

Contributors to Lower Frequency Pass-by Noise Levels under Cruise Conditions

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Illingworth & Rodkin Inc.

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ABSTRACT

With increasing use of the constant speed pass-by conditions to capture the noise generated by this portion of the vehicle operating cycle, knowledge of the contributing sources of noise has become increasingly important. For frequencies above 400 Hz, the noise is dominated by tire/pavement noise as can be demonstrated by comparing on-board sound intensity (OBSI) measurements to constant speed pass-by noise levels. At lower frequencies, direct on-board measurements become more difficult as the tire/pavement noise source strength decreases with decreasing frequency and microphone induced wind noise increases. To investigate the contribution of sources at these lower frequencies, cruise and coast pass-by measurements were made for a number of different pavement types and two different tire designs at test speeds of 56, 72, and 97 km/h over a frequency range from 50 to 10,000 Hz. OBSI measurements were also conducted for these same conditions. From the pass-by measurements, powertrain noise was separated from "rolling" noise by comparing cruise and coast operation. For coast conditions, the noise levels below 400 Hz were found not to depend on pavement type and texture or on tire design unlike the higher frequencies. Further, the speed dependencies of the levels below 400 Hz were more consistent with aerodynamic noise than with those of the tire/pavement noise. Contribution of aerodynamic noise was also indicated with wind tunnel measurements of vehicle exterior noise. Using these results, the relationship between the various noise sources at these lower frequencies was investigated.

INTRODUCTION

Exterior and interior motor vehicle noise is generally lumped into the three broad categories of powertrain, tire/pavement, and aerodynamic noise. In terms of vehicle noise

development, it was often desired to isolate the contributions of each of these in order to reduce the total system noise level. This is typically done by either operating the vehicle at a condition that emphasizes one contribution relative to the others, such as low speed, full throttle acceleration to isolate powertrain noise, or using laboratory facilities such as chassis dynamometers or wind tunnels. These methods do however have their limitations as the operating condition of interest may actually be a blend of contributions, such as 80 km/h cruise noise. Further, the use of laboratory facilities can create ambiguities relative to the simulation of actual on-road noise production. A good example of this latter point is indoor pass-by dynamometer facilities in which powertrain noise can be well represented, while tire noise is typically not well replicated.

For the specific case of exterior noise from light vehicle cruise pass-by, the problem seems somewhat straightforward as the powertrain noise contribution can be readily isolated by comparing cruise and coast pass-by. Once this is achieved, it is generally considered that tire/pavement noise is the sole remaining contributor, at least up to speeds around 120 km/h on an overall A-weighted level basis¹. Recent research conducted to examine the relationship between on-board sound intensity measurement of tire/pavement noise and cruise/coast pass-by has indicated that for one-third octave band spectral levels, this source level measurement of tire/pavement noise does not account for the pass-by contributions measured for frequencies 400 Hz and below². At frequencies of 2000 Hz and above, a similar behavior is noted. Although the contribution of these frequency regions are only minor contributors to overall A-weighted cruise pass-by levels, they are of interest given the regulatory emphasis on cruise conditions in the proposed revisions to ISO 362 pass-by noise procedure and the regulatory requirements placed on tire noise as measured under cruise.

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The exterior noise generated under cruise is also of interest in determining for the load cases for predicting interior noise contributions with tools such as Statistical Energy Analysis.

In past research, acoustic beam forming has been used to identify noise source regions for trucks and light vehicles under cruise conditions on actual highways³. Although this technology is useful in the mid frequency range, the spatial resolution in the frequencies below 500 Hz is insufficient to separate different potential noise sources. In order to investigate the lower frequency contributions indirectly, pass-by measurements taken on a closed test track were analyzed specifically for this issue. The measurements include both cruise and coast on four pavements with two different tire designs producing varying noise levels. Although the contribution of aerodynamic noise to cruise/coast conditions below 110 km/h is often cited to be minimal¹, aerodynamic noise from vehicle underbodies is documented and reported in the literature^{4,5,6}. The possibility of aerodynamic noise contribution can be inferred from the on-road results as well as from wind tunnel data measured at the OBSI measurement locations and from sound pressure levels measured out of the flow 7.5m to the side of test vehicles. This paper reports the analysis of these data and the resultant findings.

MEASUREMENT DESCRIPTION

TEST TRACK AND TIRES

On-road testing was conducted at the National Center for Asphalt Technology (NCAT) test track facility in Opelika, Alabama. The NCAT track consists of 48 hot mix asphalt (HMA) test sections, typically about 200 ft in length around a 1.7-mile oval. These pavements provide a range of surface roughness, construction type, and porosity. The track is sufficiently wide that pass-by measurements were made with the sound propagating over HMA at a distance of 7.5m. For the testing, four pavements were selected that produced a large range in noise level. Three of the sites were essentially identical in geometry with different pavements. These are identified as test section S1, S4, and S5. These sections were flat and level, with the pass-by microphone located just off the edge of asphalt. The pavement in section S1 was a medium texture stone mastic asphalt, 46mm thick and non-porous. Section S4 was an open graded asphalt pavement of coarse texture, 25mm thick and porous. Section S5 was asphalt "Superpave" construction of fine texture, 38mm thick, and non-porous. The geometry of the fourth test site (section W3) was somewhat more complex. This test section was located on a banked corner of the track. At this location, although the surface is sloped, it remains visually flat across its width. This section was chosen especially for its unique surface. The pavement consists of relatively fine aggregate with transverse grooves cut into the surface. This transverse texture generates sounds that are similar to concrete

counterparts with aggressive transverse texturing or grooving. Photographs of each of the test surfaces are provided in [Figure 1](#).

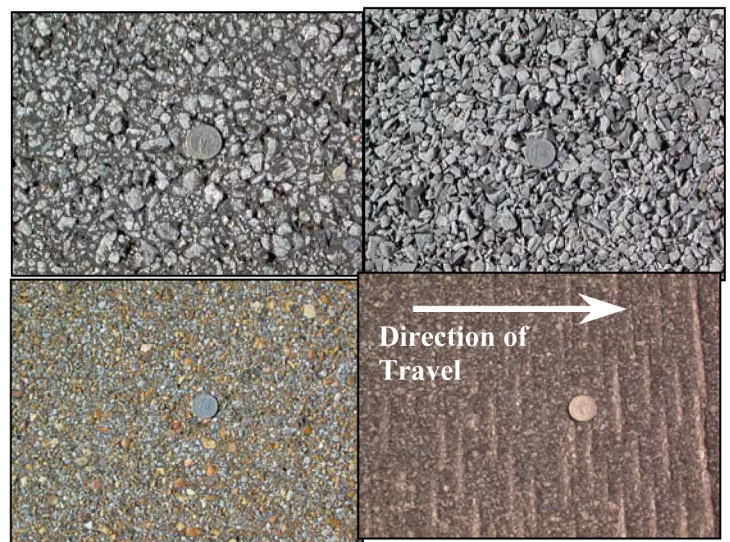


Figure 1. Test Surfaces - S1 upper left, S4 upper right, S5 lower left, and W3 lower right

The original intent was to conduct the testing for all sections at 56, 72, and 97 km/h consistent with those speeds specified in the American Association of State Highway Transportation Organizations (AASHTO) provisional OBSI test procedure⁷. This was readily achievable for sections S1, S4, and S5. For section W3, it was found that 97 km/h could not be safely maintained through the banked corner without putting additional side force on the tires. As a result, the upper speed at this site was limited to 88 km/h.

Two tires were used in the testing. The first was the ASTM Standard Reference Test Tire (SRTT) in the P225/60R16 size. The second tire was a Dunlop SP Winter Sport M3. This tire has a more open tread pattern than the SRTT and has been found to produce OBSI levels about 2 dB higher than the SRTT². Photographs of the two tires are shown in [Figure 2](#).



Figure 2. Test tires - Dunlop SP Winter Sport M3 on the left, ATSM Standard Reference Test Tire (SRTT) on the right

MEASUREMENT METHODS

For the vehicle pass-by measurements, the distance between the centerline of travel and the microphone was 7.5m as specified in the ISO 362 procedure. The microphone height was set to be 1.5m above the height of the pavement. To collect overall pass-by sound pressure levels a Larson Davis Model 820 sound level meter (SLM) was used at the track. The acoustic signals from the SLM were captured on a Sony LCD-100 two-channel digital audio tape recorder and these were used later to determine maximum pass-by level in one-third octave bands using a Larson Davis 2900 dual-channel real time analyzer and an one-eighth second exponential averaging time. Multiple runs were made for each test condition and those falling within a ± 1.6 km/h window about the nominal test speed were averaged together. Vehicle speed was measured with a calibrated radar gun during the pass-bys. A photograph showing a typical pass-by test set-up on the NCAT track is provided in Fig. 3. The test vehicle was 2006 Pontiac Grand Prix. The pass-by tests were performed with the vehicle operated in a cruise condition with the transmission in drive producing the lowest possible engine speed and with the vehicle coasting by with the transmission in neutral and the engine at idle.

The OBSI measurements were performed following the AASHTO procedure. The OBSI probe consisted of two $\frac{1}{2}$ " (12.5mm) G.R.A.S. phased matched condenser microphones installed on Larson Davis $\frac{1}{2}$ " (12.5mm) Model PRM900C microphone preamplifiers. The microphones were used in a "side-by-side" configuration with a 16mm spacing of the microphones. The probe was oriented such that its sensitive axis (a line perpendicular to the length of microphones/preamplifiers and determined by the line through the microphones) was pointed toward the tire sidewall (Fig. 4). Prior to the measurements, the microphones were protected

from airflow using a spherical foam windscreen. Measurements were made with the probe 75mm above the pavement, 100mm out from the tire sidewall, and at two locations, opposite the leading edge of the tire contact patch and opposite the trailing edge. These positions were measured separately with the probe re-positioned as necessary. The sound pressure signals from the two microphones went directly into the LD 2900 analyzer and the sound intensity level was produced in one-third octave bands in real time. The signals were also captured on the DAT recorder. Sound intensity levels from each probe position were averaged for typically three repeat runs and then the levels for the two positions were averaged to yield a single spectrum for each test condition.



Figure 3. Pass-by measurement setup at S4

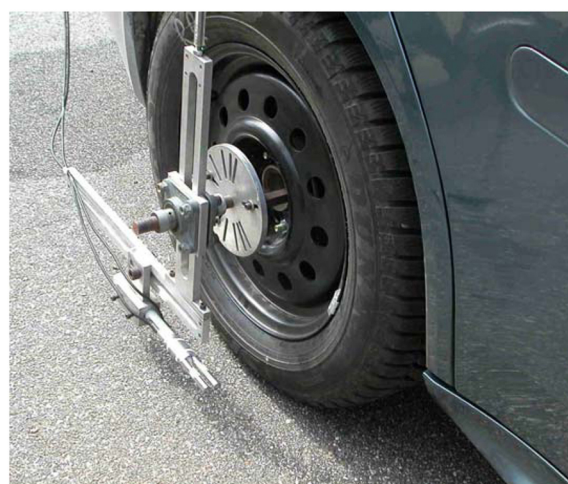


Figure 4. On-board sound intensity tire noise measurement fixture on test vehicle shown without spherical windscreen over the side-by-side microphone pair of the intensity probe