NOISE OUTPUT OF ROAD RACING MOTORCYCLES FROM MEASURED L_{eq} DATA

A.K. Mitchell[1]
[1]*School of Engineering, Acadia University, Wolfville, Nova Scotia, Canada*
[Andrew.Mitchell@acadiau.ca]

ABSTRACT

This paper reports the results of an experimental study of the noise output from road racing motorcycles competing in the Canadian Superbike race series. L_{eq} data from single-point measurements are presented for five events, which are then analyzed to determine an energy average noise output per competitor at each event. The analysis, which considers track geometry and total time spent on track by all competitors, seems to indicate a moderately rising trend in the noise output per participant over time that is attributed to the changing composition of the field. The single-number noise descriptor obtained is suggested as a useful tool for predicting noise levels at future events at this or other venues.

RÉSUMÉ

Cet article présente les résultats d'une étude expérimentale sur le bruit des motocyclettes de courses de la série «Canadian Superbike». Les valeurs L_{eq} enregistrées en un seul point pour les cinq courses sont présentées et sont ensuite analysée afin de déterminer une moyenne énergétique du bruit produit par chaque concurrent pour chaque évènement. L'analyse, qui comprend la géométrie de la piste et le temps passé par chaque concurrent sur la piste, semble indiquer une augmentation du niveau de bruit par concurrent au fil du temps. Ceci pourrait être attribué au changement de la composition du groupe de motocyclettes sur la piste durant l'évènement. Le descripteur de niveau à chiffre unique pourrait être utilisé outil pour prédire le niveau de bruit aux courses à l'avenir à cet endroit ou sur d'autres pistes de course.

1. INTRODUCTION

Road racing is a form of motorsport that sometimes produces noise annoying to those living nearby. This noise is often variable in level and intermittent, making it difficult to quantify with a single measurement. The courses used for competition are often several kilometers in length and cover significant geographical areas, which can also make it difficult to predict and/or monitor noise exposure at every potentially sensitive receiving location. Reference [1] describes some of the noise-related problems recently encountered at one prominent Canadian road racing site. Other venues have faced similar issues.

As part of an ongoing noise monitoring program, Atlantic Motorsport Park (a 2.56 km road racing facility located near Halifax, N.S.) has been recording A-weighted L_{eq} noise data at Canadian Superbike race series events held there since 2008. The equivalent continuous sound pressure level L_{eq} is a common measure used to describe time varying noise. In A-weighted form it is thought to reliably indicate the onset of community annoyance problems, and is used as the basis for many widely accepted noise control standards [2]. Data was collected for five events, but meaningful comparisons of the noise levels obtained from year to year were impossible because of inconsistencies in the recording techniques used, the variable numbers of competitors contributing to each recording and the intermittent, unpredictable way the race programs unfolded during the monitoring periods.

An investigation was begun to assess trends from year to year and determine the effectiveness of noise control regulations in effect at the time of each competition. This paper is the result of that effort. It describes a way to extract an energy-average noise output per competitor at each event from the available data. The analysis is based on the actual pattern of usage observed on track during each monitoring period and seeks to determine the noise level that a corresponding number of ideal, constant-output, uniformly radiating moving noise sources would have to produce in order to match the observed L_{eq}. Although perhaps simplistic, this approach produces a single-number descriptor that is thought to be not only useful for comparing trends in the data from year to year but could also be used for other purposes such as making estimates of the noise impact of similar future events at this or other venues.

2. LITERATURE REVIEW

Several authors have explored ways to predict L_{eq}'s in the surrounding community resulting from motorsport noise, but none have attempted to determine information about the source from an observed result. In 1989 Dearden and Jennison [3] presented a technique for predicting levels near idealized circular and elliptical shaped race tracks with multiple moving sources. Also in 1989, Wilson [2] included an example community noise assessment of an imaginary go-kart track using a L_{eq} technique in his book. In 1997 Fillery and Thorpe [4] described how to estimate trackside L_{eq}'s for various types of car racing events from experimental pass-by measurements. And finally, Mitchell [5] in 2009 demonstrated how geomatics information for complex track shapes could be used to predict L_{eq}'s at surrounding arbitrary locations.

3. THEORY

Assume that every vehicle on a race track contributing to a measured L_{eq} can be represented as an identical point source, radiating sound uniformly in all directions at a constant level as it moves around the course. Neglecting directivity and shielding effects, a conservative (over) estimate of the instantaneous sound pressure level L from any one of these imaginary point sources at an arbitrary measurement location would be

$$L = L_0 + 10 \log\left(\frac{r_0^2}{r^2}\right)$$

Where L_0 is the level of the constant source measured at some known distance r_0 and r is the actual distance between source and the receiver. The L_{eq} is defined as

$$L_{eq} = 10 \log\frac{1}{T}\int_0^T \left(10^{L/10}\right) dt$$

Where T is the period over which the measurement is to be carried out, L is the level of the time-varying noise at the observation point and t is time. Combining the previous two expressions gives the following:

$$L_{eq} = 10 \log\frac{1}{T}\int_0^T \left(10^{L_0/10} * \frac{r_0^2}{r^2}\right) dt$$

Now introducing a summation to account for the possibility of m non-correlated sources contributing to the measured L_{eq} and recognizing that L_0 and r_0 are constant for all vehicles and with respect to time gives

$$L_{eq} = 10 \log\frac{1}{T}\sum_{i=1}^{m} 10^{L_0/10} * r_0^2 \int_0^T \frac{1}{{r_i}^2} dt$$

Assuming that each vehicle completes an integer number of laps of the track during the measurement period (a reasonable assumption in a racetrack scenario), the integral term on the right can be approximately evaluated by subdividing the path around the track into k sectors of equal time duration Δt_i each and using a summation, i.e.

$$\int_0^T \frac{1}{r_i^2}dt \cong \sum_{j=1}^{k} \frac{\Delta t_i}{r_j^2} = T_i * \frac{1}{k}\sum_{j=1}^{k}\frac{1}{r_j^2}$$

Where T_i is the total time on track for the i^th^ vehicle and the r_j's are the distances between the centers of the equal-time segments and the receiver. For simplicity, a new variable, r_{eff}, is defined as follows

$$\frac{1}{r_{eff}^2} = \frac{1}{k_j} = \frac{1}{k}\frac{1}{r_j^2} \qquad (1)$$

So that

$$\int_0^T \frac{1}{r_i^2}dt \cong \frac{T_i}{r_{eff}^2}$$

The L_{eq} expression then becomes

$$L_{eq} = 10\log\frac{1}{T}\sum_{i=1}^{m} T_i * 10^{L_0/10} * \frac{r_0^2}{r_{eff}^2}$$

The r_{eff} term just introduced can be thought of as a single number descriptor of the "effective" distance between the source and the receiver. It is a function of the shape of the track, placement of the microphone and the relative speed of a given vehicle as it moves around the track. Most vehicles on a race track would experience similar relative speed variations as they move around the course (and all follow essentially the same path), so it seems reasonable to assume that r_{eff} will be nearly constant from vehicle to vehicle. Taking r_{eff} as a constant, the L_{eq} expression can be written as

$$L_{eq} = 10\log\frac{r_0^2}{r_{eff}^2} * \frac{T_T}{T} * 10^{L_0/10}$$

Where T_T has replaced the summation of the individual T_i's and represents the total cumulative time that all vehicles spend on track during a measurement.

The previous expression may, for convenience, be separated into individual terms as follows:

$$L_{eq} = L_0 + 20\log\frac{r_0}{r_{eff}} + 10\log\frac{T_T}{T} \qquad (2)$$

Re-arranging Eq. (2) gives

$$L_0 = L_{eq} + 20\log\frac{r_{eff}}{r_0} + 10\log\frac{T}{T_T} \qquad (3)$$

which allows the sound pressure level L_o of the imaginary source proposed at the beginning of the derivation to be calculated from the observable data.

4. MEASUREMENTS

As mentioned in the introduction, L_{eq} results were obtained for five events in the Canadian Superbike series at Atlantic Motorsport Park. This is the premier motorcycle road racing series in Canada, crowning a national champion every year based on six to eight events held at venues across the country.

Fig. 1: Aerial view of Atlantic Motorsport Park.

A typical Superbike event consists of three days of practice, qualifying and racing for various classes of rider and machine. More on-track time is spent practicing than actually racing, which happens only on the final afternoon of an event. Some events are run as four day "doubleheaders" with racing on two consecutive afternoons, but this is unusual.

The series makes an annual visit to AMP, which is located about 60 km west of Halifax, Nova Scotia, Canada. An aerial view of the facility is shown in Figure 1. Sound levels were recorded for two events forming a "doubleheader" weekend on August 9-10 2008, a second double weekend on August 7-8 2010 and a single event August 7, 2011. No data was obtained in 2009 because of inclement weather.

Two different recording locations were used in obtaining the noise data, approximately located as shown in Figure 1. Measurement location A straddled a property line at the eastern end of the facility while location B was in a cleared infield area normally reserved for emergency medical helicopter landings. Both areas were off-limits to the public to prevent non-racing related noise from contaminating the measurements. Background noise at these locations due to external events (i.e. airplane flyovers, thunder, etc.) was insignificant compared to that generated by the motorsports activity during each measurement period. Location A was used for the two events held in 2008, after which data collection shifted to location B.

Measurements at both sites were made using a Larson-Davis model 712 integrating sound level meter, calibrated before use by a matching Larson-Davis CAL150 pistonphone calibrator. Data was collected in the form of a series of consecutive ½ hour duration L_{eq}'s each day using "A" weighting and the slow meter constant. A tripod held the microphone approximately 0.25 m above ground at each site and directed towards the nearest approach of the track surface. A hand-held GPS device was used to precisely determine the longitude and latitude of each measurement location for use in later calculations.

The results obtained each day are given in Table 1. Although recording generally began each day at 8:30 A.M. and continued until the end of on-track activity, values are only reported here for the afternoon sessions when racing was actually taking place.

Interval Start, P.M.	Aug. 9th, 2008	Aug. 10th, 2008	Aug. 7th, 2010	Aug 8th, 2010	Aug. 7th, 2011
1:00	69.2	70.6	79.5	77.6	76.3
1:30	53.1	61.9	71.1	73.6	64.6
2:00	72.3	73.3	74.2	73.4	73.1
2:30	62.3	68.9	76.1	70	76.2
3:00	70.4	67.5	76.6	74.9	77.1
3:30	66.5	66.1	77.5	69.4	76.9
4:00	65.7	73.1	66	76.4	78.4
4:30	72.2	61.3	72	72.2	-
5:00	67.6	72.3	73.9	74.9	-
5:30	69.4	-	-	-	-

Table 1. Recorded ½ hour L_{eq} data (dBA).

5. Calculations

Before the average output level L_o of the competitors on a given race afternoon could be calculated from Equation 3, it was necessary to determine the overall L_{eq} value and measurement time T for the particular day, the total cumulative time T_T spent on track by all competitors and the r_{eff} value for the microphone location used.

The overall time duration T for each measurement day was found by adding the time together for all intervals in Table 1 that have recorded data. The L_{eq} results were consolidated into a single overall L_{eq} for each day using the formula

$$L_{eq} = 10 \log\left(\frac{1}{n}\sum_{i=1}^{n} 10^{L_i/10}\right)$$

where L_i are the individual ½ hour L_{eq}'s recorded for the day and i is the total number of intervals used. Both sets of calculated values appear in Table 3.

T_T values for each event were calculated from published race results. Since no activity other than racing took place on the track on the afternoons studied, these provided an accurate record of all on-track activity during each measurement period. Table 2 shows a summary of lap data from the five afternoons studied. Total time on track T_T each day was calculated from this data by multiplying all of the laps run in each class on a given day by the representative lap time for that class listed in the table and summing the results. The calculated values are again listed in Table 3. The r_{eff} value at each of the measurement sites was determined using experimental data captured by a GPS data acquisition system mounted on a race motorcycle.

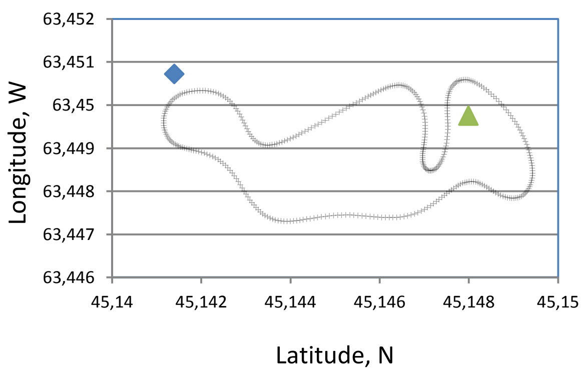

Figure 2. GPS data used to calculate r_{eff}.

This GPS system recorded five longitude and latitude position samples each second as it was carried around the track at speed. A 76 second s practice lap was used in the analysis, which gave 383 equally-time-spaced data point pairs outlining the track shape. The recorded position data was transferred to an excel spreadsheet, where it was used with the previously obtained positions of the microphone locations in Eq. (1) to calculate r_{eff} values for each site. Figure 2 graphically displays the GPS data used in calculations and the relative positions of the two recording locations (the diamond marker is at location A and the triangle marker is position B). These results are also given in Table 3.

6. RESULTS AND DISCUSSION

The final calculated L_o results for each event are listed at the bottom of Table 3 and are presented graphically in Figure 3. An arbitrary r_o value of 15.24 m was used in these calculations, primarily because this allowed an easy comparison with a previously obtained set of "pass by" measurements for similar motorcycles at that distance. The agreement between calculated L_o values for events on the same weekend is quite good, but there seems to be a trend towards increasing levels as time moves forward.

Race Class	Aug. 9th, 2008	Aug. 10th, 2008	Aug. 7th, 2010	Aug 8th, 2010	Aug. 7th, 2011	T_{lap}, sec.
Pro 600	211	251	269	239	136	70
Thunder	220	211	-	-	-	71
AM 600	262	288	251	278	166	73
Pro SBK	415	371	392	322	306	69
SV cup	99	113	84	77	-	74
AM SBK			166	155	-	73
CB 125			266	132	-	95
XR 1200			-	-	204	73

Table 2. Laps by class and event.

Calc'd Value	Aug. 9th, 2008	Aug. 10th, 2008	Aug. 7th, 2010	Aug 8th, 2010	Aug. 7th, 2011
L_{eq},dBA	68.89	70.03	75.44	74.31	76.00
T, sec	18000	16200	16200	16200	12600
T_T, sec	85477	87536	107805	88795	57644
r_{eff}, m	172.5	172.5	136.9	136.9	136.9
L_o, dBA	83.19	83.77	86.26	85.98	88.45

Table 3. Calculated values.

Several explanations can be advanced to account for the variations seen in the calculated levels. Foremost would be the fact that at location A the microphone was partially screened from the track by 2-3 meters of light vegetation, while at location B it had an unimpeded line of sight access to the racing surface. This would tend to artificially reduce the recorded noise levels at the 2008 events. The amount of attenuation caused by the screening is impossible to calculate exactly, but it does not seem unreasonable to attribute at least part of the roughly 3 dBA difference seen between the 2008 and 2010 results to this effect.

Another factor thought to have a significant effect on the observed results was the changing mix of machines participating in the events. In 2011 a new class of large-capacity, air-cooled twin cylinder machines was added to the race schedule and these machines accounted for quite a high percentage of the laps run. Air-cooled motorcycles are known to generate higher noise levels than the more common water-cooled machines used for other classes, so this could well account for the higher calculated L_o value obtained for the 2011 event.

A more subtle effect that might contribute to the depression of the 2008 values involves the placement of the recording microphones. Recall that the L_o value is calculated from the L_{eq}, which is an energy average that is disproportionately affected by the loudest sounds received during a measurement. The loudest sounds here would tend to occur as the moving vehicles reach their point of nearest approach to the measurement locations. At location A this would occur on a gently curving section of the track normally taken at part throttle; at location B it was on a straight section where the vehicles were under maximum acceleration. The sound power output from the same vehicle might be quite different in these two situations. The L_o values would tend to reflect this, as the sound power of the sources at the sections of track having the greatest influence on the L_{eq} measurement would be different. It is unclear just how significant this effect might be, but in any case it could not be used to explain the observed difference between the 2010 and 2011 results.

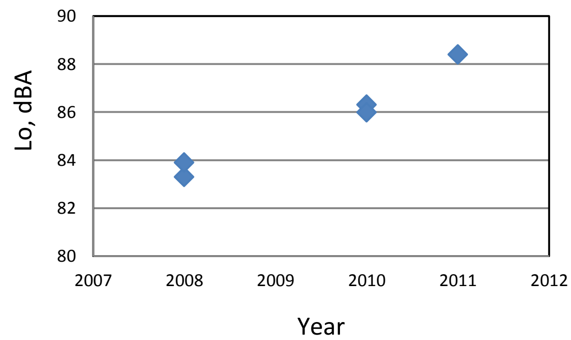

Figure 3. Calculated L_o values by year.

As mentioned in the introduction, part of the rationale for the study was to determine the effectiveness of noise control regulations in effect at the time of the competition. Unfortunately, this still proved difficult to do. The Canadian Superbike series (in common with most other North American road racing series for motorcycles) sets its maximum allowable noise level for competitors based on a test procedure loosely following the SAE J1287 standard. In this type of test, the microphone is held at a distance of 0.5m away from the exit of the exhaust pipe and at a 45 degree angle to the long axis of the motorcycle while the engine is run at part of its maximum speed. In 2010, the series limit was set to be 106 dB under ½ throttle conditions (with no mention of A-weighting appearing in the rules as written). Re-calculating the L_o values given in table 3 with a new r_o value of 0.5m simply adds 29.68 dB to each measurement obtained. This would put all of the L_o values obtained above the 106 dB maximum allowed in the series noise test when corrected for distance, with the 2011 event being the worst offender at 118.1 dBA. However, these values were obtained under racing conditions where engine speeds would be at or near their maximum, while the limit was specified at partial throttle. It is impossible to account for the difference in engine speed between the observed results and that called for in the test procedure, so no conclusions regarding overall compliance can be drawn.

The effect of the using the A-weighting network during recording (versus lack of same during series noise testing) would always be to reduce the levels obtained to less than would otherwise be observed though, so this would tend to make the calculated results a bit more conservative with respect to the rules than might actually be true.

As a point of discussion, it should be noted that despite the widespread acceptance of L_{eq} measurements for community noise monitoring, real-time systems for trackside noise control have proven difficult and costly to implement. Watson [6,7,8] has written quite extensively describing his experiences in the UK on this topic. Simpler testing methods such as the SAE test just mentioned are much more commonly used for on-site noise control at race tracks. These generally break down into two types of tests, static or pass-by. In North America motorcycle racing organizations tend to favor the static test, whereas car racing organizations such as the Sports Car Club of America prefer the pass-by technique. The advantages and disadvantages of both types of tests are discussed in Reference [9]

Even when searching for data collected using these simpler techniques, relatively little material appears in the literature that can be used for directly comparative purposes. In 1967 Ford [10] reported levels of 110-112 dBA for 1000 c.c. racing motorcycles when measured at a distance of 10 yards, but the machines he studied were all unsilenced. Modern superbikes such as those studied here are required to carry commercial silencers certified for street use. In 1999 Roberts [11] published an extensive study carried out at a number of Australian tracks in which he claims to have measured a noise level of 96 dBA at a distance of 30 m for a group of modern superbikes. No mention is made of how many machines made up the group, however.

The results do agree well with a secondary study carried out by the author that measured the noise output of a group of club racing motorcycles broadly similar to those in the Superbike series. In this study 191 measurements were obtained using the pass by technique described in Ref. [9], with the sound level meter in "peak hold" mode and located a distance r_0=15.24m from the racing surface. The average result obtained was 88.6 dBA, which compared well with the calculated L_o results from the first four events, considering that these were peak values and the calculated results were of the "equivalent continuous" type. No XR1200 type machines (thought to be responsible for the rise in overall levels observed at the 2011 event) were present when the club racing results were recorded.

It would be straightforward to use the L_o data obtained here in Eq. (2) to predict L_{eq} levels for future events provided the composition of the field was similar. All that would be required would be the selection of an appropriate r_{eff} value and the specification of new values for the overall time spent on track T_T and event duration T. Because of the relatively large amount of data used in this study (Five events comprising 5,884 laps of competition for 8 different classes of machine) it might reasonably be expected that the L_o values obtained here would have some statistical validity when used in this way. Equation 2 could even be used as a planning tool, allowing organizers to adjust the planned T_T for a hypothetical event to achieve a desired L_{eq} at some selected location.

The L_o results could also be used to predict levels at other venues holding similar events provided an appropriate r_{eff} value could be obtained. This would require obtaining a GPS trace for the new venue similar to the one used here and performing new calculations. For best accuracy, the type of vehicle used to obtain the trace should match as closely as possible the characteristics of the motorcycles used to obtain the original L_o values.

It would be quite easy to obtain L_o data for specific classes of machine with the technique described here by recording individual L_{eq}'s for the individual races and/or practice sessions and analyzing them separately. This method might have allowed more definite conclusions to be drawn regarding the cause of the rise observed in the overall 2011 results by isolating results for the various groups participating. It would also be possible to incorporate separate L_o information for different classes in any future predictions made using Equation 2.

Finally, the accuracy of results obtained in either the analysis or predictive stages could be improved by modifying the r_{eff} calculation to include equivalent distances to match known excess attenuation at individual points around the track resulting from topographical changes, barriers, etc.

The reader is reminded that L_0 values of the type obtained here are not L_{eq}'s in the normal sense; they are simply an abstraction used to describe the observed energy average noise output per competitor. Also, L_{eq} measurements, although widely used, do not always accurately predict the onset of community noise annoyance problems.

7. CONCLUSIONS

A method for obtaining the aggregate energy averaged equivalent continuous noise level per competitor at motorsport events from L_{eq} data has been presented. The analysis takes into account track geometry, the speed variation of the vehicles and the number of competitors present during each measurement period. The noise model obtained could plausibly be used to predict noise impact of similar constituted fields of competitors at other events or venues.

The analysis, when applied to the events in the Canadian Superbike race series studied, seems to indicate a moderately rising trend in the noise output per participant over time that is primarily attributed to the changing composition of the race field.

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