Criteria

To test the alternative explanations an experiment was carried out in which all of the stimuli were presented to the subjects at the same Sound Level dBA. The stimuli were those of one of the experiments referred to above, in which they were presented at naturally occurring levels, but they were adjusted in level alone to have the same Sound Level dBA as each other for the new experiment.

The subjects made preference judgements which were similar in consistence and agreement to those made in previous experiments and this clearly shows that criteria, other than Sound Level dBA, exist as bases for preference.

It was noticed that the preferred stimuli of the new experiment were the same as those that were more preferred than predicted by Sound Level dBA in the original experiment from which the stimuli of the "equal dBA" experiment were derived. Also the least preferred stimuli were less preferred than predicted by the Sound Level dBA in the original experiment. The possibility was therefore raised of using the subjective scale of the "equal dBA" experiment as a measure of the other criteria and combining this measure with the Sound Level dBA of the natural stimuli to obtain an improved value for correlation with the subjective preference scale of the natural stimuli.

This procedure was applied to an experiment in which the correlation coefficient between subjective preference and Sound Level dBA was -0.90 but when Sound Level dBA was modified as described the coefficient increased to -0.98. The procedure was repeated on different stimuli and this time the correlation coefficient was improved from -0.87 for Sound Level dBA alone to -0.99 for the modified values of Sound Level dBA.

Therefore there is little doubt that criteria other than Sound Level dBA exist and that they can be subjectively assessed and used to account for the majority of the variance not accounted for by Sound Level dBA.

The Identification and Measurement of Other Criteria

1% band spectra of the stimuli were examined in pairs and compared with the subjects' preference votes for the appropriate pair. As a result of this comparison it appeared that, in the absence of Sound Level dBA as a variable, the subjects responded to differences in levels above about 800 Hz (wind noise, combustion noise etc) and differences in levels at frequencies below engine firing frequency (engine rotational frequency, bump-thump, etc).

These findings were confirmed and refined by objective analysis. The multi-dimensional analysis program MDSCALV (Refs 1 and 2) was used to determine whether there were independent, orthogonal dimensions (ie criteria) in the subjects' judgements of preference for noises having the same Sound Level dBA.

This was found to be the case and the rank order of the stimuli on two orthogonal dimensions could be correlated with objective measurements of the stimuli. One of the dimensions was found to correlate well with Speech Interference Level (expressed as the arithmetic average of the unweighted levels in octave bands centred on 1 kHz, 2 kHz and 4 kHz). The arithmetic average of unweighted levels in octave bands below firing frequency (typically 31.5 Hz and 63 Hz) minus SIL, which was named Spectrum Balance SB, was found to correlate fairly well with the second dimension.

The suggested explanation is that occupants attend selectively to noise at higher frequencies (combustion and wind noise). As the level of such noises is reduced the vehicle becomes more acceptable; hence the correlation between preference and SIL. But as the level at higher frequencies is reduced attention switches to low frequency noise which is not liked; hence the correlation with preference of the difference between levels of low and high frequency noise.

When MDSCALV was applied to experiments in which the stimuli were presented at naturally occurring Sound Levels it was again possible to clearly identify two dimensions. In these cases, one was associated with Sound Level dBA, or, equally, Zwicker Loudness, and a second was associated with the level of high frequency noise but in this case the appropriate measure was Sound Level dBA minus SIL. It was not possible to identify clearly a dimension associated with low frequency noise, presumably because it had a relatively weak influence compared with Sound Level dBA. Thus, the primary influence on preference was found to be measured by Sound Level dBA, the secondary influence was found to be the level of high frequency noise relative to Sound Level dBA measured by Sound Level dBA minus SIL and the tertiary influence was found to be the relative levels of low and high frequency noise measured by SB.

The Composite Rating of Preference, CRP

Having identified two criteria other than Sound Level dBA and obtained satisfactory methods of measuring them, it is necessary to combine the three into a single composite rating. The results of multidimensional analysis show the criteria as orthogonal dimensions and the obvious approach is therefore vectorial summation. As a result of optimising scaling factors for maximum correlation with subjective preference, the Composite Rating of Preference was defined as:

$$CRP = ((dBA)^2 - 1.5(HF)^2 + 0.5\,(SB)^2)^{\frac{1}{2}}$$

where HF = Sound Level dBA minus SIL

SIL = Arithmetic mean of unweighted levels in the octave bands centred on 1, 2 and 4 Hz.

SB = Arithmetic mean of unweighted levels in the octave bands covering the audible frequency range below firing frequency minus SIL.

The average correlation coefficient between CRP and subjective preference was -0.96 compared with -0.92 for Zwicker Loudness and -0.87 for Sound Level dBA. Perhaps the most impressive result of a single experiment was one in which a number of the stimuli were recorded in diesel-engined cars. Because of the strong emphasis of low frequency noise in these cars the correlation coefficients of Zwicker Loudness and Sound Level dBA were unusually low at -0.78 and -0.77 respectively but that of CRP was only slightly lower than usual at -0.92.

Conclusions

(1) Reliable subjective scales of preference for the noise inside mid-market cars were obtained.

(2) Three criteria were identified on which the subjective judgements were based.

(3) A simple objective measurement method, the Composite Rating of Preference, was defined which gave the highest correlation with subjective preference (-0.96) averaged over four experiments. This was followed in effectiveness by Zwicker Loudness (-0.92) and Sound Level dBA (-0.87). For the pooled results of four experiments, the standard error of the prediction of subjective preference by CRP was 0.57 times that of Sound Level dBA. Therefore CRP gives an estimate of preference which is nearly twice as accurate as that given by Sound Level dBA.

(4) The three factors used in the formula for CRP are relatively simple to measure. Also, they are broadly influenced by separate noise sources and therefore are amenable to independent control in engineering terms by selective reduction of noise from relevant sources.

References

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