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RWDI Project #1803556

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RE: VANCOUVER ISLAND MOTORSPORT CIRCUIT – POTENTIAL NOISE MITIGATION MEASURES

As requested, RWDI provide herein a discussion of potential noise mitigation measures which could be applied at the existing Vancouver Island Motorsport Circuit (VIMC) circuit to reduce noise received in residential areas to the south of the Cowichan Valley Highway. These measures include operational controls and noise barriers.

Background

The VIMC requested that RWDI was consider (at a conceptual level) all mitigation measures that could realistically be taken to reduce the spread of motorsport noise towards the residences located largely to the south of the existing circuit. To facilitate understanding of the challenges involved in controlling noise from a facility such as the VIMC, and the physical phenomena that will largely dictate the effectiveness of various noise control approaches, background information is provided below regarding outdoor sound propagation and interaction of sound with physical objects (i.e., barriers)

Outdoor Sound Propagation

SOUND WAVES AND THE DIRECTIVITY OF SOUND SOURCES

Sound is a wave phenomenon in which tiny fluctuations in atmospheric (air) pressure are created by vibrating surfaces (a drum, bell or loudspeaker), flowing liquids, or turbulent/pulsating gases (such as the exhaust from a car engine). Sound created by a true "point source", such as an exploding balloon or firecracker, propagates out from the source with equal intensity in all directions. But the sound from common sources such as a car exhausts, gun barrels, or loudspeakers, are to varying degrees "directional" – that is the sound is radiated more intensely in some directions than others. With car exhausts and gun barrels, sound radiation (at least at middle and higher frequencies) is strongest in the direction the exhaust pipe or gun barrel is facing. Such sources produce sound over a substantial range of frequencies from low-pitched to high-pitched.

Over the range of sound frequencies of concern with car engines/exhausts (approximately 100 to 10,000 Hz.) the wavelengths of sound in air range from 3.4 m to 3.4 cm. The higher frequency (short wavelength) components of sound tend to be more directional and are more readily scattered and reflected by objects such as tree branches and leaves, while the lower frequency components (long wavelengths) tend to be less directional, (i.e., they are radiated more uniformly in all directions) and require much larger objects to scatter and reflected them. A good analogy to sound scattering is what occurs if one attempts to bounce a ball on a gravel driveway. If the ball is smaller or comparable in size to the gravel (e.g. a golf ball), it will bounce in all directions, while if it is much larger (e.g., a basketball), it will bounce more-or-less straight back up. Low frequency sounds also diffract, or bend, more readily around objects than high frequency sounds. These characteristics of sound waves are important when considering the effectiveness of noise mitigation measures such as noise barriers.

SOUND ATTENUATION WITH DISTANCE

There are at least six different factors that can act to reduce/influence the intensity of sound waves reaching distant receivers:

- geometric spreading,
- atmospheric absorption,
- ground effect,
- wind and air temperature gradients,
- the presence of physical objects such as terrain features, buildings, barriers (e.g., walls or earth berms), and
- the presence of vegetation/forest belts.

Each of these are described in the following sections.

Geometric Spreading

Geometric spreading refers to the steady reduction in sound intensity that occurs as sound waves radiate out from the source. As the wave fronts expand, their energy is distributed over larger and large areas, thereby reducing the intensity (or level) of the sound (analogous to the decrease in brightness as one moves away from a light source). For localized noise sources (sources that are small in relation to the source -receiver distances involved), sound levels decrease at a steady rate of 6 decibels per doubling of distance. This form of attenuation is always present unless it is disrupted through the interaction (e.g. focusing) of sound waves with large objects such as in a narrow valley or urban streetscape.

Atmospheric Absorption

Atmospheric (or molecular) absorption refers to the steady decrease is the intensity of sound waves (which propagate via the back-and-forth oscillations of air molecules) as they pass through the atmosphere. Various molecular mechanisms are involved and the rate of extraction of energy from sound waves varies with the temperature, pressure and relative humidity of the air. This effect increases strongly with sound frequency so that at 10,000 Hz., the losses can be as much as 10 dB per 100 m of distance, while in the lower frequency range where most cars using the VIMC would tend to have their high-throttle exhaust frequencies (roughly 200 to 400 Hz.), the rate of sound attenuation from atmospheric absorption is only about 0.1 to 0.2 dB per 100 m. (or 1 to 2 dB/km)

Ground Effect

Ground effect refers to additional sound attenuation that can occur when the sound propagation path from the source to the receiver lies close to the ground and the ground surface is "acoustically soft". Acoustically soft ground is porous ground, such as lawns, farmland, or forest floors, which allows the sound waves to penetrate the surface. There are generally only two paths by which sound waves can travel from source to receiver – the first is the "direct path" (i.e. essentially along the line of sight), and the second is the "reflected path" along which the sound wave interacts with the intervening ground at some point. Sound waves which encounter soft ground are partially absorbed (particularly the higher frequencies), and partially reflected (lower and mid frequencies). However, upon first penetrating and then being reflected from such "soft" surfaces, the ground-reflected sound wave is slightly delayed. Because of this delay, when the direct and reflected waves converge at the receiver, they are sufficiently out of phase that their sound intensities tend to cancel one another. This effect does not occur over "acoustically hard" surfaces like water or pavement because the reflected waves are not significantly delayed. This phase cancellation effect can reduce noise levels at large distances (150 m or more) over soft ground by more than 20 dB over the frequency range from 200 to 6,000 Hz. Ground effect is greatest when both the sound source and receiver are close to the ground and the intervening ground is both soft and flat or steadily sloping.

Wind and Temperature Gradients and other Meteorological Effects

The presence of wind (or more accurately, wind speed gradients) and/or air temperature gradients causes sound waves to deviate from their normal straight paths. Under upwind propagation (sound travelling in direction opposite to the wind) or normal daytime temperature lapse (air warmer near the ground) conditions, sound travels faster near the ground and sound waves are refracted, or bent, upwards away from the earth so that lower-than- normal noise levels will be experienced at distant receivers (receivers in a "sound shadow"). Conversely, when sound waves travel with the wind (downwind propagation), or when a temperature inversion (air colder near the ground) exists, sound travels more slowly near the ground, and sound waves are bent downwards towards the earth. Such conditions can lead to higher-than-normal sound levels at large distances. What happens in this case is that the "ground effect" is partially or entirely defeated by the downward bending sound waves and the situation becomes more akin to sound propagation over hard ground or water. Under calm/windless conditions, or in crosswind situations (which is the most common situation at VIMC where east-west winds prevail), there is little of no effect on sound propagation, other than that caused by atmospheric turbulence - which is always present to some degree. Such turbulence tends to influence (diffract and scatter) higher frequency sound more than lower-frequency sound.

Intervening Objects (Sound Barriers)

Sound barriers (walls, buildings, earth berms or natural land forms) work by blocking the direct sound path (i.e., the line of sight) from source to receiver. Sound must then diffract, or bend, to get over the top, or around the ends, of the barrier to reach the receiver. In diffracting, the intensity of the sound is reduced and the barrier creates a partial "sound shadow".

Barriers tend to work best when located near either the sound source or receiver so that sound waves must bend more sharply to reach the receiver. The amount of noise reduction provided by a barrier (assuming it is solid and heavy enough to sufficiently limit sound transmission directly through it) varies from about 5 dB (when the line of sight from receiver to source is just blocked) to a practical maximum of 15 to 20 dB. The more the direct sound path is interrupted by the barrier, the larger the noise reduction, or "insertion loss" achieved. As we have seen under downwind propagation and temperature inversion conditions, sound waves tend to bend downwards towards the ground and can therefore diffract more readily overtop the barrier. However, the more the line of sight is interrupted by the barrier, the more pronounced these atmospheric conditions must be to decrease the noise shielding provided by the barrier.

Vegetation/Forest Belt Effects

As described above, vegetation/forests can scatter and reflect sound in all directions (particularly higher frequencies). Forest belts, due to their typically deep, soft and porous ground surfaces (forest floors), can also enhance the ground effect. Therefore, when a substantial belt (30 m or more) of mature dense forest lies between a noise source and a noise receiver, it can provide additional noise reduction over and above that from soft ground alone. However, in other situations, the presence of forest belts can lead to higher noise levels. Such situation occurs when sound is scattered back towards the ground by a tree line along the edge of a clearing (such as that along the northern edge of VIMC site), or when trees overtop a natural or constructed noise barrier such as a ridge line, earth berm or noise wall. In this latter case, the vegetation can scatter sound down behind the barrier, thereby reducing its noise shielding effect. When in leaf, broad-leafed deciduous trees tend to scatter more sound (and lower frequencies) than evergreen trees.

Nature of the VIMC Site and its Surroundings

The VIMC is largely surrounded by forest belts and there are substantial forested areas between the circuit and the nearest residences. The terrain within the VIMC property rises moderately steeply from the southern to northern extremities of the circuit, with the northern edge, at about 133 m, being roughly 25 m higher than the southern edge, and about 29 m higher than the Cowichan Valley Highway. The terrain between the highway and the more distant residences at which residents report hearing circuit noise (i.e., Riverbottom Road and Glenora at 4 to 5 km away), is fairly flat, but it contains many localized undulations that result in some residences being shielded, or partially shielded, from circuit noise. Alternatively, other locations are 15 m or more above the level of the highway and receiving no terrain shielding. The effects of this terrain unevenness on predicted exposures to circuit noise (as modelled for the proposed Phase 2 circuit) at various residential locations is apparent in the sound level contour maps provided by BeSB GMBH Berlin in their April 13, 2108 report.

Worst-Case Circuit Noise Levels at Residences to the South

Data provided by BeSB GMBH Berlin on page 15 of their April 13, 2108 report, indicates that, at full load, street legal GT class cars and upper-class sedans produce a noise level of 95.5 dBA at 15 m, which corresponds to a sound power level of 127 dBA. **Table 1** presents estimated noise levels at various setback distances from the southern edge of the existing circuit, with one such car operating, assuming worst-case sound propagation conditions (i.e., no terrain shielding, ground effect, or forest belt attenuation. It should be noted that these levels are not average noise levels, such as those presented in the April 13, 2108 BeSB GMBH report, but rather instantaneous maximum noise levels (L_{max}) from a car operating at full load.

Table 1; Worst Case (Full Load) Noise Levels (L_{max} in dBA) at Various Setbacks from Southern Edge of Circuit, One Car Operating

Distance (m)	300	500	750	1,000	2,000	3,000	4,000	5,000	6,000
Geometric Spreading	69.5	65.5	61.5	59.5	53.5	49.5	47.5	45.5	43.5
Geometric Spreading plus Atmospheric Absorption[1] (1.5 dB/km[1])	69.0	64.7	60.4	58.0	50.5	45.0	41.5	38.0	34.5

1 Atmospheric absorption results in a rate of attenuation of approximately 1.5 dB/km in the frequency range typical of engine exhaust "notes" (200 to 400 Hz). Attenuation rates at higher frequencies are progressively larger.

Note that the above worst-case sound levels would only occur when there was either a pronounced northerly wind blowing from the circuit towards the residences, or when there was a strong temperature inversion in the Cowichan Valley. Wind roses collected at the weather station located at the Cowichan Valley Regional District offices on Highway 1 (as per the Cowichan Valley Regional District Air Quality Study; Stantec, January 2015) show that north winds exist at this location about 25% of the time. At the VIMC It is expected that northerly winds would be even less common and that east-west winds would be prevalent. Note also that background noise levels, particularly in forested areas, increase in the presence of wind, so that noises such as those from the circuit operation will tend to be less audible.

Temperature inversions often occur when a clear night follows a warm day so that, during the night, the earth has been able to radiate off the previous day's warmth to the night sky leaving the ground surface (and the layer of air immediately above it) colder than the air at higher elevations. It is not known how often such conditions exist in the immediate area around the VIMC.

When neither a north wind nor a temperature inversion exist, circuit noise levels at residences to the south of the VIMC would be expected to be considerably lower than those shown in **Table 1**. An indication of the significance of the additional noise attenuation that can be provided by ground effect and forest belt shielding, can be obtained from a noise measurement which I conducted at 11:00 AM on April 27, 2018 with the assistance of the Circuit Manager, Paul Rossmo. The measurement was made at the end of the small road leading eastwards from the cul-de-sac at the end of Mina Drive, and it revealed a noise level of approximately 45 dBA created by a single Alpha Romeo 4C (reportedly one of the noisier cars used at VIMC). The car was stationary at the east end of the southern straight-away with its exhaust directed southwards and its engine revved up and held at ¾ of red line. The distance from the Alpha 4C to this measurement location was approximately 320 m. This measured level was then approximately 24 dBA lower than the corresponding (300 m) worst case levels shown in **Table 1**. A second measurement of the noise from the Alpha Romeo 4C was attempted on April 17 at a location along Sahtlam Road directly south of the VIMC. However, due to shielding provided by the intervening terrain and the presence of daytime background noise in the neighbourhood, the noise created by Aplha Romeo 4C was not audible at this location.

Potential Noise Mitigation Measures

OPERATIONAL CONTROLS

Operational controls are mitigation measures aimed at reducing the noise produced by cars on the circuit without resorting to physical measures on the track itself. A significant advantage of operational controls is that the noise reductions achieved through such efforts will benefit all noise sensitive areas (residences and recreation areas) fairly equally regardless of where they are located relative to the circuit. In addition, the effects of operational controls will be maintained under all meteorological conditions. Potential operational controls include:

- Setting a noise emission limit for cars
- Setting a limiting for the numbers of cars on the track at any given time
- Reorientating the direction of car exhausts

Noise Emission Limits

It is understood that all cars used on the track are subject to a noise emission limit that is enforced by drive-by noise measurement. The measurements are conducted by a logging sound level meter and microphone which are located about 12 m from the edge of the track near the end of the southern straightaway where cars are operating at or near maximum power. It is also understood that, in recent months, the maximum permissible noise level has been reduced from 100 to 95 dBA). It would then be expected that similar reductions have occurred in the maximum circuit noise levels experienced at residences to the south.

Numbers of Cars on the Circuit

Assuming that all cars have equal noise emissions and are driven in exactly the same manner, then the total sound energy emitted from the circuit will increase by 3 dBA with every doubling of the number of cars operating on the circuit at one time. Therefore, going from two to four cars increases average noise emission levels (L_{eq}) by 3 dBA, going from four to eight cars would increase overall noise emissions by a further 3 dBA. However, because of our ears' non-linear sensitivity to sound pressure, it would take a tenfold increase in the number of cars (i.e. going from one to ten cars, with an associated 10 dBA increase in average noise levels) to typically double the perceived loudness of the noise being received at the residences.

The effects of increasing the number of similar cars on the circuit on the maximum noise levels experienced at distant residences would be more complicated. If two cars happen to produce their maximum noise outputs at precisely the same time, then the L_{max} heard at distant residences will increase by 3 dBA, four cars, by 6 dBA etc. However, such simultaneous occurrences of maximum noise outputs would not be expected to occur often given the typical numbers of cars[1] on the circuit at one time. The more prevalent effect of increasing the number of active cars would be expected to the more frequent occurrence of maximum levels, or 'noise peaks" – i.e., generally greater variability in noise levels.

Reorientation of Exhausts

It is possible to reorient the exhaust outlets of cars so that they point downwards at the pavement rather than straight to the rear. This would be expected to be a positive thing from the perspective of noise radiation offsite. For the higher frequency components of exhaust noise (1,000 to 4,000 Hz.), which are radiated fairly directionally from the exhaust pipes, orienting the exhaust pipe outlet straight down would reduce the levels of noise initially radiated horizontally towards the residences by from about 5 to 20 dB. The downward directed sound would, of course, be largely reflected off the pavement and some portion of it would interact with the underside of the car and be reflected/scattered in various directions, including towards the residences. In spite of this, I would expect a reduction in the levels of higher frequency sound being radiated towards the residences. However, these higher frequency components of exhaust noise do not tend to reach distant residences at audible levels. Typical engine firing frequencies fall in the 200 to 400 Hertz range, and wavelengths of sound in this frequency range (2.8 to 5.6 feet) are much larger than the diameters of the exhaust pipes – the result being that sound is radiated much more uniformly in all directions. The beneficial effects of orienting the exhaust outlets downward on the levels of "engine note" sound reaching distant residences would likely be marginal (i.e., 1 to 2 dB).

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[1] Typically, 3 to 4 cars are on the circuit at one time. This can increase to 4 to 8 cars in typical lead/follow situations, but this activity is done at lower speeds with less noise produced per car. Still larger numbers of cars (maximum of 12 to 15) may be involved in some lead/follow situation.

NOISE BARRIERS

Effectiveness of Constructing Noise Barriers at the VIMC

The principle challenges to achieving significant noise reductions at distant residences from noise barriers on the VIMC are:

1. While it may be possible to locate noise barriers fairly close to the noise sources (cars), the relevant noise receivers (residents) are far away;
2. The primary sound frequencies of concern are fairly low;
3. The VIMC is largely surrounded by forested areas; and
4. One of the two main straightaways is oriented largely north-south so that it will be more difficult to locate a noise barrier to effectively block the line of sight to residences when cars are on this section.

As was described above, the meteorological conditions most unfavorable from a noise control perspective (i.e., northerly winds and temperature inversions) are not expected to occur very frequently. Therefore, most of the time, sound created at the VIMC (particularly the "engine notes") will tend to travel in reasonably straight lines from the cars to the residences. Under such conditions, a well-designed and located noise barrier should be able to achieve meaningful reductions in car noise as received at distant residences. The measurements taken on April 27, 2108 at the end of the minor road leading east from the Mina Drive cul-de-sac (with the Alpha Romeo 4C first located well to the east of the building, and then directly behind it), showed that the VIMC building provided a noise reduction of at least 5 dBA at a setback distance of 320 m from the car. It is expected that the noise reduction achieved was actually greater than 5 dBA, but daytime background noise levels of about 40 dBA obscured any residual noise arriving from the Alpha 4C when it was located behind the building. This outcome indicates that any sound scattering due to the trees on either side of the VIMC building, and between the building and the Mina Drive area, was not pronounced enough at the frequencies of primary concern (200 to 400 Hz.) to defeat the noise shielding effects of the building.

Effectiveness of Various Types of Noise Barriers at the VIMC

To be effective in this situation (i.e., with distant receivers), noise barriers will have to be located as close to the noise sources as possible, and rise to height well above the cars they are intended to shield. In addition, the most effective locations for noise barriers will be at points along the circuit where the cars typically emit their highest noise levels. As such, the most effective locations for noise barriers would be as shown in **Figure 1**.

Figure 1; Preliminary/Conceptual Locations[2] for Noise Barriers at VIMC – Noise Wall (Red), Earth Berms or Berm/Walls (Green).

Two types of noise barrier are indicated in **Figure 1**. A vertical noise wall (in red) is located along the southern edge of southern straightaway and abutting either end of the building. As shown, this wall is approximately 450 m long and would likely need to be 4 to 5 m high from its eastern end almost all the way to Turn 2. After that, the height of the wall would need to steadily increase from 4 to 5 m to perhaps as much as 7 to 8 m to continue to provide noise shielding for cars heading up the incline into Turn 3. Such a noise wall would presumably need to be protected from vehicle collisions by a concrete roadside barrier or Jersey barrier.

The barriers shown in **Figure 1** as green lines (total length of about 800 m) could be earth berms or berm/wall combinations. In most locations, there is between15 and 20 m of space available between adjacent circuit segments so that if earth berms were constructed with 2:1 side slopes, they could reach heights of 3 to 4 m (allowing for 1.0 m of shy distance on each side and a 1 m wide flat top). However, since

[2] These locations are indicative only and, should the design of noise barriers proceed, more detailed assessments of the noise emission patterns of the circuit and of its terrain will be required in order to optimize barrier locations and heights.

the ground generally slopes downward between circuit segments from north to south, the effective height of such berms, relative to the cars on the circuit segments to the north, would be less than 3 to 4 m. An approach which would appear to have greater potential would be to use lower berms (2 to 3 m) but top them with a noise wall of moderate (2 to 3 m) height, so that the combined berm plus wall height will place the tops of the walls at 4 to 5 m above the level of the immediately adjacent pavement to the north.

Noise Wall Materials

To sufficiently prevent motor vehicle noise from passing through it, a noise wall need only weigh about 10 kg/m2 (2 lb./ft2) and be free from gaps and cracks. Therefore, noise barriers could be made of concrete, steel, aluminum, timber, glass or plastic, as well as from various recycled materials. However, these materials are, in their traditional forms, sound-reflective, so that most of the motorsport noise that strikes them would be reflected back towards the cars, generally in a northerly direction. Fortunately, there are several aspects of the VIMC layout that will tend to reduce the effects of such reflected sound:

1. The green noise barriers in **Figure 1** (berms or berm/walls) will be located well above the sections of circuit immediately to the south of them, and somewhat above those to the north. If these barriers are simply earth berms, they will absorb much of the sound that strikes them and reflect most of the remainder skywards;
2. If the berms are topped with noise walls, they will be located above the cars. As such, the reflected sound will also tend to be directed skywards rather than horizontally; and
3. As previously discussed, forest wall sound reflections are expected to be largely limited to middle and higher frequency components of motorsport noise. The wavelengths of the 200 to 400 Hz. "exhaust notes" at 1.72 to 0.86 m (5.6 to 2.8 ft.), appear to be too long for this sound to be strongly reflected by the surrounding forests.

While the above factors will limit the magnitude of reflected received at residences to the south, there would still be benefits to making the noise barriers sound absorptive. The obvious benefit is that there will be less total sound radiated from the circuit, but a less obvious benefit is that barriers with sound absorptive surfaces provide somewhat greater insertion losses (noise reductions) than do reflective barriers.

The sound absorption capacity of a material surface (such as noise barriers) is indicated by their sound absorption coefficient. A surface with a sound absorption capacity of 0.5 absorbs 50% of the sound energy that strikes it, while one that has a coefficient of 1.0, absorbs 100% of the sound energy. To significantly reduce the perceived level of reflected sound, say by at least 5 dB, a noise barrier should have an average (over the relevant frequency range) sound absorption coefficient of at 0.7 or more. Of course, what is most important is the barriers ability to absorb sound in the engine exhaust note range of 200 to 400 Hz. Two concrete-based sound absorptive noise barrier products are available that provide average sound absorptive coefficients in the range of 0.7 to 0.1: The Durisol NB24 Panel System by Armtec and SoundSorb by Concrete Solutions Inc. (a sound absorbing cementitious material which can be applied to solid concrete panels/barriers).

How will Reductions in Circuit Noise Levels be Perceived?

As previously discussed, it typically takes about a 10 dB reduction in the level of a given noise for people to judge (or perceive) that the sound is now half as loud as it used to be. The following list shows the typical perceived loudness reduction associated with various sound level reductions:

- 1 dBA reduction in sound level ≈ 7% reduction in perceived loudness,
- 3 dBA reduction in sound level ≈ 19% reduction in perceived loudness,
- 5 dBA reduction in sound level ≈ 30% reduction in perceived loudness,
- 7 dBA reduction in sound level ≈ 39% reduction in perceived loudness,
- 10 dBA reduction in sound level ≈ 50% reduction in perceived loudness (1/2 as loud)

It is generally considered to take a reduction in noise levels (typically expressed as average noise levels, or L_{eq}) of approximately 5 dBA for a community to clearly notice the change and to potentially alter their level of response (e.g. expressed annoyance) to the noise. Smaller reductions (1 to 3 dBA) are generally only clearly noticeable if an immediate A to B comparison is provided. Therefore, a reasonable objective for the further reduction of noise emissions from VIMC through a combination of operational and physical control measures would be in the range of 5 to 10 dBA.

We trust this has provided you with the information you require at this time. Please let us know if you have any questions regarding the information presented in this report or if you would like to pursue any of the noise mitigation options that were discussed.

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