Locomotive Horn Effectiveness at Operating Speeds

Gordon W. English and Thomas N. Moore

One aspect of a study undertaken for Transport Canada—as a component of the joint government- and industry-funded Direction 2006 Highway–Railway Grade Crossing Research Program—is addressed. The study's objective was to provide recommendations to ensure adequate warning for safety reasons and to address excessive loudness complaints from crews and from residents near tracks. A description is given of the field measurements and analyses undertaken to assess the influence of horn position on the effectiveness of the horn at operating speeds; an in-service assessment of alternative horns is also presented. Conclusions and recommendations are made to reposition horns in new-build locomotives and to add emergency-only or two-level horns at the front of some models of existing locomotives.

On July 12, 1996, a VIA Rail passenger train struck and fatally injured a pedestrian in the town of Tecumseh, Ontario, Canada. The Transportation Safety Board of Canada (TSB) investigated this occurrence and presented its findings and the factors that contributed to this accident (*1*). TSB concluded that, in addition to numerous contributing factors, the sound of the approaching train's locomotive horn did not become audible in time for the pedestrian to localize its source, decide on a course of action, and execute the action to avoid the oncoming train. Although the locomotive horn was tested and exceeded the recommended output of 96 dB, measured at 30.5 m in front of the stationary locomotive, TSB raised the following safety concern: "It is also noted that the frequency of the horn evolved from the requirement to sound similar to a steam whistle and that the horn placement has been dictated by crew considerations. The board is concerned that the lack of a comprehensive approach toward the requirements of the locomotive horn has compromised its effectiveness as an adequate warning device."

This paper is derived from one component of a large study of locomotive horn effectiveness (*2*). The objectives of the full study were to "study horn placement on locomotives and emitted sound, and provide recommendations to ensure adequate warning for safety reasons while also addressing excessive loudness complaints from crews and residents near tracks." This paper's focus is on the influence of train speed and horn position on its effectiveness. Readers with an interest in other aspects (alerting characteristics, signal detection, community noise, and in-cab noise exposure constraints) are referred to the full report.

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TEST SITES AND PROCEDURES

A major focus of this project was to characterize the output of a range of horn types (three- and five-flute air horns) and positions (front, midcenter, midside, rear-of-center) as well as to determine the influence of train speed on their output. To accomplish both goals with a minimum of disruption, pass-by sound-level measurements of revenue trains (freight, commuter, and intercity passenger) were undertaken. The advantage of revenue service testing is that the actual field conditions are captured exactly as they would be experienced in the intended application. The principal objective in the selection of revenue service tests (other than the reduced cost and disruption effects) was to characterize the influence of train speed on output performance. Comparisons have been made of the warning effectiveness of approaching trains for a wide range of horn types and positions at train speeds ranging from 15 to 145 km/h. These comparisons represent a direct measure of the actual field experience, many occurring within minutes of each other under the same environmental conditions.

"As-received" signals represent the most realistic and accurate representation of a locomotive horn's alerting performance because they measure what would be heard at the crossing location. Nonetheless, it is not a measurement on which a standard can be based. Most characterizations of locomotive horns are based on the present industry recommended standard, which is based on a stationary measurement made at 30.5 m. The Volpe Center has conducted a number of stationary tests on the influence of horn position on its effectiveness (*3, 4*). Some static measurements were taken to characterize the spectral content of individual horns and a number of combination horns. With the exception of a front-mounted, three-flute horn, results similar to the Volpe Center's measurements were obtained. The low-speed measurements also showed general agreement with the static tests conducted by the Volpe Center. However, it was found that train speed has a significant influence on the forward projection of some horn positions.

Because of the dominance of 30.5-m reference data, the recorded signals were further analyzed to estimate the characteristics of the source signal as it would be measured at the standard's reference distance of 30.5 m. Several grade-crossing locations were used to measure the output of horns under revenue service conditions. One of the best sites for a wide range of locomotive horn positions and train speeds was South Blair crossing of the CN and parallel GO Transit lines in Whitby, Ontario, Canada. The approach geometry is such that the initial sounding of the horn occurs at shallow horn angles (about 15° to 20°), while the last blow occurs at 65° for westbound trains and 150° for eastbound trains.

Measurements were made using a number of different Bruel and Kjaer (B&K) Type 1 sound-level meters (B&K 2239, B&K 2231, or

B&K 2209), with calibration checks using B&K 4230 or Quest 12-M calibrators (94 dB, 1 kHz). Outdoor measurements used B&K UA-0237 windscreens on the microphones. The signals were recorded on either a B&K 7006 reel fm tape recorder, or a TEAC R61D fm cassette recorder. Digitization and spectral analyses were done at sample frequencies ranging from 12 to 48 kHz using 16-bit digital signal processing hardware (either Siglab 20-42, Keithley-DAS-1600, or CS-4297A). Train speed was measured with a Kustom HRS handheld radar gun; wind, temperature, and humidity conditions were measured with a Kestrel 3000 weather meter.

AS-RECEIVED SIGNAL COMPARISON

Total-Energy Sound-Level Comparison

In this subsection the full spectrum sound pressure level (SPL) as recorded at the measurement location is compared for several different horn locations and train speeds. Representative measurements are also presented. Figure 1 shows the horn-sounding sequence (two long blasts, one short, and one more long) of GO Transit five-flute horns mounted in two different positions on trains approaching the South Blair crossing.

The sound level, as measured at a point 70 m north of the grade crossing, is shown on the vertical axis, and the distance between the train front and the sound-level meter at the corresponding sound-level measurement is shown on the horizontal axis. A measurement was taken every 0.5 s. The top solid line is a reference line showing the theoretical falloff of 6 dB per distance doubling, referenced at 110 dB at 30.5 m (100 ft). The dashed line plots the sound output of the westbound GO Transit commuter train traveling at 90 km/h with a five-flute horn mounted at the top front edge of the cab roof. The horn sequence was initiated late (inside the normal 400-m whistle post). The horn produced an output in proximity to the reference line over its full pattern (representing output at a 20° horn angle at first and increasing to 60° at the end).

The solid line is the SPL measurement of an eastbound GO Transit commuter train traveling at 60 km/h with a five-flute horn mounted midlocomotive behind the exhaust duct of an F59 locomotive. Because of the 60° angle geometry at the crossing, eastbound trains pass a point perpendicular to the sound-level meter before reaching the crossing. The last horn blast of the eastbound train occurs close to the perpendicular point (shortest distance to the sound-level meter). There are several measurements plotted over a track distance that involves very little change in distance to the sound-level meter. The train then moves farther away from the sound-level meter as the horn continues to blow. The horn output is considerably below the 110-dB reference line at the initial shallow angles of output (about 15°) and attains the reference line before and after the perpendicular point is reached. Thus, the solid line turns back on itself, whereas the dashed line does not.

Spectrogram Comparison

A total energy SPL number has analytic advantages for some comparisons but does not provide a good illustration of the complex warning mechanism involved. Spectrograms are used to visually illustrate and compare three warning signals, as shown in Figure 2. The vertical axis is the frequency component of the signal going from 200 Hz at the top to 5,000 Hz at the bottom in steps of 11 Hz. The horizontal axis is the time scale, adjusted to cover the sounding pattern of the horn in its approach to a grade crossing. A spectral slice is measured every 85 ms. The third dimension of the plot is the sound level of the received signal as indicated by color variation. The color scale starts with purple at 47 dB and proceeds with increasing sound level through blue, green, yellow, and orange to red at 95 dB. The printed paper is not in color. Some guidance to the gray scale is provided in the figure. The colored figure can be seen at www.transys.ca, or the full report can be downloaded from www.tc.gc.ca/tdc/publication/listing.htm (*2*).

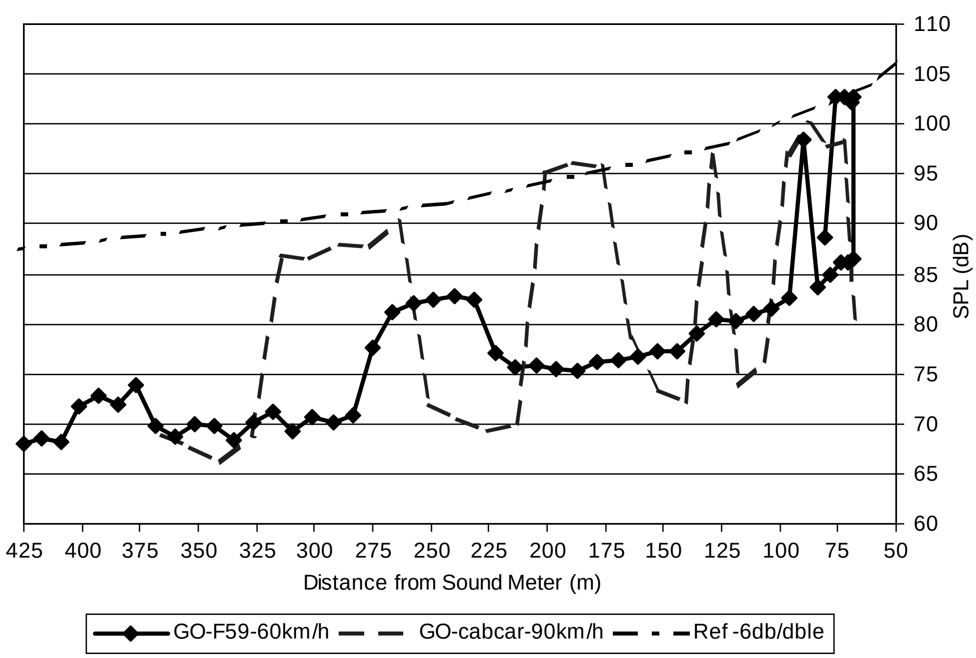

FIGURE 1 Comparison of sound pressure levels of five-flute horns.

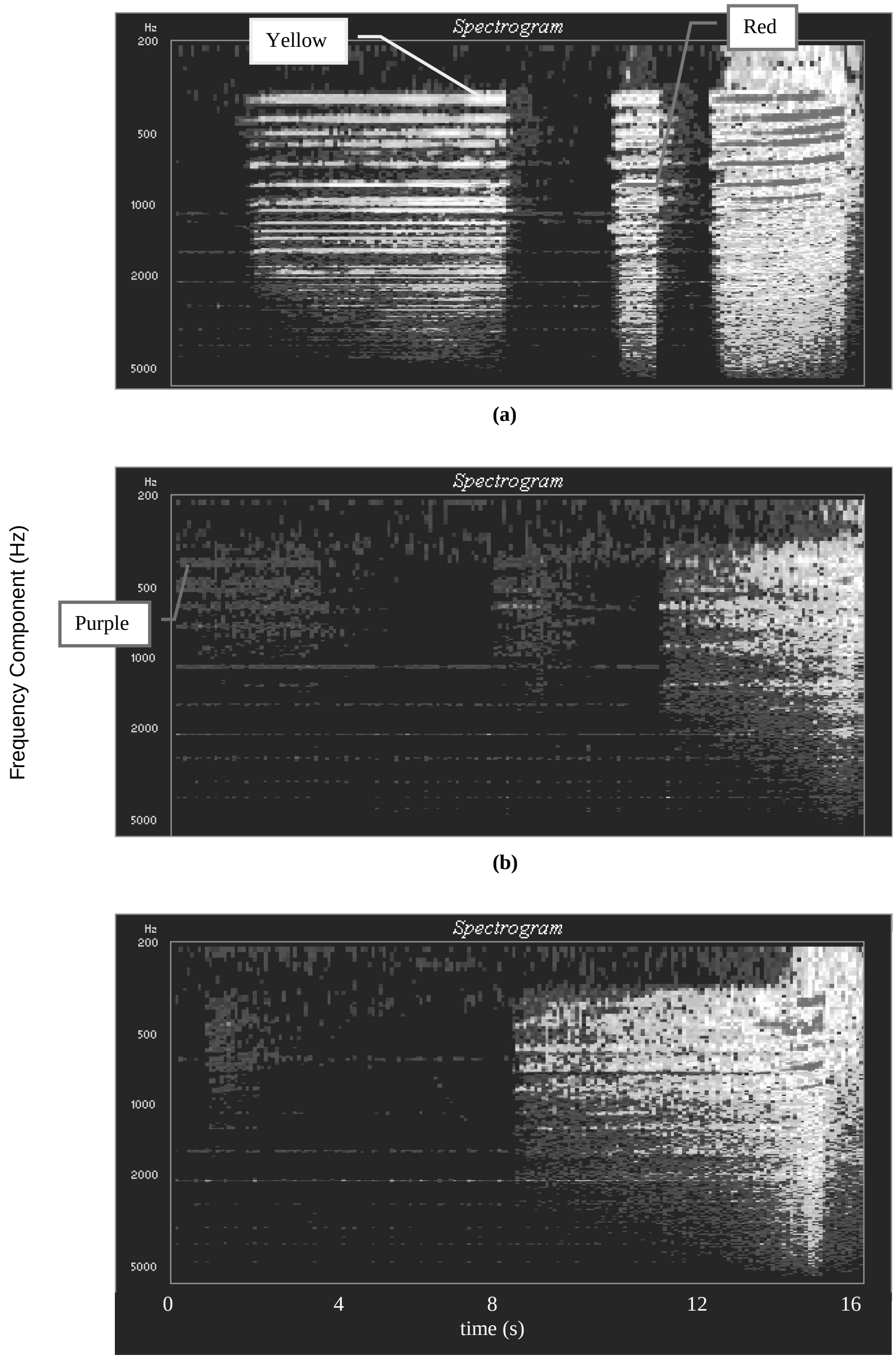

FIGURE 2 Spectrograms of five-flute horns: (*a*) front (121 km/h), (*b*) midlocomotive (behind exhaust hood) (127 km/h), and (*c*) midlocomotive (behind exhaust hood) (97 km/h).

The elimination of sound below 47 dB combined with the absence of signal content below 200 Hz removes much of the train-source background noise from the chart. The spectrograms offer some insight into the detectability and urgency of the various horn signals. The colors can be roughly interpreted as follows:

- Purple represents the onset of audibility to a pedestrian in an outdoor low-noise environment,
- Yellow represents the onset of alerting inside an automobile with low internal noise levels,
- Orange has a good chance of being detected inside a noisy automobile and being alerting inside a quiet vehicle, and
- Red would be alerting for many in-vehicle situations.

Figure 2 compares the 16-s approach spectrogram of a five-flute horn at 121 km/h when mounted at the front (Figure 2*a*) with those of midlocomotive positions at 127 km/h (Figure 2*b*) and 97 km/h (Figure 2*c*). The midlocomotive horns were audible at 15 s out, but the intensity and clarity are well below that of the up-front horn, even though the 97-km/h midlocomotive horn was closer at 15 s than was the up-front horn on the 121 km/h train.

The broken lines shown between 1,000 and 5,000 Hz of the lower left and upper right spectrograms are from the sound of the crossing bell that is heard in these measurements. Looking at the two midlocomotive horn's spectrograms and applying the color scale interpretation above, it can be seen that

- Early horn soundings were audible only intermittently and were subjectively assessed by test personnel to lack clarity and
- The horn would not be detectable inside a quiet automobile (yellow color) before the 127-km/h train is about 1 s from the crossing and the 97-km/h train is 5 s from the crossing.

DERIVED SOURCE-SIGNAL POLAR PLOTS

Procedure

The same measured data used above have been analyzed further to estimate the equivalent performance of the horn at a 30.5-m distance. The use of revenue service trains in this way introduces a number of undesirable factors that increase the uncertainty of the derived source characteristics. Although the primary influencing factors have been measured and incorporated into the analyses and data reduction activity to minimize the uncertainty, the findings will contain a larger uncertainty band than would be realized with controlled stationary tests. The principal items of uncertainty as well as the mitigating measures taken are each discussed briefly below.

Train-Speed Variation

Train speed was measured with radar, and acceleration performance was included in position calculations where relevant.

Varying Whistle Patterns

The position at which the horn stopped blowing was noted (relative to the crossing exit) and, in combination with speed measurements, distance versus time data were provided.

Grade-Crossing Geometry

Most grade crossings were selected for straight track approaches. A 1° curve was present at two sites and was accommodated in the distance and angle calculations.

Frequency-Dependent Ground Effects

Ground effects can be very complex. Because the main interest is the received signal rather than deriving the originating signal, ground effects were ignored from both the derivation of source characteristic and the attenuation in later applications to needs–effectiveness comparisons. The full study dealt with ground effects to assess the relative influence of varying mounting heights of the horn (*2*). The simplified case of someone in front of the train under conditions of flat and open terrain was considered. An assessment was done of the ground effects of different mounting heights on the warning signal received by a pedestrian or trespasser on the track in front of a locomotive using the community noise model of the University of Central Florida (*5*). The ground effect routine used in the model, which is based on the implementation of Rudnick's algorithm (*6*), gave reasonable correlation with field measurements made by the Volpe Center (*7*).

Temperature Inversion Effects

Temperature inversion effects are also complex, and thermal gradients are difficult to measure. Most measurements were undertaken at midday to minimize the magnitude of thermal gradients. An effort was also made to measure more than one horn location during each test interval to ensure that relative performance measures were consistent. Geometry and environmental factors are discussed in more detail in the section on weather and geometry influences.

Low Signal-to-Noise Ratio Levels

One-third-octave data were used to isolate the horn spectrum from the train's background noise, which was dominated by engine noise below 300 Hz—the higher frequency wheel-rail noise was more than 10 dB lower than the horn SPL. In general, an effort was made to avoid situations such as the passing of highway trucks where background noise was high in the horn spectrum. Most measurements in which coincident spectral noise was a significant factor were eliminated. However, there were a few situations in which either there were no other data measurements of a specific locomotive–speed combination or the horn signal was always very low. In cases in which the ⅓-octave band signal-to-noise ratio was less than 5 dB, the horn signal was derived by subtracting the measured background noise as follows:

$$S = 10 \times \log\left[10^{(M/10)} - 10^{(B/10)}\right]$$

where

S = horn signal SPL (dB),
M = measured SPL (dB), and
B = average measured background noise in the absence of a horn signal (dB).

The measured ⅓-octave-band horn signal was then converted to a standard 30.5-m reference SPL by adjusting for signal attenuation at 20 times the logarithm of the distance ratio.

Frequency-Dependent Absorption

Atmospheric absorption effects were included with ANSI-1.26-1978 calculations (*8*). The atmospheric absorption calculations are most sensitive to temperature and humidity and have a significant influence in the 3-to-5-kHz range of the horn spectrum. However, because the horn SPL is dominated by the frequency components in the 600-to-1,200-Hz range, the influence on the cumulative SPL of the horn was in general less than 2 dB.

Each data point derived in this way occurred at a specific time in the approach sequence. The distance between the horn and the sound-level meter, and the corresponding angle of output for the horn relative to its direction of travel, were calculated on the basis of the grade-crossing geometry and measured train speed. The result is an estimate of the polar output of the horn at a reference distance of 30.48 m.

Longitudinal Position Influence

It was possible to measure a wide range of horn positions. The focus was on passenger locomotive horns; however, a limited number of freight locomotive horns were measured to see whether the same sensitivities held. The GO Transit cab cars and one GO Transit locomotive had a five-flute horn at the front top corner of the crew cab's windscreen. The VIA Rail locomotive [a light rapid comfortable train system (LRC), which was only operational for a few months early in the study] had a three-flute horn on the cab roof roughly 1 m back from the front edge of the roof. Its roofline was flat, and the front edge of the roofline was rounded. The GO Transit-F59 locomotives, VIA Rail-F40 locomotives, and GP9 freight locomotives all had the horn mounted behind and close to the engine exhaust hood (five-fluted for GO Transit and three-fluted for VIA passenger and the GP9 freight locomotives). Many of these had air-conditioning equipment mounted on the cab roof in front of the exhaust. The newer VIA Rail Genesis locomotives had a five-flute horn on the right side of center and recessed in a well that partially shielded some of the horn flutes. The roofline was otherwise smooth in front of the well. The SD40 freight locomotives had a three-flute horn on the left side of the locomotive (one at 8.7 m and the other at 12.2 m back from the front of the locomotive). West Coast Express had newer F59 locomotives with a five-flute horn fully recessed in a well and behind the engine exhaust. The Dash 9 freight locomotives had a three-flute horn in a well, at a midlocomotive position but ahead of the engine exhaust. The SD70 freight locomotives had a three-flute horn in a well and behind the exhaust but much farther back from the well face than in the other locomotives.

The polar output for a range of speed and horn positions is presented in this subsection. The polar plots illustrated are valid for the speed at which they were measured. Train speed influences the horn's effective forward output in a nonlinear relationship as is discussed in the subsection on longitudinal position influence.

Figure 3 illustrates the loss of output in the forward direction for several three-flute horn positions. Figure 3*a* presents the polar plots of two types of passenger locomotives at high speed (nominal 145 km/h). The F40 locomotives have the horn mounted behind the exhaust hood; the LRC's horn is mounted on the cab roof. The plots present the 30.5-m equivalent output of the horn for increasing

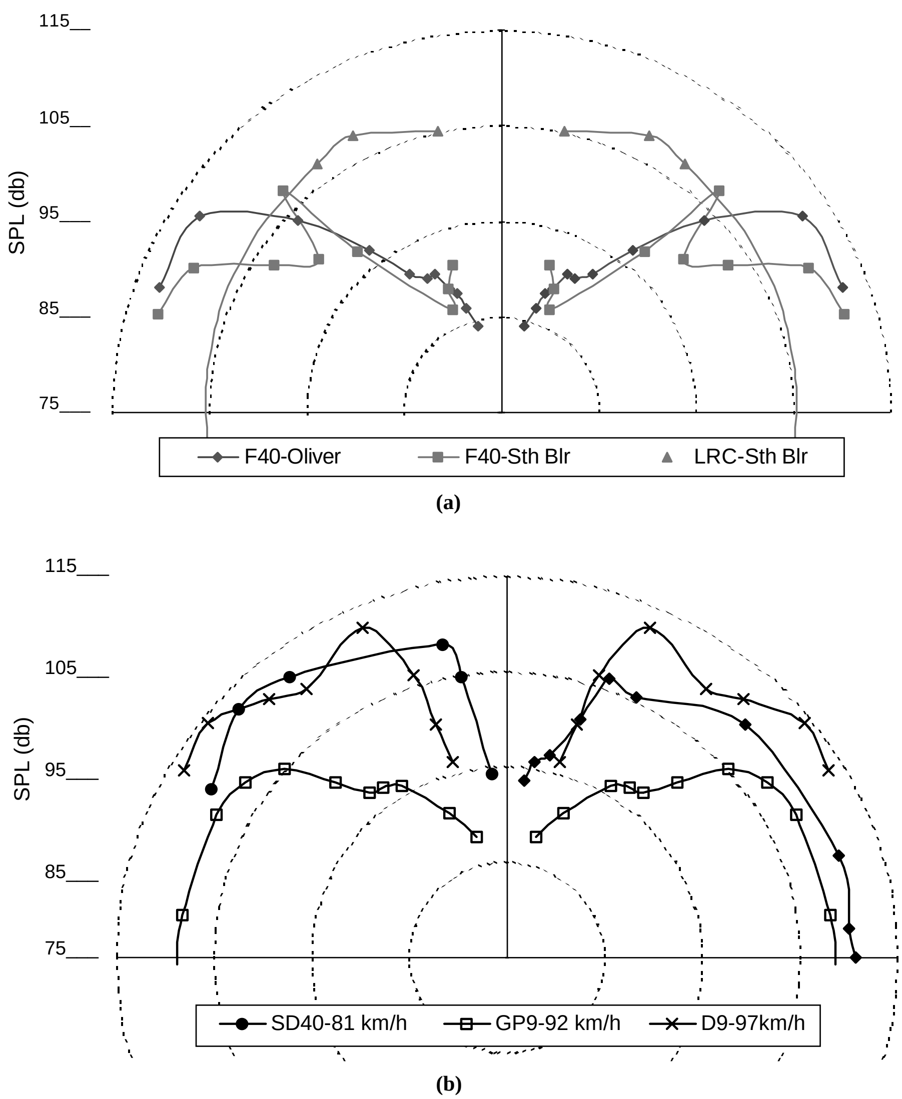

FIGURE 3 Three-flute horn polar plots: (*a*) passenger horns' directional output at 145 km/h and (*b*) freight horns' directional output.

angles from the forward direction. Two different F40 locomotives at two different test locations are illustrated in the plot. The nominal speed is 145 km/h (actual speeds were 144 km/h at South Blair grade crossing and 148 km/h at Oliver grade crossing). The measurements were made on one side only, and symmetry is assumed for the center-mounted horn. The characteristic is such that the forward output is well below the minimum recommended standard, and full output of the horn is not realized until ±40-degree angles from forward. The LRC's characteristic was measured at South Blair grade crossing at 147 km/h (and decelerating). VIA Rail replaced the LRC locomotive with newer Genesis locomotives early into the study and, thus, it was not possible to obtain a wide range of LRC measurements.

Figure 3*b* presents the polar plots of a number of different freight locomotives that use three-flute horns. It can be seen that the GP9 locomotive, which has a horn placement similar to that of the F40 and F59PH locomotives, produces a similar result. The other freight locomotives have a steeper rise in output with increasing angle. The SD40, which has the horn mounted on the left side of the locomotive, is seen to have a reduced effectiveness at shallow angles on that side of the locomotive, even though there is a direct line of sight from horn to sound-level meter. That is consistent with findings for five-flute horns of passenger locomotives.

Speed Influence

There was enough range in speeds for most horn positions to infer an influence of train speed on the horn's sound output. Output was not significantly changed for horns mounted at the front of the locomotive (or other lead vehicle). However, the sound output to the front of the locomotive deteriorated with increasing speed for all horns tested in locations back from the front of the locomotive. Because this study is dependent on revenue train testing, it was not possible to obtain all of the data points for all horn combinations. The most complete set was for the passenger trains, which were the only trains to exceed 97 km/h in the tests. Nonetheless, all midlocomotive horn positions showed decreases to the front that were larger than reported in the literature for static testing, and are consistent with the fuller data set obtained for the passenger locomotives.

The sound loss characteristic as a function of speed is illustrated in Figure 4 for GO Transit's F59 locomotive (five-flute horn, behind exhaust). The loss characteristic is such that a leveling off is achieved for speeds between 45 and 100 km/h and then it continues to decrease with increasing speed beyond 100 km/h. The loss characteristic is derived from revenue train testing at different locations and different times and does not reflect the accuracy of experimental design and controlled conditions. Nonetheless, it is representative of the losses seen in multiple locomotives across several locations. It also fits with the controlled test measurements reported by Labour Canada for the side-mounted horn used in its tests for the measurement distance range 50 m to 400 m (*9*). Labour Canada found that the SPLs for the locomotive approaching at 67 km/h were all lower than the SPLs measured over the same distance range for a stationary locomotive.

It is thought that Figure 4 is a reasonable characterization of the influence of speed on horns that are located behind and close to the exhaust stack. The loss of output is accentuated when the horn is located behind the engine exhaust, but also appears to be related to the air turbulence produced by roof-mounted equipment or abrupt changes in the roofline. Attenuation due to normal wind turbulence has been documented (*10*). The loss is only in the forward direction. Output to the side is unaffected (and possibly amplified at some lateral angles) by the midlocomotive positioning.

The loss to the front that was illustrated in the polar plots of the SD40 locomotive (Figure 3) indicates that there is an impact even when there is a clear line of sight between source and receiver. The horn suffers a loss of output at shallow angles from the side of the locomotive on which it was mounted.

In one of the alternatives assessed (involving VIA Rail's Genesis locomotive) the existing horn was elevated above the roofline and the outer high-frequency flutes were further elevated to obtain the most clearance for the most easily deflected frequency components. The horn position (relative to the roofline) of the existing horn and the position of the elevated horn are illustrated in Figure 5. The horn is situated on the left side of the locomotive, about 10 m back from the front end. This elevation was thought to be sufficient because the Genesis locomotive has a streamlined roof and the amount of elevation available within VIA Rail's clearance envelope was enough to provide a line-of-sight path for the horn's emitted sound at most required warning distances.

Raising the Genesis's horn did not achieve as significant an improvement as expected. There was an improvement in loudness, a reduced sensitivity to wind conditions, and a significant improvement in higher-frequency content at high train speeds. However, the SPL output to the front of the locomotive was not significantly improved.

Figure 6 summarizes the influence of train speed and horn height on the horn's warning characteristics at about 4-s warning for the

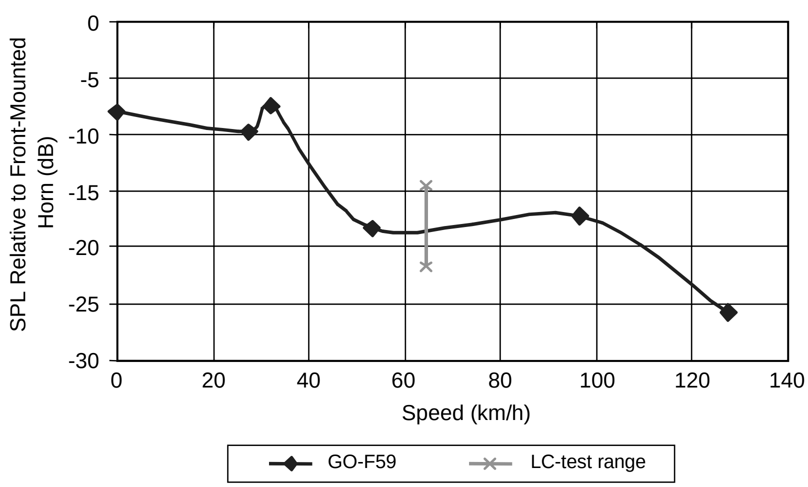

FIGURE 4 Speed influence on forward output sound attenuation.

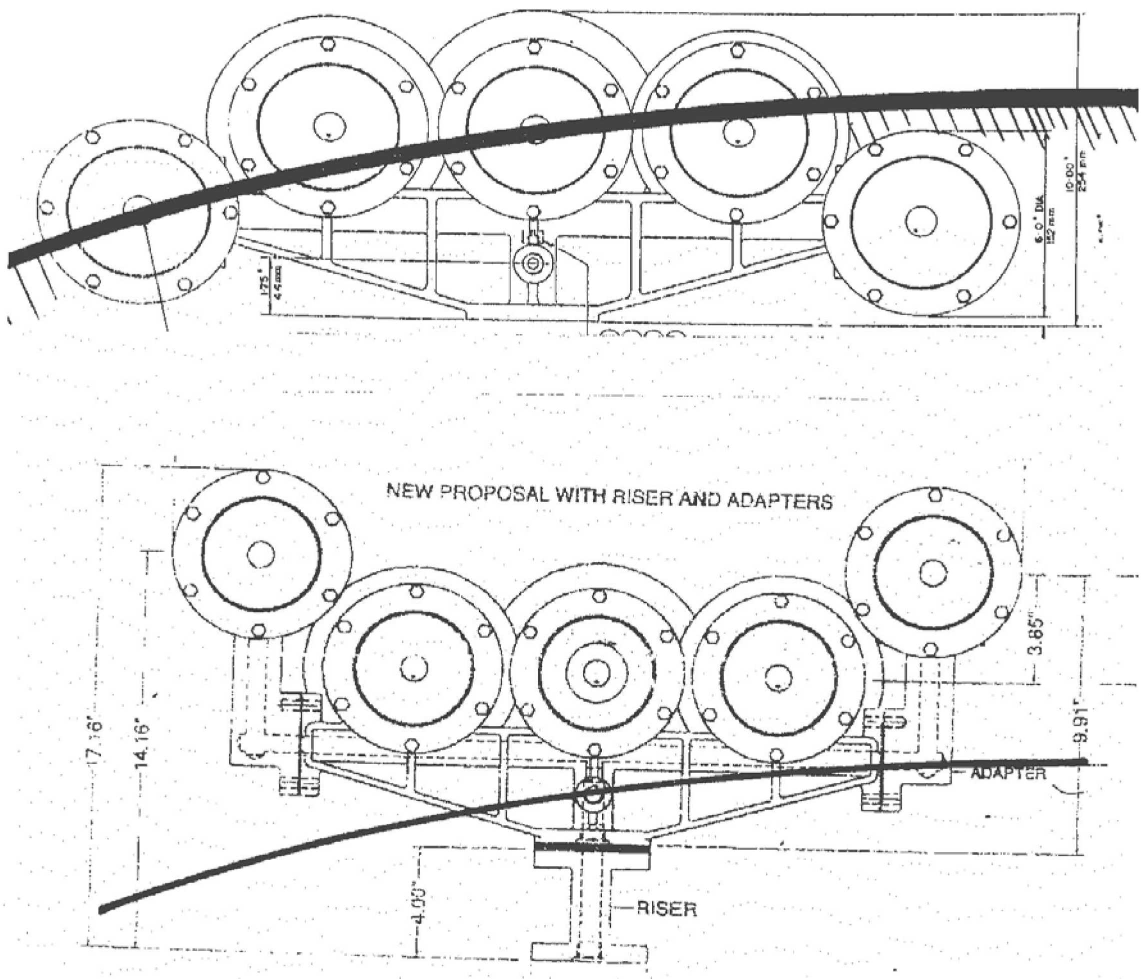

FIGURE 5 Illustration of Genesis horn modification.

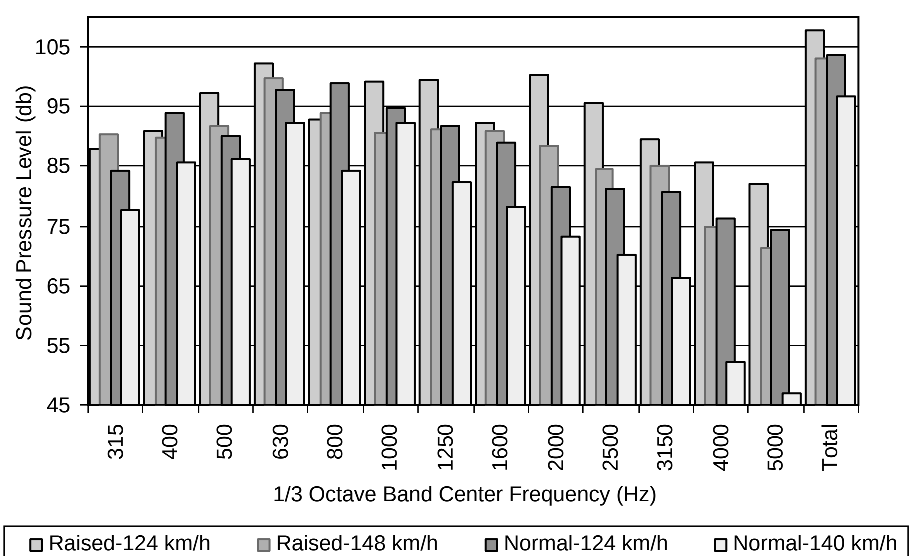

FIGURE 6 Genesis locomotive horn height–speed influence.

Genesis locomotive horns in comparison with a front-mounted horn. The selection of a 4-s reference point has no particular meaning but was dictated by the data—all of the different trains were blowing their horns at this time interval from the grade crossing.

The total SPL bars at the right side of Figure 6 indicate that the full-spectrum SPL is improved only by 6 dB with raising the horn (and is still 8 dB below that measured at a different location for a front-mounted horn at the same speed). On the other hand, the higher-frequency content is significantly affected. Looking at the 4,000 Hz ⅓-octave band, it can be seen that the raised horn at 148 km/h has a 25-dB higher sound level than the unraised horn at 140 km/h. Laboratory tests on alerting characteristics that were conducted in the full study but are not presented here indicate that the increased higher-frequency components would improve the horn's alerting characteristics (*2*).

It is presumed that, in addition to turbulence, there might be a diffraction impact from the effective wind gradient set up by the locomotive body moving through air. Headwind gradients are known to bend sound upward in a mechanism known as refraction (*11*). The effective air-speed gradient seen by the propagating sound along the locomotive body will increase in speed the farther it moves away from the body (see Figure 7). The horn sound could be bent away from the body through this sound refraction mechanism.

It would be expected that both turbulence and refraction would be mitigated with smoother roof surfaces and increasing mounting height of the horn. However, the raised horn SPL measures indicate that there is an impact even when the horn is mounted such that there is a clear line-of-sight path from horn to receiver.

WEATHER AND GEOMETRY INFLUENCES

The revenue tests were conducted to purposely avoid conditions of high wind. An indication of the average signal was obtained by testing in low-wind conditions. It is known that wind and temperature gradients will bend sound paths much as a glass refracts light rays. Thus, the polar plots generated from low-wind conditions would display a wider variation in different wind (and possibly temperature) conditions. Horns that are positioned behind protrusions (or other shielding influences) are more significantly influenced by wind conditions. The Genesis horn, which was the midlocomotive horn with the least amount of shielding, can be expected to be most sensitive to wind and temperature effects, but all shielded horn positions will exhibit sensitivity to wind.

Figure 8 illustrates the influence of tests done within 15 min of each other, under wind conditions that averaged 13 km/h (at ground level) with gusts to 19 km/h. The test conditions were outside this study's test criteria. Nonetheless, the measurements offer insight into the effects of wind and wind gradient. The wind was blowing along the track, such that an eastbound train had a tailwind condition and a westbound train had a headwind condition. The impact of the wind is significant, producing a 20-dB difference between train

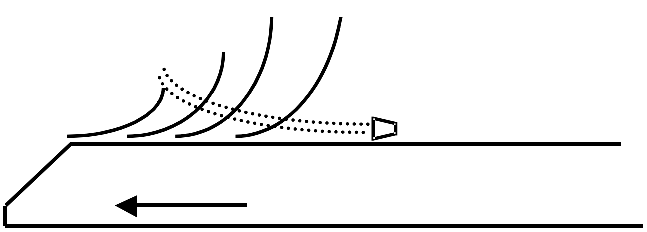

FIGURE 7 Illustration of horn sound refraction.

directions at the shallowest measurement angle. In the same way, lateral winds can be expected to either reduce or exacerbate the angle at which full output is attained in polar plots. Consequently, situations in which the midlocomotive horns perform either better or worse than this study's low-wind measurements indicate can be expected. Nonetheless, these influences are not as significant for front-mounted horns, for which there is a direct path for the sound. Those locations that require an indirect path for the sound will exhibit the most sensitivity to wind conditions.

Similarly, the geometry of approach roads will have an influence. This study's measurements were all made at a height of 1.5 m above the road surface, which in most cases presented a height of 0.5 to 2 m above top-of-rail. An elevated approach road could avoid the shielding effect of roof wells on midbody locomotive horn positions, while an elevated track would exacerbate the shielding effect. The former has been demonstrated in stationary tests with a sound-level meter mounted on a 4.9-m-high pole (*12*). Just as with wind conditions, there will be geometric conditions under which a midlocomotive horn will be more effective than this study's site measurements indicate. However, such scenarios will be in the minority, and there will be an equal number of scenarios that are worse than the average conditions presented here.

The tailwind condition depicted in Figure 8 might offer additional insight into the refraction mechanics affecting the sound of the horn. When the locomotive moves closer, the angle of refraction is not enough to bend the sound down to the sound-level meter. The farther away the locomotive, the higher the SPL (30.5-m equivalent) reaching the sound-level meter, to the extent that on its first sounding (at about 400 m) the horn is operating at 110 dB. The actual wind gradient was not known; however, it is possible that the gradient associated with the 13-km/h ground wind speed required 400 m to bend the sound path down enough to counteract the 145-km/h aerodynamic wind gradient acting over the 10 m of locomotive body length that the sound initially travels. It is expected that any scattering effects of turbulence would be similar for both the headwind and the tailwind conditions.

The front-mounted horn avoids locomotive-body-induced screening, air turbulence, and refraction influences. Avoiding these influences with midlocomotive horn positions requires elevation of the horn. It is noted that the increased line clearances generated on many mainline railways to accommodate double-stack containers and trilevel auto-rack cars might allow elevation of midlocomotive horns to a height at which they can realize a warning effectiveness comparable with front-mounted horns. The effectiveness was assessed of raising the horns of a VIA Rail Genesis locomotive above the well in which it normally sits, and some improvement was attained. It was not possible to conduct tests to determine the necessary height to achieve the performance of a front-mounted horn fully.

CONCLUSIONS AND RECOMMENDATIONS

It was found that a horn's location on the locomotive is extremely important to its effectiveness at operating speeds. The sound output to the front of the locomotive (and particularly that of the higher-frequency components) deteriorates with increasing train speed if the horn is not mounted at the front of the locomotive. As a consequence, front-mounted horns were found to be more effective than those mounted in other locations.

Implementing changes in future-generation locomotives is much easier than in existing locomotives. In particular, newer locomotives have been shown to better attenuate the horn noise, helping to mitigate the key concern with in-cab noise levels (*7*). Thus, the same find-

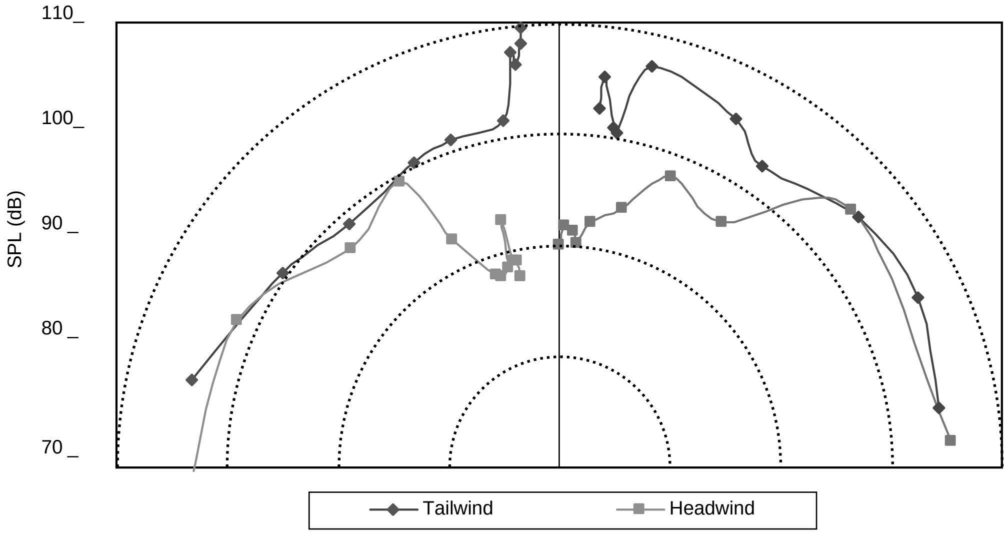

FIGURE 8 Wind sensitivity of Genesis locomotive horn; trains traveling at 153 km/h in ambient wind conditions of 13 km/h.

ing can lead to different recommendations for new-build locomotives than for existing locomotives.

It is recommended that all new locomotives be built with horns located at the front of the locomotive. In the event that a locomotive's horn is not positioned at the front of the locomotive, its effectiveness should be demonstrated at its highest operating speed.

Of existing midlocomotive horns, those mounted behind and close to the engine exhaust hood performed much worse than those mounted in other locations. It is believed that the reduction of warning area exhibited by horns positioned behind and close to the engine exhaust hood is large enough that action is required.

It is recommended that existing mainline locomotives with a horn positioned behind and close to the engine exhaust hood either have the horn moved to the front or have an alternative emergency horn added at the front of the locomotive.

Repositioning the horn on older locomotives would exceed noise regulations unless other noise mitigation measures are taken. The full report found that hearing protectors are effective in fully resolving the noise concern (*2*). Also, adding an emergency-only horn at the front would meet the 8-h time averaged noise exposure regulations without requiring additional noise mitigation measures.

Other midlocomotive horn positions, while not as effective as the up-front horn position, did perform better than those positioned behind and close to the exhaust. No alternative position was found that provided as effective a warning device as one mounted at the front of the locomotive.

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