EXPERIMENTAL EVALUATION OF AUTOMOTIVE CABIN NOISE USING PSYCHOACOUSTIC ANALYSIS TECHNIQUES

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1. INTRODUCTION

In recent years, the automotive industry has invested significant time and money in research and development associated with the reduction of vehicle noise pollution. Much of this attention has been devoted to the areas of the Noise, Vibration and Psychoacoustics as how they relate to the automotive interior. This has been in answer to consumer demands for more comfortable vehicles. This is particularly important with today's increased use of cellular phones, entertainment multimedia systems and interactive voice controls.

Psychoacoustics, or quality of sound, is very important aspect in the development of a product if it is to portray a sense of quality. There are many different psychoacoustic metrics that are used today. Some of the more common metrics include: Loudness, Sharpness, Roughness and Fluctuation Strength. Some of the lesser known ones would be: Brightness, Pitch Strength, Impulsiveness, Rhythm, Speech Interference Level (SIL) amongst others.

2. SOUND QUALITY METRICS

As already stated, many sound quality metrics exist; however, care must be taken in their application. Each metric has a specific use and applicability dependant on the source of noise. In addition to the traditional FFT analysis the psychoacoustic metrics considered in this investigation include: Zwicker Loudness, Fluctuation Strength and Roughness. These will be considered in the evaluation of automotive cabin noise.

Zwicker Loudness is one of the most widely used psychoacoustic metrics and is standardized in ISO 532B. This metric takes into account the critical band spectrum of the human hearing. Tonal components as well as the masking properties of the sound are also considered [1]. Loudness is expressed in units of "Sones" rather then dB and Loudness level in "Phons". A relationship exists between sound pressure level and Phons where a pure tone of 1000 Hz having an SPL of 40dB equals 40 Phons. This point is taken to be "loudness unity". From here, it can be seen that 1 Sone equals 40 Phons. The most significant benefit of using Sones instead of Phons as the unit of Loudness is the fact that this perception of level can be expressed in a linear matter [2].

Modulation Metrics such as **Fluctuation Strength** and **Roughness** measure modulation between specific frequencies. Hearing sensation that describes modulation of sound in the frequency range between about 0.5 Hz to 20 Hz is referred to as Fluctuation Strength. "*The unit of measure for FS is vacil, with 1 vacil arbitrarily defined as the FS associated with a 60 dB SPL, 1 kHz tone 100% amplitude-modulated at 4 Hz*" [3]. Alternatively, sound modulations that occur within the range of 20-300 Hz are characterized as Roughness. "*The reference value for roughness of 1 "asper" is defined as that generated by a 60dB 1 kHz tone which is 100% amplitude modulated by a 70 Hz tone*" [4].

3. PROCEDURE

For this investigation, acoustic pressure measurements are taken inside the vehicle cabin both at the driver's ears location using conventional microphones as well as at the passenger's ears position using a binaural head. The purpose of the binaural head was to acquire the acoustic data in a manner representative of what a human passenger would perceive. The intent of this study is to relate the results of the psychoacoustic analysis of the vehicle cabin noise to the operation of the vehicle.

In order to simulate a real life scenario, as well as to conduct the tests in a safe manner, an automotive test track of 500 meter length was used. Testing was done using the operating conditions of both a self propelled and towed vehicle. The speed of the towed and self propelled vehicle was maintained during all periods of acquisition at 50 km/hr.

4. RESULTS

At the tested road speed, it is observed that the engine noise contributed little to the overall loudness (Fig. 1) within vehicle's cabin since the "driving curve" is only marginally greater then the "towing curve" (mean 16.92 sones compared to mean 16.51 sones). Given this, it is surmised that, under the test conditions, that the predominant source of noise measured was due mostly to the road-tire-suspension interactions. Although not presented in this paper a sharpness analysis of any high frequency content indicated that wind noise was also negligible.

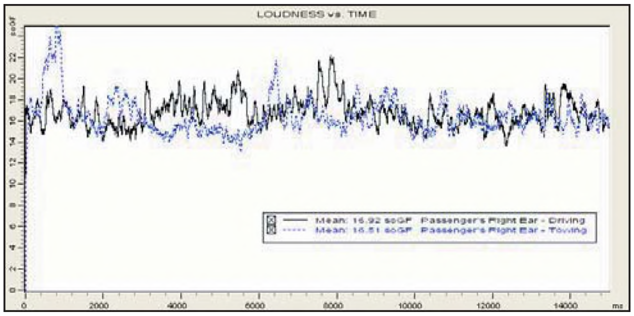

Fig. 1: Results of Loudness vs. Time (measurements taken at passenger's ear using binaural head for both driving and towing cases.

Inspection of the graph representing Roughness (Fig. 2) indicates the presence of two "strange" peaks that occur at the beginning of the measurement for the case of the towed vehicle and at the end for the driving case. These peaks were due to the presence of a series of small "wash board" speed bumps in the test track which resulted in high modulation levels for a very short period of time. There are present at only one end of the test track. Since the towed testing was done in one direction and the driving in the other, this phenomenon is shown at opposite sides of the results, i.e. one at the beginning and the other at the end of measurement. The towed vehicle showed higher levels indicating that the presence of engine noise contributed to the masking of the modulated signal from the road noise.

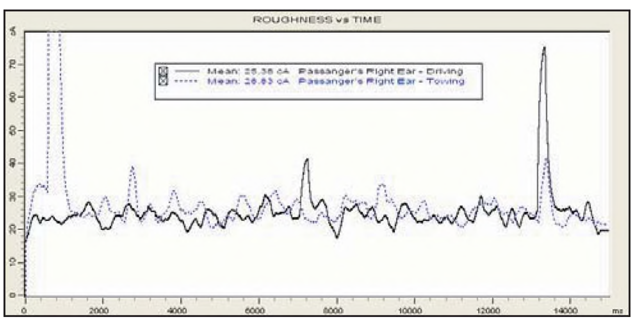

Fig. 2: Results of Roughness vs. Time (measurements taken at passenger's ear using binaural head for both driving and towing cases.

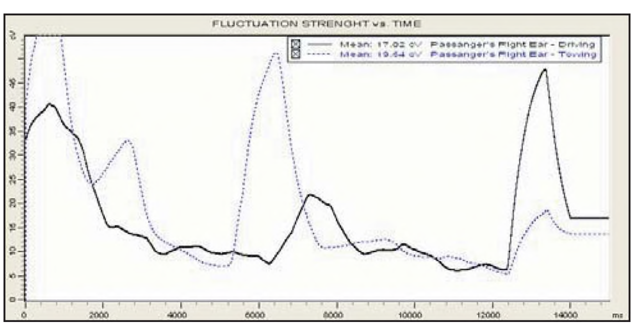

Fig. 3: Results of Fluctuation Strength vs. Time (measurements taken at passenger's ear using binaural head for both conditions.

Similar observations are made with Fluctuation Strength (Fig. 3) where due to a lack of any more lower frequency modulation, the curves are relatively smoother.

While little additional information is provided by the FFT spectrogram (Fig. 4), confirmation of some of the previous observations is given. Specifically, the predominant frequency of the measured noise is in the low spectrum, under 100 Hz. This again is indicative of the road-tire-suspension mechanism being the primary noise contributors. The lack of the high frequency signal again indicates the absence of any aeroacoustic noise generation.

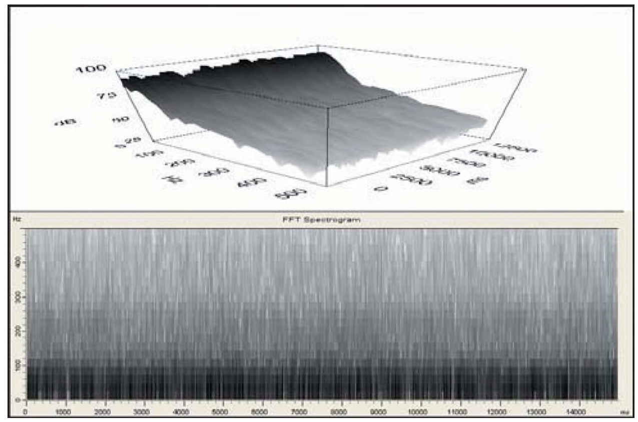

Fig. 4: FFT Spectrogram (measurements taken at passenger's ear using binaural head driving at 50 km/h).

5. CONCLUSION

From the results discussed above, it is observed that predominate noise contribution within the vehicle cabin is the result of road - tire- suspension interactions. Future studies of this vehicle will focus on relating vibration measurements taken of this vehicle's suspension and relating any realized Transfer Path Analysis to the resulting cabin noise from a psychoacoustic perspective.

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