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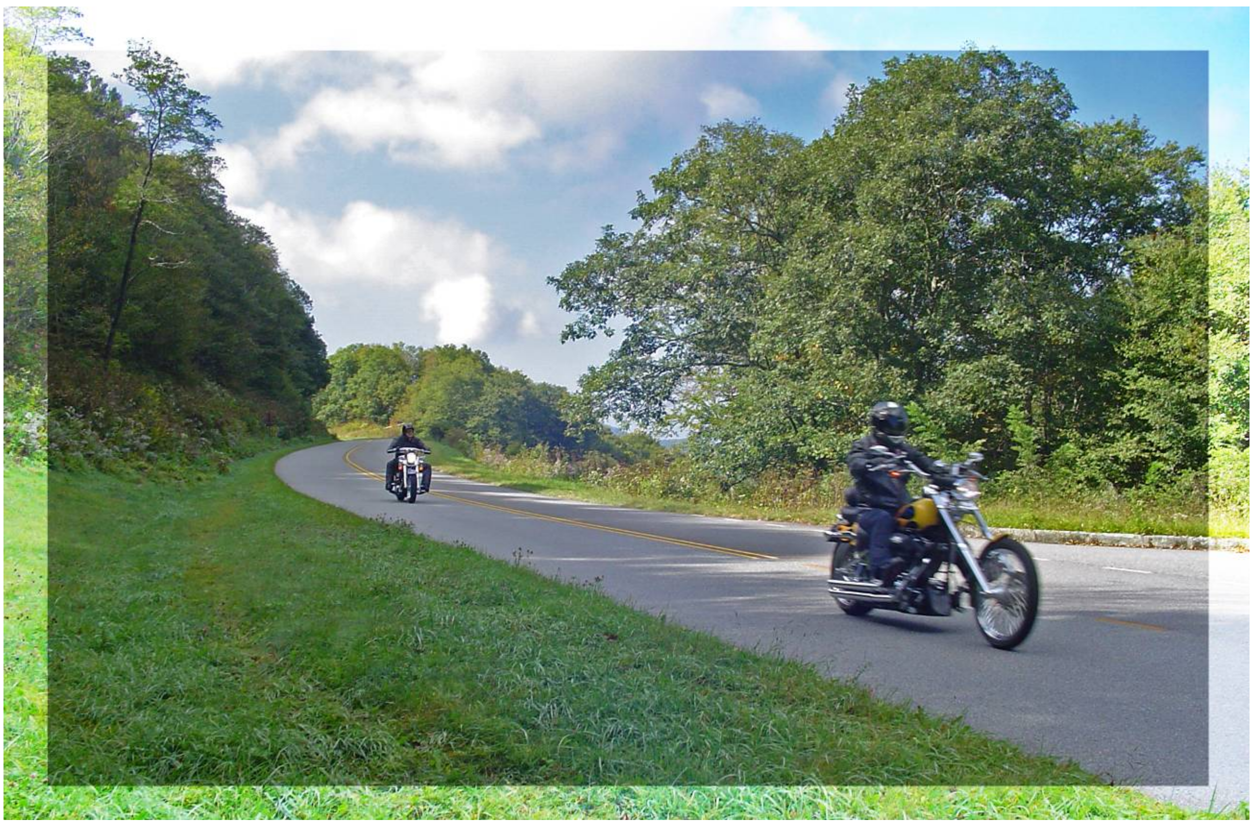
Natural Resource Stewardship and Science

Motorcycle Noise in a Park Environment

Natural Resource Technical Report NPS/NSNS/NRTR—2013/781



ON THE COVER
Motorcycles on the parkway at Blue Ridge Parkway National Park.
Photograph by: Judith Rochat

Motorcycle Noise in a Park Environment

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Judith L. Rochat

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June 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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13. ABSTRACT (Maximum 200 words)
The Blue Ridge Parkway National Park provided an environment where sound level measurements could be made for numerous motorcycle pass-by events. Data were examined for five motorcycle categories: cruiser, sport, dual purpose, touring, and moped/scooter, in terms of broadband sound levels and on a spectral basis (one-third octave bands). Then the cruiser category was examined further since these motorcycles generated the loudest and some of the quietest measured sound levels. Initial investigations were made for the following: sound levels for groups of motorcycles, sound levels at sensitive receiver locations, and predictions of sound levels using five motorcycle categories in a special research version of the FHWA Traffic Noise Model® (TNM®).

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F	=	y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

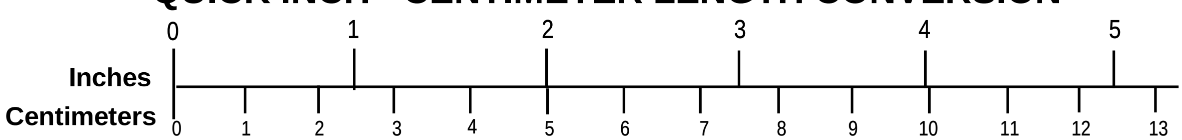
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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1. INTRODUCTION

1.1 Background

NPS personnel identified several topic areas where road noise research and related products could help parks better assess, predict, and minimize road noise (including road-tire noise), providing best practice recommendations. Desired road noise research was also identified through work done to date for the air tour management plans (ATMPs). (The work described in this report supports the research being conducted for the Air Tour Management Plan (ATMP) Program regarding the determination of ambient sound levels in National Parks [Volpe 2007]. Ambient data are used to establish a baseline from which aircraft-related noise impacts can be assessed.)

Of the topics identified, the one reported on in this document is to provide improved evaluation and prediction methodologies related to motorcycle noise. In order to provide improved evaluation and prediction methodologies, it is necessary to modify an existing traffic noise model to incorporate a more refined representation of motorcycles. (Existing noise models already include complex equations for sound propagation, which is needed for park noise predictions.) The modifications would allow for more accurate motorcycle noise predictions at desired locations throughout parks. Increased accuracy is due to proper spectral representation of the noise (it is known that various types of motorcycles sound different, and this is due to differences in spectral content [Ishiyama 1991][Sandberg 2002]). Sound propagation effects such as ground reflections, shielding due to objects in the propagation path, and atmospherics are frequency-dependent, so starting with the best representation of motorcycle noise emissions possible will result, after propagation, in the best predictions possible.

Commonly used traffic noise models have very broad implementations of motorcycle noise emission levels or no motorcycle representation. Broad implementation includes the Federal Highway Administration (FHWA) Traffic Noise Model® (TNM®) (version 2.5) [Menge 1998][Anderson 1998]. Some other models do not inherently include motorcycle emissions levels, but they allow for input of vehicle noise emissions levels, (e.g., NMSim [Ikelheimer 2005], NORD2000 [Kragh 2009]), and motorcycle noise could be measured and included. For the current study, it was determined that TNM would be used to provide improved evaluation and prediction methodologies, where data would be collected and analyzed in accordance with the vehicle noise emission level data in the model [Fleming 1996] and implemented in a modified version of TNM. The data would then also be available to analyze for input to other models.

The current version of TNM divides vehicles into five categories: automobiles, medium trucks, heavy trucks, buses, and motorcycles. The noise emissions database for each vehicle type is an average for many vehicles. For some of the vehicle categories, average sound levels may not properly represent all vehicles in that category; for example, aggressive motorcycles with modified exhaust systems would likely be louder than the average motorcycle sound level represented in TNM. While use of the five TNM vehicle categories and their average levels is fully appropriate for most highway noise impact predictions for typical highway noise projects, there are places, such as some National Parks, where motorcycle noise dominates. When trying to determine noise impacts for these places, a better assessment could be made if categories within motorcycles were available.

Motorcycle noise measurements were taken in the Blue Ridge Parkway National Park in order to help better categorize motorcycle types, establish typical noise emissions data for each category, and assess such noise in the park environment. This park is known to have a high volume of motorcycles and has received numerous complaints about motorcycle noise adversely affecting visitors' experiences.

1.2 Study Overview and Report Organization

The next section (Section 2) lists the motorcycle categories applied to this study. Section 3 describes the measurement sites at Blue Ridge Parkway. Section 4 describes the noise and supporting measurements conducted. Section 5 describes the data analysis procedures applied to the data collected and the results of each analysis. Section 6 provides conclusions and recommendations.

2. MOTORCYCLE CATEGORIES

For this study, motorcycles were divided into five categories, where the categories were based on visible and audible similarities. Literature reviews, internet searches, and conversations with motorcyclists provided guidance for designating and describing the five categories of motorcycles [Hale 2007][Austin 2011][Wikipedia 2010]. The five categories are: cruiser, sport, dual purpose, touring, and moped/scooter. Table 1 below was prepared for, and used in the field to help identify motorcycle types as they passed by each noise measurement site. Included in the table are visual and auditory descriptions to help with identification. (Note: A more refined categorization, such as for engine power or exhaust system modifications, was not pursued due to the nature of the measurements; closer inspection would interfere with this type of measurement, which follows the methodology used for data collection for TNM.)

Table 1. Five motorcycle categories: cruiser, sport, dual purpose, touring, and moped/scooter.

Category	Motorcycle characteristics	Rider position	Photos
Cruiser (C)	Possibilities: - front wheel extending out - high handlebars - backrest for passenger Includes choppers Deep throated "Harley" rumble sound	Upright or laid back Various handlebar styles Legs forward 	   
Sport bike (S)	Possibly futuristic looking Back tilts up, away from tire Includes naked bikes High-pitched, whine or buzz sound	Hunched forward 	 

			
Dual purpose (D)	Back tilts up, away from tire Raised fender on front A.k.a adventure touring bikes / dual sports, includes supermoto Dirt bike rattle or raspy sound	Upright Hands close to body 	  
Touring bike (T)	Backrests Large windscreens Built-in saddlebags Quieter, low hum sound	Upright Often 2 passengers 	 
Moped or scooter (M)	Smaller than other bikes Step-through chassis Includes power scooters Medium sound, buzzing hum	Upright 	  

3. MEASUREMENT SITES

3.1 Measurement Sites Overview

All measurement sites were at the Blue Ridge Parkway National Park or surrounding land. Measurement sites were chosen to accommodate two types of measurements: 1) wayside near the road, capturing motorcycle noise emission levels, and 2) wayside sensitive receiver locations (areas of frequent human use). Each is described more below.

The emission level measurement locations allowed for the capture of the maximum sound level for a single vehicle passing by, without intrusion of noise from other vehicles or other noise sources. The emission levels were used to develop categorized motorcycle Reference Energy Mean Emission Levels (REMELs) [Fleming 1996] to be applied in a special research version of the FHWA Traffic Noise Model® (TNM®) [Menge 1998][Anderson 1998]. The emission levels were also used to examine spectral differences among motorcycle categories.

The sensitive receiver locations allowed for the capture of sound levels in areas of frequent human use. These included such locations as park overlooks, picnic areas, campgrounds, hiking trails, and visitor centers. (See Figure 1 below for an example of an overlook measurement site.) Measurements from these locations were used to help validate the research version of TNM that includes motorcycle categories and to assess the sound environment as experienced by park visitors.

Some measurement locations accommodated both noise emission level and sensitive receiver measurements. Below are descriptions of each location.

Note: On-Board Sound Intensity (OBSI) measurements [AASHTO OBSI] were taken, using an automobile equipped with OBSI instrumentation, at 35 mph at most sites to evaluate the tire/pavement noise at these potential locations. OBSI levels ranged from about 90 to 94 dBA, with most sites having a level of about 92 dBA. This was noted for two reasons: 1) to eliminate any sites with extreme tire/pavement noise levels, of which there were none, and 2) in case vehicle types other than motorcycles were to be evaluated in the future (tire/pavement noise is not the major noise source for motorcycles, so any differences in tire/pavement noise had no measurable effect on the motorcycle noise levels, but it could affect other vehicle types).

Figure 1. Example of park overlook measurement site – also used for measurement of noise emission levels.

3.2 Measurement Sites Listed

Table 2 below lists each of the measurement sites and dates of measurements. Photos of the sites can be found in Appendix A.

Table 2. Measurement sites at Blue Ridge Parkway National Park.

Site ID	Site Location	Type of Measurement	Measurement Dates
BR01R	Thunder Struck Ridge Overlook	emission level, sensitive receiver	9/17/2010
BR02S	Waterrock Knob	sensitive receiver	9/17/2010
BR03R	Balsam Gap Overlook	emission level, sensitive receiver	9/17/2010 9/18/2010
BR04R	Grass Ridge Mine Overlook	emission level, sensitive receiver	9/18/2010
BR05S	Mountains-to-Sea hiking trail near Grass Ridge Mine Overlook	sensitive receiver	9/18/2010
BR06R	Mt. Pisgah pull-out	emission level	9/19/2010
BR07S	Mt. Pisgah campground	sensitive receiver	9/19/2010
BR08R	Beartrail Ridge Overlook	emission level, sensitive receiver	9/19/2010
BR09R	Graveyard Fields Overlook	emission level, sensitive receiver	9/20/2010
BR10S	Graveyard Fields hiking trail	sensitive receiver	9/20/2010
BR11R	Devil’s Courthouse Overlook	emission level, sensitive receiver	9/20/2010

4. DATA COLLECTION

Wayside noise measurements were conducted to determine the noise emission levels from motorcycles and the general sound environment near the roadways of interest. The measurements were conducted in conformance with the procedures in the FHWA measurements report [Lee 1996], with additional microphone locations as described in the Statistical Isolated Pass-By (SIP) methodology [Rochat 2009, AASHTO SIP] (these additional microphone locations are not used for analysis in this report, but data are available for future analysis, if desired). Please refer to Appendix A for a list of instrumentation that was deployed at each site.

4.1 Wayside Noise Measurements for Motorcycle Noise Emission Levels

At all noise emission level sites, sound levels were measured at the FHWA Traffic Noise Model® [Anderson 1998][Menge 1998] emissions database location: distance is 50 ft (15.2 m) from the center of the travel lane and at height 5 ft (1.5 m) above the roadway plane. Two additional microphones were located at distances of 25 ft (7.6 m) and 50 ft (15.2 m), with heights of 5 ft (1.5 m) and 12 ft (3.7 m), respectively. Figure 2 shows an example of microphones deployed.

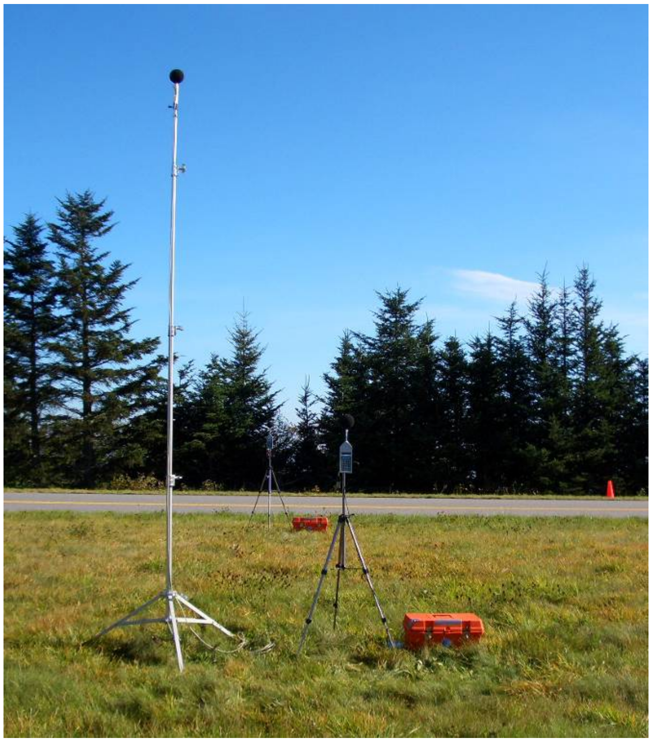

Figure 2. Deployment of microphones at site for collecting the noise emissions levels.

Sound was measured using a class 1 sound level meter and the audio recorded for use in postprocessing with a spectrum analyzer for extraction of 1/3-octave band data. Sound level meters set on fast response recorded 1-second A-weighted equivalent sound levels and maximum sound levels. Spectrum analyzers were set for 1/8-second exponential averaging and the spectrum was extracted at the A-weighted maximum broadband sound level for each vehicle pass-by event. (Sound levels are reported in A-weighted decibels, abbreviated dBA, where a decibel is a unit of measure of sound, and A-weighting is a weighting network used to account for changes in level sensitivity as a function of frequency. Spectra are reported as sound levels as a function of frequency, where frequency is reported in units of Hertz, abbreviated Hz.)

Meteorological data were also collected. Air temperature, relative humidity, wind speed, and wind direction data were collected in 1-second samples. In addition, pavement temperature and prevailing cloud cover conditions were noted hourly. Please refer to Figure 3 for a photo of meteorological instrumentation.

Figure 3. Deployment of meteorological instrumentation.

Vehicle speed and identification data were also collected. All vehicle pass-by events subjectively determined to be of good quality (no interfering noise and vehicle maintaining constant speed as it drives past the microphones) were logged in a palmtop computer. In addition, speeds were measured using a radar gun and noted in the log along with the time of the pass-by event. In addition to general vehicle category, motorcycle type, as defined in Section 2, was also noted. Please refer to Figure 4 for a photo of the vehicle data collection instrumentation.

Figure 4. Deployment of vehicle data collection instrumentation.

4.2 Wayside Noise Measurements for the General Sound Environment

Some of the noise emission locations also served to measure the general sound environment at popular overlooks in the park, some of which are sites for picnicking. In addition, microphones were deployed at sensitive receiver locations farther from the road, which included a campground site, hiking trails, and a visitor center area near picnic tables. Each of these locations was near one of the emission level locations, and a microphone and sound level meter were deployed at a height of 5 ft (1.5 m) above the ground (distances from the road were approximated and are listed in Appendix A). Sound level meters set on fast response recorded 1-second A-weighted equivalent sound levels and maximum sound levels, and audio was recorded for later analysis.

Meteorological instrumentation was also deployed at the sensitive receiver location when sufficiently far from the emission level location (far enough so that the meteorological conditions at the emission level location may not have been representative of those at the sensitive receiver location). In addition, extraneous noise determined to potentially contaminate the road noise measurements was noted in the palmtop log.

5. DATA ANALYSIS AND RESULTS

The data analysis and results will first be discussed in terms of broadband sound levels, where average values and linear regressions are presented for each motorcycle category. The data are then examined spectrally, on a third-octave band basis. Then the cruiser category is examined further both in terms of broadband levels and on a spectral basis. Examples of the following are then presented: sound levels for groups of motorcycles, sound levels at sensitive receiver locations, and predictions of sound levels using five motorcycle categories in a research version of the FHWA Traffic Noise Model® (TNM®) [Menge 1998][Anderson 1998]. All data presented in this section are for motorcycles under cruise conditions. Preliminary results for motorcycles under full throttle conditions can be found in Appendix C; further analysis will need to be conducted in order to determine if the full throttle events are statistically different or if they should be grouped with the cruise condition events.

5.1 Motorcycle Noise Emission Levels (Broadband)

Spectrum analyzers were used to process the audio recordings for each of the measurement sites. The associated broadband levels are presented here. For each single motorcycle pass-by event, the A-weighted maximum sound level (1/8-second exponential averaging), one-third octave band levels between 25 and 10,000 Hz at the time of the maximum sound level, event quality, vehicle speed, and wind speed were noted. Event quality was determined by examining the maximum sound level for the pass-by event and the sound level decrease just prior to and just after the event; the minimum level decrease in decibels was noted. Wind speed was determined by calculating the 5-second average around the time of the maximum sound level. Motorcycle pass-by events were eliminated from the final data set if the quality was not sufficient (decibel decrease < 6 dBA) or if the wind speed exceeded 11.2 mph (5 m/s). The final data set contained individual motorcycle pass-by events that were not influenced by any other sound source and were not contaminated by wind noise. The broadband sound levels are presented in this section.

5.1.1 Ranges and average L_{Amax} values by motorcycle type

For each motorcycle category, the following were calculated: number of data points; the maximum, minimum, and average vehicle pass-by A-weighted maximum sound levels

(L_{Amax}); and the maximum, minimum, and average speeds. The data are presented in Table 3, and Figure 5 shows the sound level data in graphical format.

Table 3. Table of sound level and speed ranges for each motorcycle category.

	cruiser	sport	dual purpose	touring	moped / scooter
Number of data points	73	16	10	16	2
Maximum L_{Amax} (dBA)	84.8	78.3	73.4	72.1	62.3
Minimum L_{Amax} (dBA)	60.8	60.7	64.4	61.6	61.7
Average* L_{Amax} (dBA)	72.8	70.4	68.2	65.2	62.0
Maximum speed (mph)	55	57	55	55	34
Minimum speed (mph)	22	20	33	24	32
Average speed (mph)	36	45	43	40	33

*Average is calculated arithmetically (not on an energy basis).

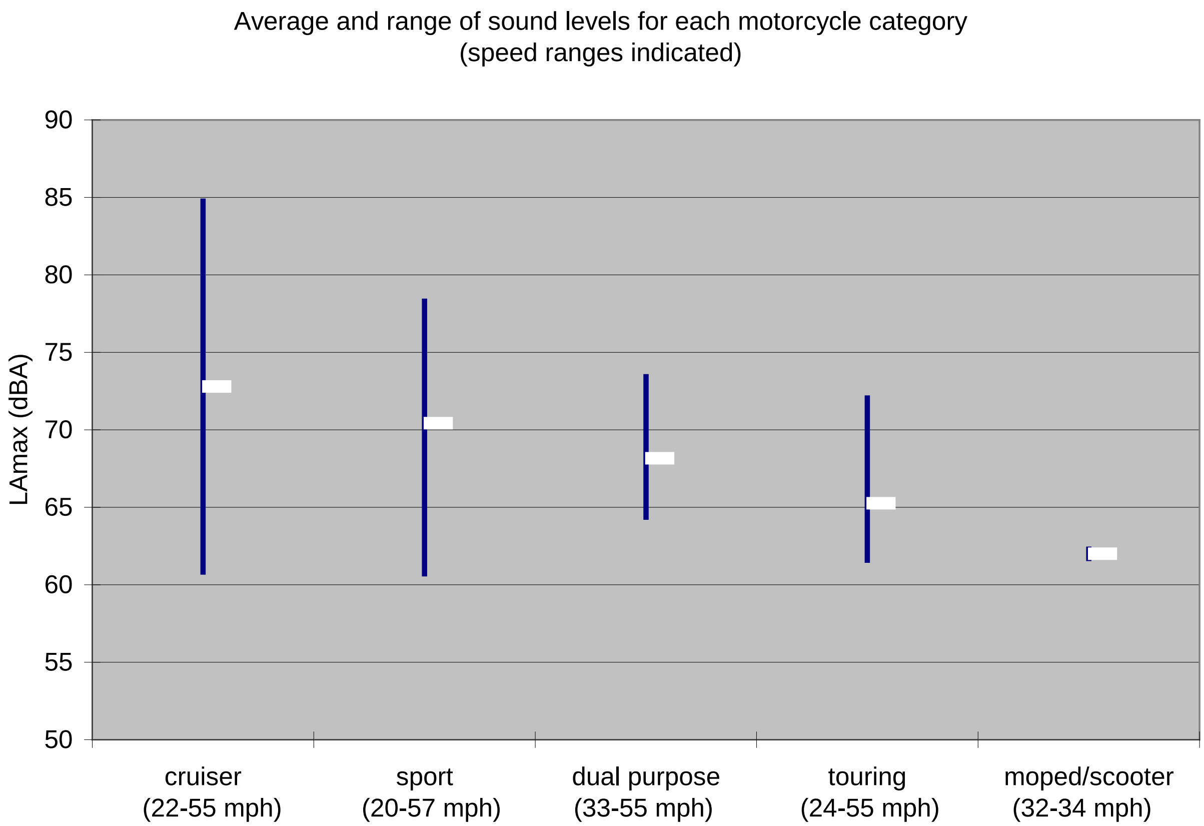

Figure 5. Plot of sound level ranges and average for each motorcycle category.

It can be seen in Table 3 and Figure 5 that the range of sound levels varies by motorcycle category. Of particular note is that the measured range for cruisers is 24 dBA; the cruiser category included the loudest motorcycle event as well as one of the quietest. The large ranges for the cruiser and sport categories are likely due to aftermarket modifications or defective parts – lower sound levels are found with original equipment [Harris 1996]. It should be pointed out that there were only two events in the moped/scooter category, both vehicles traveling at a similar speed, so it's expected that the average presented here would be lower than the other categories. Please refer to the next section, which provides more comparable averages, based on linear regressions.

5.1.2 Linear regression of L_{Amax} values by motorcycle type

A linear regression analysis was performed for L_{Amax} as a function of the log of speed for each motorcycle type, and the data are shown in Figure 6. The regression line equation was then used to determine the sound level for each motorcycle type at 30, 40, and 50 mph (48, 64, and 80 km/h); for each motorcycle type, the arithmetic average of the three sound levels associated with the three speeds was calculated, and the averages for each type are plotted in Figure 7. In addition to the levels for each motorcycle type measured in this study, Figure 7 also shows the sound level for the general motorcycle category in the national database (in TNM) [Fleming 1996] for comparative purposes.

The regression line coefficients for each motorcycle type are given below:

Cruiser	$15.875x + 48.164$
Sport	$26.172x + 27.554$
Dual Purpose	$33.935x + 13.031$
Touring	$-5.9228x + 74.662$
Moped/Scooter	$22.7x + 27.53$

where $x = \log_{10}$(speed in mph).

The following observations can be made when examining the data. Most of the motorcycle categories show an increase in sound level as a function of speed, with the touring category being an exception (although the moped/scooter category shows a similar slope to the rest, the trend should be viewed with caution since only two data points were included). The sound levels averaged from 30-50 mph (48-80 km/h) indicate the following ranking in motorcycle types, from loudest to quietest: cruiser (73.4 dBA), sport (69.2 dBA), dual purpose (67.1 dBA), touring (65.2 dBA), moped/scooter (63.7 dBA), with cruisers being substantially louder than the other types (about 4 to 10 dBA) and the national general category (in TNM) being slightly lower (72.7 dBA) than the cruiser category.

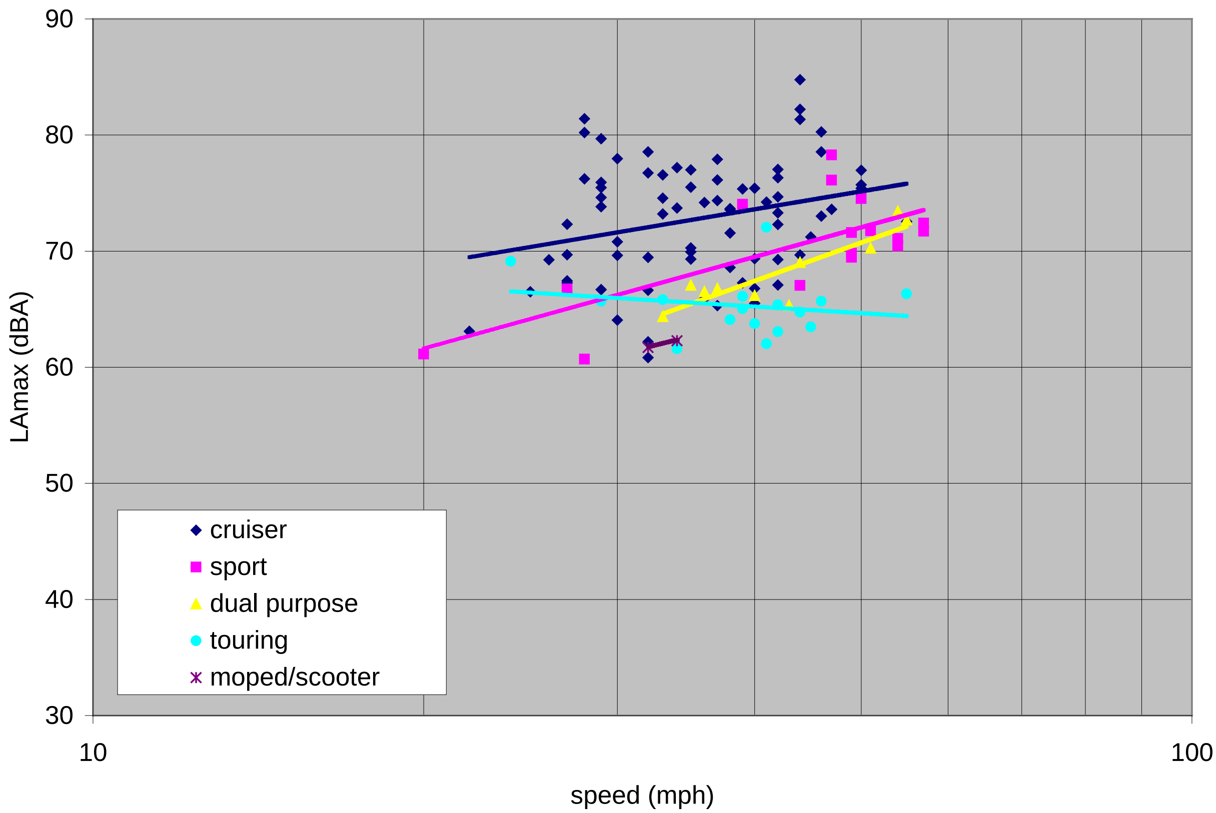

Figure 6. Sound level as a function of speed for all data points with regression lines for each motorcycle type.

A table of values for Figure 6 can be found in Appendix B.

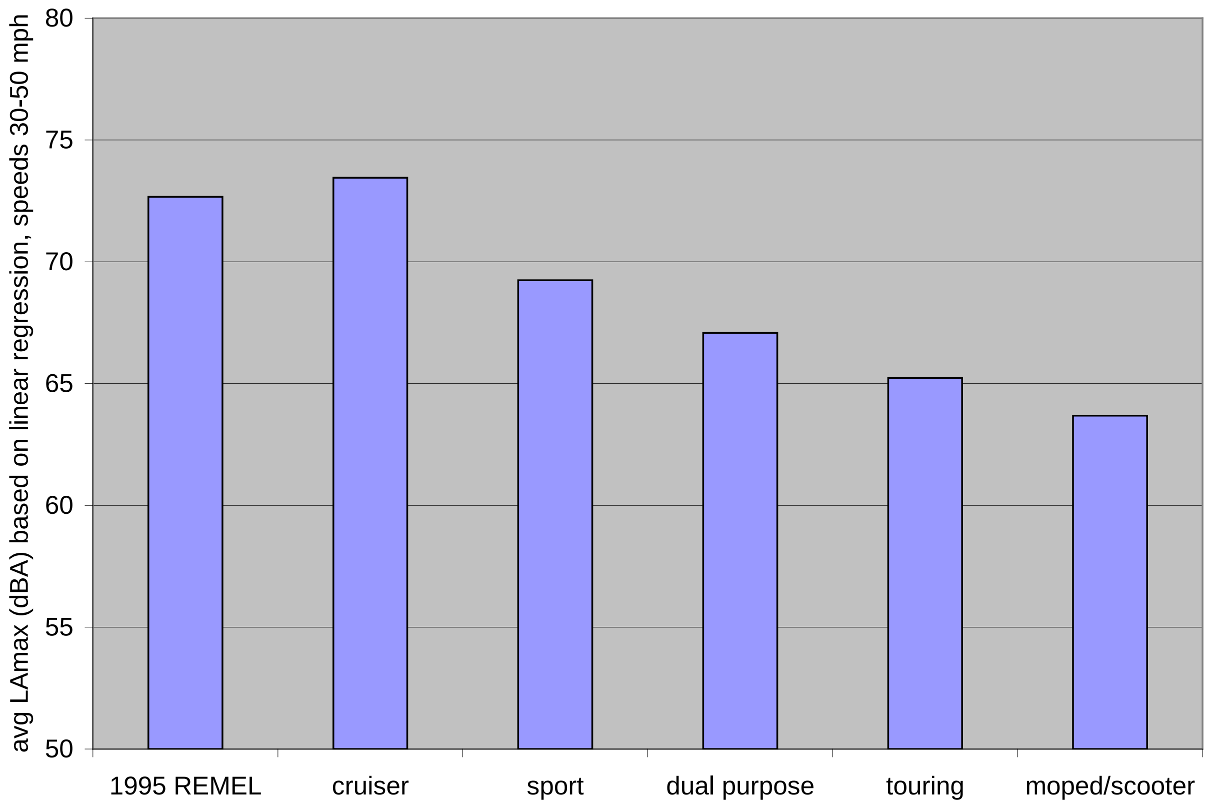

Figure 7. Average sound levels between 30 and 50 mph for each motorcycle category and for the general motorcycle category in the 1995 REMELs.

5.2 Motorcycle Noise Emission Levels (Spectral)

The analysis procedure described at the beginning of Section 5.1 applies. The spectral (one-third octave band) sound levels between 25 and 10,000 Hz are presented in this section.

Figure 8 shows a graphical representation of average one-third octave band sound levels at the time of L_{Amax} for each motorcycle category. A table of values for each spectrum in Figure 8 can be found in Appendix B. Note that the level for each one-third octave band represents the arithmetic average of the levels in that band for all events in a single motorcycle category, regardless of speed; although all categories of motorcycles except moped/scooter had approximately the same speed ranges, the absolute levels are not necessarily directly comparable – spectral shapes are the main focus of the results presented here.

It can be seen in Figure 8 that the cruisers are dominated by low frequency content, with the levels in the frequency range of 100-400 Hz far exceeding those in other frequencies and being the controlling contribution to the broadband sound level. The sport and dual purpose categories both have substantial mid to high frequency content, in the 630-8000 Hz range; there are also lower frequencies contributing to the broadband sound levels, in the range of 125-500 Hz for sport and in the range of 125-200 Hz for dual purpose. It should be noted that the sport spectrum is fairly flat in the 125-8000 Hz range. For the touring category, the most dominant frequencies are in the 630-4000 Hz range and at 100 Hz and 8000 Hz. For mopeds/scooters, the most dominant frequencies are in the 1000-2000 Hz range, with frequencies in the range of 200-5000 Hz also contributing to the broadband sound level.

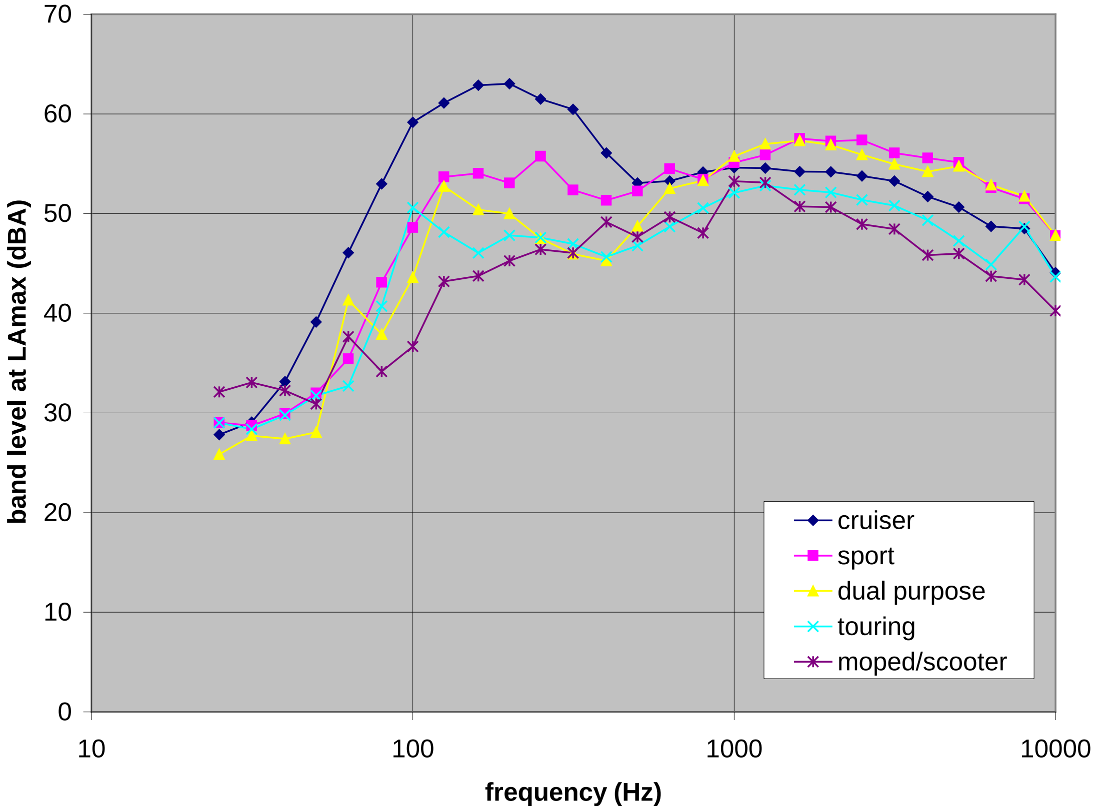

Figure 8. Average spectrum for each motorcycle type (not normalized for speed).

5.3 Further Examination of Cruiser Category

As was previously stated, the cruiser motorcycle sound levels ranged from 60.8 to 84.8 dBA. The loudest events were scattered in terms of speed. When examining the spectral data for all events, it appeared there were groupings according to spectral shape, and these corresponded to the broadband sound level. Accordingly, the cruiser category was divided into three subcategories based on the broadband sound levels. An arithmetic average of the sound levels in each one-third octave band was calculated for the following subcategories: $L_{Amax} \geq 77$ dBA, $70 \leq L_{Amax} < 77$ dBA, $L_{Amax} < 70$ dBA. Figure 9 shows the spectrum for each subcategory, along with the average for all cruiser data. Table 10 in Appendix B lists the values for data shown in Figure 9.

Figure 9 shows that the cruiser sub-categories have similar spectral shapes, with dominant frequencies generally in the 100-400 Hz range, where the sound levels in this range increase with increasing broadband levels. The spectral bump for each is fairly smooth, although the loudest subcategory shows a slight protrusion in the 200-315 Hz range. The broadband levels for each subcategory are … loudest: 79.4 dBA (average speed 38 mph or 61 km/h), middle: 74.1 dBA (average speed 38 mph or 61 km/h), and quietest: 67.1 dBA (average speed 34 mph or 55 km/h). So what makes the loudest subcategory loud? Since vehicle speed appears not to be the cause (some of the loudest events were below 30 mph or 48 km/h), and it is clear that some motorcycles in the cruiser category are relatively quiet, it's likely that modifications to factory made motorcycles (applying louder exhaust systems) or driver behavior are the cause … please refer to the next paragraph regarding federal noise regulations with which manufacturers must comply.

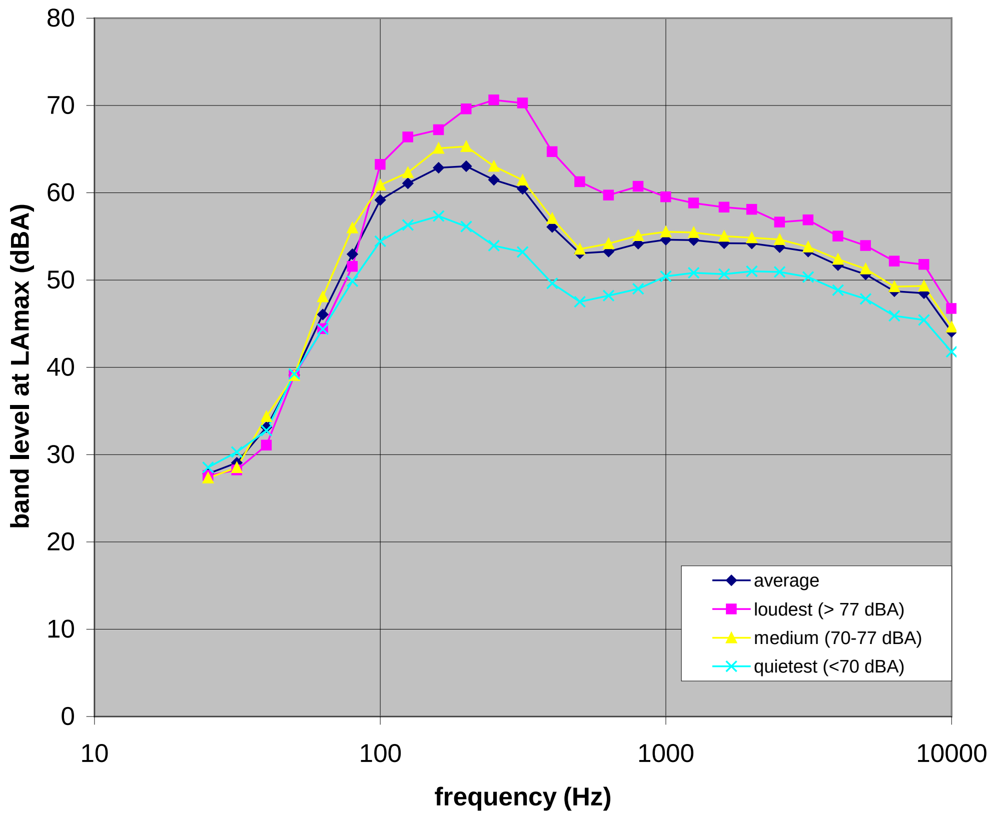

Figure 9. Cruiser category: spectra grouped by broadband levels (and shape).

According to the Code of Federal Regulations 40CFR205 Part D, motorcycles that are manufactured in 1986 or later must not exceed an L_{Amax} level of 80 dBA (exceptions for mopeds and older motorcycles) at a distance of 50 ft (15.2 m) as the motorcycle passes by. The test is based on engine speed, and the measurement site should consist of only acoustically hard ground; based on these requirements, a direct comparison to the sound levels presented in this report cannot be made. However, an approximate comparison can be made considering the following: 1) it's likely that the vehicle speeds for the required engine speeds are below 45 mph (72 km/h), which represents much of the data in this report; and 2) most of the ground, other than the road, at the Blue Ridge Parkway sites was acoustically soft, which would likely equate to a sound level approximately 1-2 dBA lower than if the ground were acoustically hard (since the soft ground would absorb some of the sound). Of the 73 cruiser pass-by events, 15 exceeded 77 dBA for their broadband L_{Amax} levels; accounting for the hard/soft ground differences and potential other differences (say 1 dBA), it's possible that 15 of 73 (21%) of the cruisers exceeded the federally regulated level. (Note: Only one other motorcycle from all the other categories exceeded 77 dBA, and it was a sport bike traveling at 47 mph or 76 km/h.)

5.4 Preliminary Examination of Groups of Motorcycles

Everything presented thus far has been for single motorcycle pass-by events. When examining groups of motorcycles it is important to state the maximum sound level (L_{Amax}), but it may also be useful to examine the sound exposure level (L_{AE}), which quantifies the sound level for an event (all sound due to the vehicle pass-by event that is within 10 dB of the maximum sound level). The sound exposure level compresses the sound energy for a vehicle pass-by event into 1 second. Table 4 below reports the maximum sound level and sound exposure level for four groups of motorcycles, a loud single motorcycle, and a quiet single motorcycle, the last two listed for comparison. Also listed are the number of seconds within 10 dB of the maximum sound level and the number of seconds where the sound level exceeds 60 dBA, based on equivalent (average) sound levels (L_{eq}). The sound levels presented here were measured at a distance of 50 ft (15.2 m).

Table 4. Sound levels for groups of motorcycles and single motorcycles, examining L_{Amax}, L_{AE}, and time above 60 dBA.

Site	Time of Maximum Sound Level	Number and Type of Motorcycles	Speed (mph)	L_{Amax} (dBA)	L_{AE} (dBA)	Duration within 10 dB Based on Leq (seconds)	Duration Exceeding 60 dBA Based on Leq (seconds)
BR01R	14:12:37	6 cruisers	27	81.6	86.9	11	18
BR04R	13:45:50	8 cruisers, 1 sport	34	81.4	85.4	6	25
BR06R	11:29:32	7 cruisers	34	78.4	82.5	10	14
BR04R	13:29:03	8 cruisers	37	77.2	82.7	12	24
BR01R	14:19:30	1 loud cruiser	28	80.9	81.8	4	12
BR01R	12:24:22	1 quiet cruiser	32	62.2	64.8	8	1

It can been seen that the sound exposure levels for all the groups of motorcycles exceed those for the single loud motorcycle event, even though the maximum sound level for the single loud motorcycle exceeded the level for two of the groups. This is to be expected considering the extended time for the events due to multiple motorcycles passing by. The sound levels for the groups of motorcycles (and some single ones) are fairly loud, particularly when considering the length of time the sound level exceeds 60 dBA, the level at which speech interference can occur (for sentence intelligibility of 95% or better, the sound level must not exceed the normal sound level of a conversation, about 60 dBA [Kinsler 1982][Pierce 1989]). When considering a park environment, where levels well below 60 dBA can negatively affect a park visitor's experience, the amount of time would far exceed the exposure times listed for 60 dBA. As an example, if one were to consider a park ambient sound level to be 35 dBA (equivalent or average sound level), which is approximately the case for site BR06R, the 7 cruisers passing by at about 11:39:32 caused the sound level to be above 35 dBA for at least 80 seconds, and the sound level actually only decreased to about 40 dBA, at which point the sound levels started increasing again due to other vehicles passing by. More examples of sound levels associated with groups of motorcycles are given in Section 5.5.

5.5 Examples of Motorcycle Noise at Sensitive Receiver Locations

Much of the data presented thus far was for sensitive receiver locations, since several of the 50-ft (15.2-m) microphones were placed at overlooks on the Blue Ridge Parkway, where visitors stop to enjoy the view and, at some overlooks, have a picnic. The maximum A-weighted sound level reached at these sensitive locations for the single motorcycle events that were examined was 84.8 dBA, as seen in Table 3. The minimum level for a motorcycle event was 60.7 dBA.

Table 5 shows examples of sound levels associated with groups of motorcycles at several of the sensitive receiver locations. For these sites, a group of motorcycles was identified, and based on the 1-second L_{Amax} time histories in the sound level meter files, the maximum sound level for the group was extracted, and the time in seconds that the group of motorcycles exceeded the ambient sound was determined. In some cases, noise from another source could be identified before the sound from the motorcycles completed faded (sound was not at the ambient level either before or after the event); these cases are marked with "+"; this indicates that the time exceeding ambient would be longer than indicated had there been no other noise sources. Please note that the times being calculated do not represent a time audible metric, which would require a sound detectability analysis.

Table 5. Example sound levels and exposure times at sensitive receiver locations.

Site ID	Site Location	Approximate Ambient Sound Level (dBA)	L_{Amax} for Group of Motorcycles (dBA)	Approximate Time Exceeding Ambient (seconds)
BR01R	Thunder Struck Ridge Overlook	high 30s	81.6	48+
BR02S	Waterrock Knob (near visitor center)	mid 40s	56.9	22
BR04R	Grass Ridge Mine Overlook	low 50s	81.4	44
BR05S	Mountains-to-Sea hiking trail near Grass Ridge Mine Overlook	mid 30s	71.5	64+
BR07S	Mt. Pisgah campground	mid 30s	55.0	27+
BR09R	Graveyard Fields Overlook	high 20s	78.0	45+
BR10S	Graveyard Fields hiking trail	low 30s	59.7	59
BR11R	Devil's Courthouse Overlook	high 30s	80.0	37

"+" indicates that ambient level was not reached due to other vehicle noise.

Table 5 shows that at parkway overlook sites, the sound levels from isolated groups of motorcycles exceeded 80 dBA. On a hiking trail about 200 ft (61 m) from the road, the sound level exceeded 70 dBA. Near a visitor center about 300 ft (91 m) from the road, at a campground about 550 ft (168 m) from the road, and on a hiking trail about 1005 ft (306 m) from the road, the sound levels reached 55-60 dBA. (Distances given as slant distance – accounts for distance from the road and change in elevation.) The time exceeding ambient was from 22-64+ seconds.

The above information is shown to give some indication as to what a park visitor may experience from a motorcycle or group of motorcycles passing by. The motorcycles may be loud or quiet and the time exceeding the ambient sound level varies.

To get an idea of how many times park visitors were exposed to motorcycle noise during a visit to Blue Ridge Parkway National Park on a Saturday in mid September, an approximate 5-hour time block was examined for Sites BR04R and BR05S (same section of roadway affected both sites), Grass Ridge Mine Overlook and Mountains-to-Sea hiking trail, to see how many motorcycles passed by. The total number of motorcycles passing by (traveling both directions) was 385 (approximately 74% cruisers, 7% sport, 3% dual purpose, 12% touring, and 4% moped/scooter). So if a visitor were at the location for 20 minutes (a reasonable duration for an overlook visit), they would have been exposed to an average of about 25 motorcycles. It should be noted that in addition to the motorcycle noise, there was also noise from other vehicle types, to which visitors were exposed.

5.6 Examples of Motorcycle Noise Predictions

Analysis of the motorcycle pass-by data collected on Blue Ridge Parkway was conducted in compliance with the noise emission levels in the FHWA Traffic Noise Model® (TNM®) [Fleming 1996] [Menge 1998][Anderson 1998] in order calculate regression coefficients for input in TNM v2.5 for each of the motorcycle categories. Once calculated, the coefficients were implemented, and a special research version of TNM was generated to provide predictions of sound levels associated with the different types of motorcycles and for different scenarios. A validation process showed that the implementation in TNM was providing sound levels for single motorcycle pass-by events that were in close proximity to those measured for each motorcycle type, which indicated that the motorcycle research version of TNM was suitable for analysis of other scenarios.[a]

For this report, analysis was focused on decrease in sound level as a function of distance, for each of the motorcycle types. Other analyses that would be beneficial to the understanding of motorcycle noise include: examination of spectral results, sound level predictions for groups of

[a] It should be noted that TNM v2.5 extrapolates lower frequency sound levels, and due to the high level low-frequency content for some of the motorcycle types, predictions should be limited in distance for the TNM v2.5 research version (at farther distances, lower frequencies contribute more to the broadband sound levels); it is planned that TNM v3.0 will do full calculations for all frequencies, so it is anticipated that motorcycles implemented in a similar special research version of TNM v3.0 will not have the same distance limitations.

motorcycles, and sound level predictions for various park topographies or sensitive receiver locations (not limited to Blue Ridge Parkway).

The importance of analyzing sound level as a function of distance is related to the fact that lower frequencies diminish in sound level more slowly than higher frequencies as the sound propagates. This is particularly true over acoustically soft ground, which effectively absorbs higher frequencies better than lower frequencies. As a result, motorcycles *with* dominant low frequency content can be heard farther away from the road than motorcycles *without* dominant low frequency content, assuming the same sound level near the road for both motorcycle types.

In analyzing sound level as a function of distance, a TNM case was set up with one very long single-lane roadway, grass next to the roadway, and receivers out to a distance of 800 ft (244 m), each at a height of 5 ft (1.5 m). Taken from Section 5.5, it was assumed that 25 motorcycles passed by the receivers in a period of 20 minutes, and they were traveling at a speed of 40 mph (64 km/h). Figure 10 and Table 6 show the predicted sound levels for each motorcycle type as a function of distance. It can be seen that, as with measured sound levels, the order from loudest to quietest is: cruiser, sport, dual purpose, touring, and moped/scooter. Next, the data were normalized such that the sound level for each motorcycle type was the same at 50 ft (15.2 m) in order to better compare how the sound decreases with distance. Figure 11 and Table 6 show normalized predicted sound levels for each motorcycle type as a function of distance. It can be seen that the sound level decreases less rapidly for cruisers than for the other motorcycle types; from a distance of 50 ft (15 m) out to 800 ft (244 m), the predicted sound level for cruisers decreased 16.1 dBA, 21.4 dBA for sport, 23.7 dBA for dual purpose, 22.6 dBA for touring, and 23.8 dBA for moped/scooter. This and an examination of the spectral data confirms that the dominant low frequency content of cruisers will propagate more efficiently than the sound for other motorcycle types, resulting in higher sound levels farther from the road assuming the same sound level near the road.

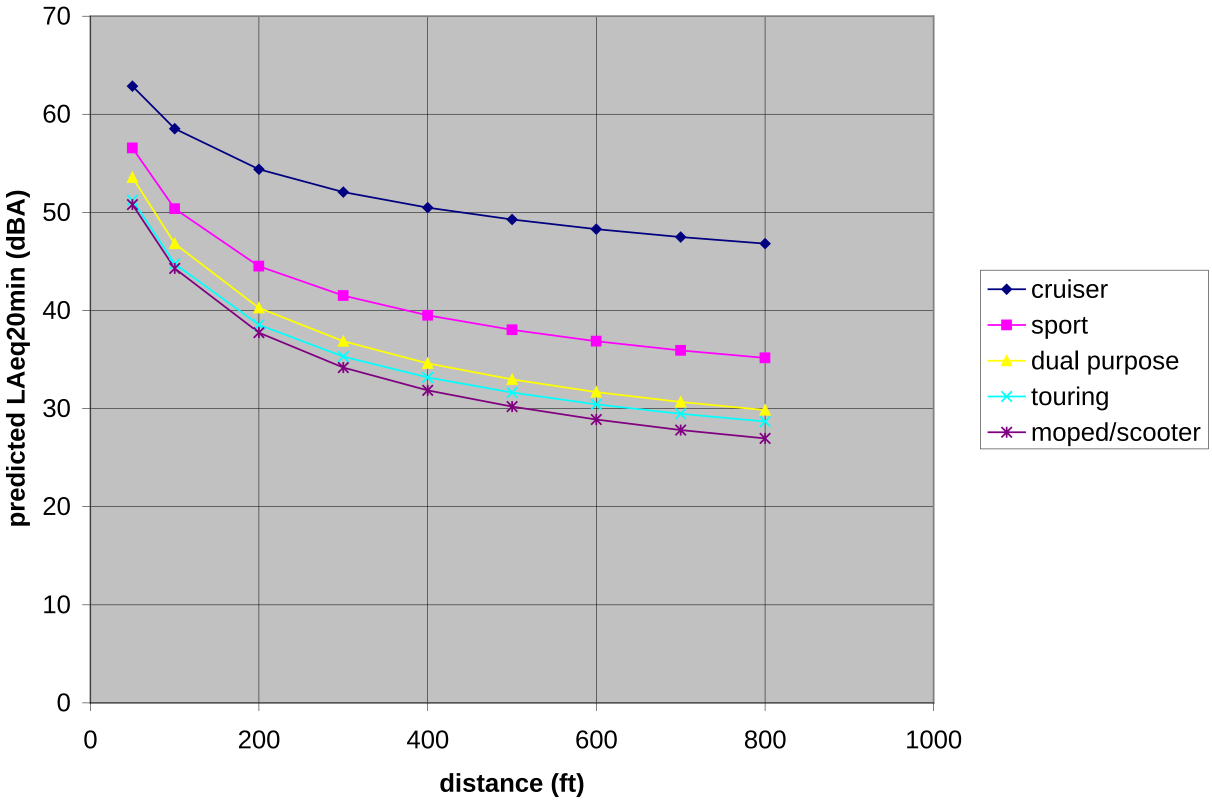

Figure 10. TNM-predicted sound levels as a function of distance for each motorcycle type.

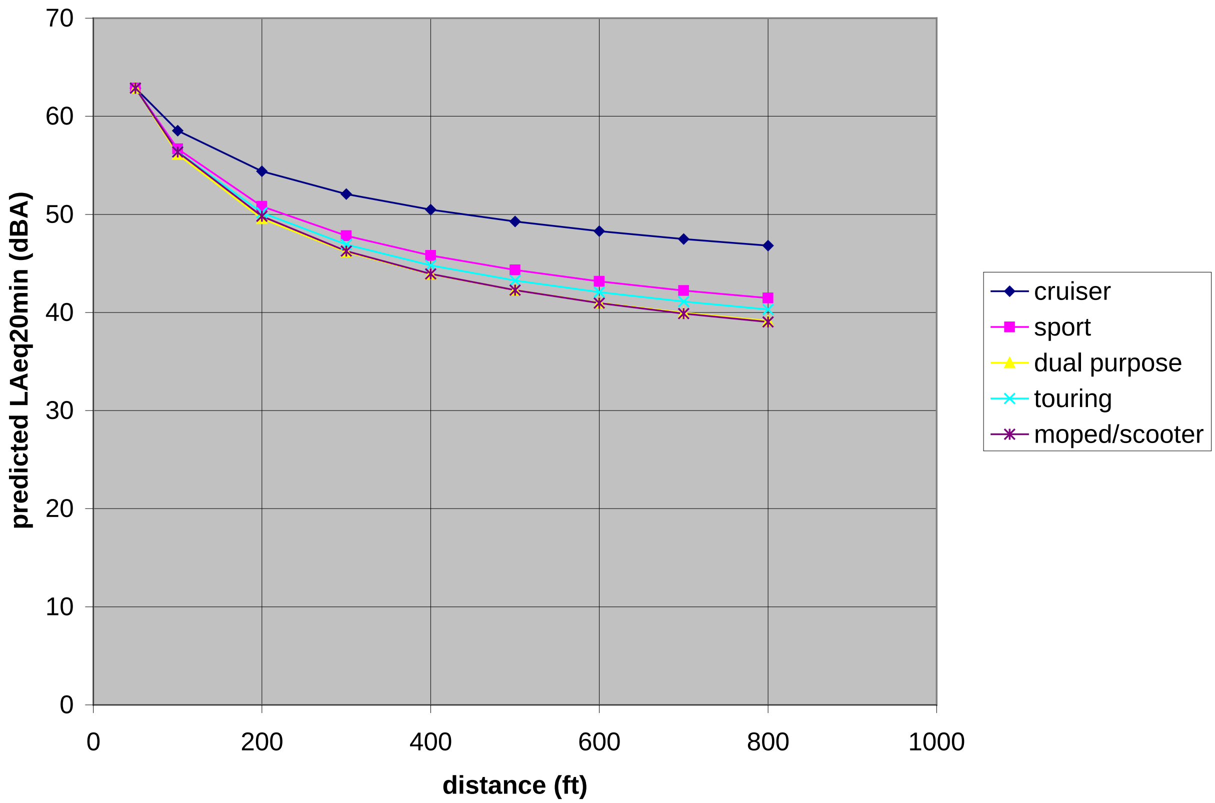

Figure 11. Normalized TNM-predicted sound levels as a function of distance for each motorcycle type.

Table 6. TNM-predicted sound levels as a function of distance for each motorcycle type (un-normalized and normalized)

Distance from road (ft)	LAeq20min (dBA)				
	cruiser	sport	dual purpose	touring	moped/scooter
Sound levels predicted using TNM					
50	62.9	56.6	53.6	51.2	50.8
100	58.5	50.4	46.8	44.8	44.3
200	54.4	44.5	40.3	38.5	37.7
300	52.1	41.5	36.9	35.3	34.2
400	50.5	39.5	34.6	33.2	31.9
500	49.3	38.0	33.0	31.6	30.2
600	48.3	36.9	31.7	30.4	28.9
700	47.5	35.9	30.7	29.5	27.8
800	46.8	35.2	29.9	28.7	27.0
Sound levels predicted using TNM then normalized to level of cruiser at 50 ft					
50	62.9	62.9	62.9	62.9	62.9
100	58.5	56.7	56.1	56.4	56.4
200	54.4	50.8	49.6	50.2	49.8
300	52.1	47.8	46.2	46.9	46.2
400	50.5	45.8	43.9	44.8	43.9
500	49.3	44.3	42.3	43.3	42.3
600	48.3	43.2	41.0	42.1	40.9
700	47.5	42.2	40.0	41.1	39.9
800	46.8	41.5	39.2	40.3	39.0

6. CONCLUSIONS AND RECOMMENDATIONS

The focus of this research was to provide improved evaluation and prediction methodologies related to motorcycle noise. This was accomplished by measuring categorized motorcycle noise emission levels and building a research version of the FHWA Traffic Noise Model® (TNM®) that allows for more accurate motorcycle noise predictions.

The Blue Ridge Parkway National Park provided an environment where sound level measurements could be made for numerous motorcycle pass-by events. Data were examined for five motorcycle categories: cruiser, sport, dual purpose, touring, and moped/scooter, in terms of broadband sound levels and on a spectral basis (one-third octave bands).

The motorcycle categories were ranked in terms average broadband sound levels (based on linear regression analyses of L_{Amax} as a function of log of speed), listed from loudest to quietest: cruiser, sport, dual purpose, touring, moped/scooter. The cruiser category exceeded the other categories by 4.2, 6.4, 8.2, and 9.8 dBA, respectively.

There were spectral distinctions among the motorcycle categories, most notable: 1) cruisers have dominant low frequency content (100-400 Hz), with the loudest events having the largest bump in that range and ; 2) sport motorcycles have substantial mid-to-high frequency content (630-8000 Hz) and also lower frequency content (125-500 Hz) contributing to the broadband sound level; 3) dual purpose motorcycles have substantial mid-to-high frequency content (630-8000 Hz) and also lower frequency content (125-200 Hz) contributing to the broadband sound level; 4) touring motorcycles have dominant frequencies in the range of 630-4000 Hz and also at 100 Hz and 8000 Hz; and 5) mopeds/scooters have dominant frequencies in the 1000-2000 Hz range with frequencies down to 200 Hz and up to 5000 Hz also contributing to the broadband sound level. It should be noted that the cruiser category had the loudest and some of the quietest pass-by sound levels, with the loudest contributing extra energy to the 200-315 Hz range; it's possible that about 15 cruisers (21% of the cruisers measured) exceeded federally regulated noise limits, and the likely cause is modifications to the exhaust and/or driver behavior.

A brief examination of groups of motorcycles and sensitive receiver locations (outlooks, hiking trails, campgrounds, visitor centers) showed that groups can generate loud sound levels and the amount of time the sound levels exceed ambient sound levels can be substantial (22 to 64+ seconds for one group). Of the groups of motorcycles examined, some exceeded 60 dBA, the level at which speech interference can occur, for up to 25 seconds. Groups and single motorcycles should be examined further both in terms of metrics to perhaps better quantify the perception of motorcycle noise and also in terms of noise prediction (described further below).

A special research version of TNM was generated with the sound levels and spectral shapes from the five motorcycle categories implemented. A brief analysis examining predicted sound levels as a function of distance for each of the motorcycle categories showed that sound from the cruisers dissipates less quickly while propagating than sound from the other types of motorcycles, due to the substantial low frequency content. It can be projected that sound from cruisers can be heard farther from the road than sound from other types of motorcycles. A thorough validation should be conducted to compare measured and predicted sound levels for both single motorcycles and groups.

Analysis remains to be performed to determine if enough events were available to properly represent each category (likely this is not the case for mopeds/scooters). In addition, it should be determined if each of the categories is statistically different from one another and from the current general motorcycle category in TNM. Depending on the number-of-events analysis and the statistical-differences analysis, it is possible that a recommendation may be made to group certain motorcycle categories together and/or collect more data. When each data set is determined to be sufficient and a special research version of TNM v3.0 (currently being developed) is available, an analysis of sound levels at sensitive receiver locations at various parks should be conducted to help with the understanding of how road noise contributes to sound levels found in park environments.

Additional information (subjective) …
The Blue Ridge Parkway provides an incredible driving experience for motoring enthusiasts, with a twisting road and breathtaking views. It’s understandable why so many motorcyclists partake, whether as individuals or in groups. Even knowing that the National Park is centered

around a road, and that therefore some noise is to be expected, there are still times when loud motorcycles become surprisingly intrusive while trying to enjoy the park (or simply trying to have a conversation). During measurements, numerous park visitors asked research team members what we were doing; upon explaining we were measuring road noise (not specifically motorcycle noise), a majority responded with a comment similar to, “I hope you’re doing something about that motorcycle noise!” Based on these responses and experiencing the noise first-hand, it is concluded that parks could benefit from minimizing loud motorcycle noise, likely caused by equipment modifications and driver behavior.

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APPENDIX A. MEASUREMENT SITE PHOTOS AND INSTRUMENTATION

Included in this appendix are the Blue Ridge Parkway National Park measurement site photos and a list of the key instrumentation deployed at each site.

A.1 Measurement Site Photos

Figure 12 shows a map of the Blue Ridge Parkway with the measurement sites marked by site number (e.g., Site BR01R is marked as "1"). Figures 13-20 show aerial and/or site photos for each measurement site.

Figure 12. Blue Ridge Parkway map with site locations marked by number.

Figure 13. BR01R – Thunder Struck Ridge Overlook, aerial and site photos.

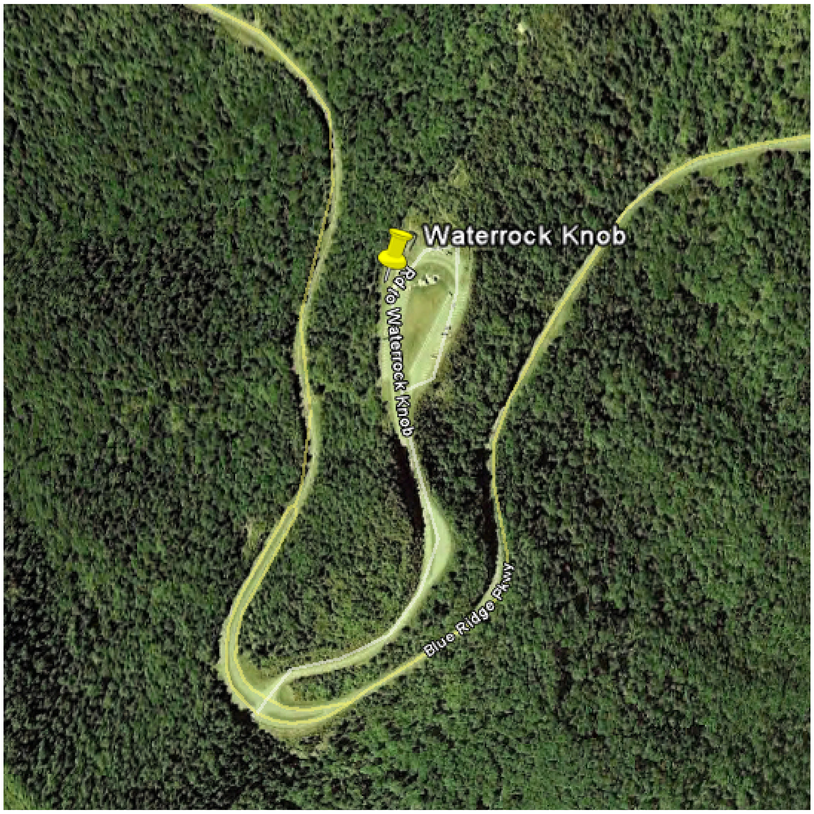

Figure 14. BR02S – Waterrock Knob (near visitor center), aerial and site photos

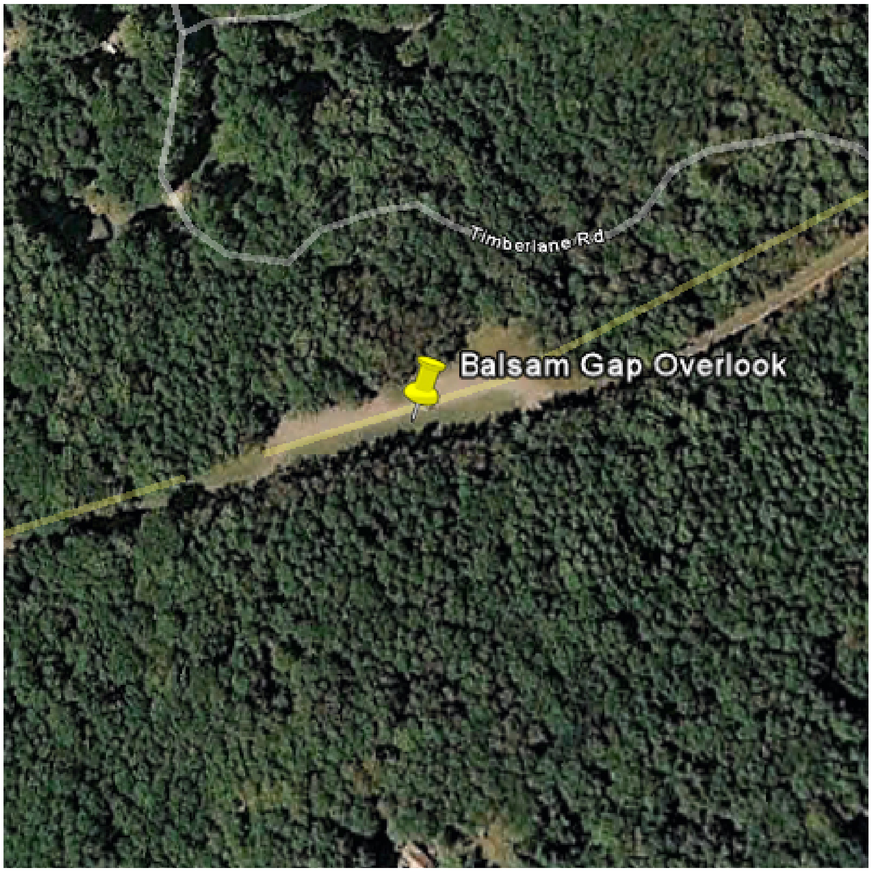

Figure 15. BR03R – Balsam Gap Overlook, aerial and site photos.

Figure 16. BR04R – Grass Ridge Mine Overlook and BR05S – Mountains-to-Sea Hiking Trail, aerial and site (BR04R only) photos.

Figure 17. BR06R – Mt. Pisgah pull-out and BR07S – Mt. Pisgah Campground, aerial and site (BR06R only) photos.

Figure 18. BR08R – Beartrail Ridge Overlook, aerial and site photos.

Figure 19. BR09R – Graveyard Fields Overlook and BR10S – Graveyard Fields Hiking Trail, aerial and site (BR09R only) photos.

Figure 20. BR11R – Devil's Courthouse Overlook, aerial and site photos.

A.2 Measurement Instrumentation

Table 7 lists the measurement sites and instrumentation deployed. Photos of instrumentation deployment can be seen in Section 4 of this document.

Table 7. Measurement sites and deployed instrumentation.

Site ID	Site Location	Microphone Distances*/Heights** (ft)	Other Instrumentation
BR01R	Thunder Struck Ridge Overlook	25/5 50/5 50/12	Radar gun Meteorological sensors Video cameras
BR02S	Waterrock Knob	~250/163 (5 above ground)	Video camera
BR03R	Balsam Gap Overlook	25/5 50/5 50/12	Radar gun Meteorological sensors Video cameras
BR04R	Grass Ridge Mine Overlook	25/5 50/5 50/12	Radar gun Meteorological sensors Video cameras
BR05S	Mountains-to-Sea hiking trail near Grass Ridge Mine Overlook	~200/17 (5 above ground)	
BR06R	Mt. Pisgah pull-out	25/5 50/5 50/12	Radar gun Meteorological sensors Video cameras
BR07S	Mt. Pisgah campground	~545/-72 (5 above ground)	Meteorological sensors
BR08R	Beartrail Ridge Overlook	25/5 50/5 50/12	Radar gun Meteorological sensors Video cameras
BR09R	Graveyard Fields Overlook	25/5 50/5 50/12	Radar gun Meteorological sensors Video cameras
BR10S	Graveyard Fields hiking trail	~1000/-100 (5 above ground)	Meteorological sensors
BR11R	Devil's Courthouse Overlook	25/5 50/5 50/12	Radar gun Meteorological sensors Video cameras

*Distances measured from center of near travel lane
**Heights measured above center of near travel lane, except where noted

APPENDIX B. SOUND LEVEL RESULTS – CRUISE CONDITION

This appendix contains the tabular format of results found in Sections 5.1.2 and 5.2.

B.1 L_{Amax} Values by Motorcycle Type

Table 8 lists the L_{Amax} values for each motorcycle pass-by event as a function of speed. These data are graphically represented in Figure 6.

Table 8. L_{Amax} and speed for all data points, listed by motorcycle type.

Cruiser		Sport		Dual Purpose		Touring		Moped/Scooter	
Speed (ft)	L_{Amax} (dBA)	Speed (ft)	L_{Amax} (dBA)	Speed (ft)	L_{Amax} (dBA)	Speed (ft)	L_{Amax} (dBA)	Speed (ft)	L_{Amax} (dBA)
44	84.8	47	78.3	54	73.4	41	72.1	34	62.3
44	82.2	47	76.1	55	72.7	24	69.1	32	61.7
28	81.4	50	74.5	51	70.2	55	66.3		
44	81.3	39	74.0	44	69.0	39	66.1		
46	80.3	57	72.4	35	67.1	33	65.8		
28	80.2	51	71.8	37	66.8	29	65.7		
29	79.7	57	71.7	36	66.5	46	65.7		
32	78.6	49	71.6	40	66.2	42	65.4		
46	78.6	54	71.1	43	65.3	39	65.0		
30	78.0	54	70.4	33	64.4	44	64.7		
37	77.9	49	69.8			38	64.1		
34	77.2	49	69.5			40	63.8		
42	77.0	44	67.0			45	63.5		
35	77.0	27	66.8			42	63.1		
50	77.0	20	61.1			41	62.0		
32	76.7	28	60.7			34	61.6		
33	76.6								
42	76.3								
28	76.2								
37	76.1								
29	75.9								
50	75.7								
35	75.5								
29	75.5								
50	75.4								
40	75.4								
39	75.4								
42	74.7								
29	74.6								

33	74.6								
37	74.4								
41	74.2								
36	74.2								
29	73.8								
34	73.7								
38	73.7								
47	73.6								
38	73.6								
42	73.3								
33	73.2								
46	73.0								
55	72.5								
27	72.3								
42	72.3								
38	71.6								
45	71.2								
30	70.8								
35	70.3								
35	69.9								
27	69.7								
44	69.7								
30	69.6								
32	69.5								
40	69.4								
35	69.3								
42	69.3								
26	69.3								
38	68.6								
27	67.4								
39	67.3								
27	67.3								
42	67.1								
40	66.8								
29	66.7								
32	66.6								
25	66.5								
36	65.9								
40	65.5								
37	65.3								
30	64.1								
22	63.1								
32	62.2								
32	60.8								

B.2 Spectral Sound Levels by Motorcycle Type

Table 9 lists the one-third octave band sound levels at the time of L_{Amax} for each motorcycle category. The data are graphically represented in Figure 8. Note that this is the arithmetic average for each band, regardless of speed; although all categories of motorcycles except moped/scooter had approximately the same speed ranges, the absolute levels are not necessarily directly comparable – spectral shapes are the main focus with the results presented here.

Table 9. Average spectra for each motorcycle type (not normalized for speed).

Frequency (Hz)	Motorcycle Type				
	Cruiser	Sport	Dual Purpose	Touring	Moped/Scooter
25	27.8	29.0	25.8	29.0	32.1
32	29.1	28.7	27.7	28.4	33.1
40	33.1	29.9	27.4	29.8	32.3
50	39.1	32.0	28.1	31.7	30.9
63	46.1	35.4	41.3	32.7	37.7
80	53.0	43.1	37.9	40.7	34.2
100	59.2	48.6	43.6	50.6	36.7
125	61.1	53.7	52.7	48.1	43.2
160	62.9	54.0	50.4	46.0	43.8
200	63.0	53.1	50.0	47.8	45.3
250	61.5	55.7	47.5	47.6	46.4
315	60.4	52.4	45.9	46.9	46.1
400	56.1	51.3	45.3	45.7	49.2
500	53.1	52.3	48.7	46.8	47.7
630	53.3	54.5	52.5	48.7	49.7
800	54.2	53.4	53.3	50.6	48.1
1000	54.6	55.1	55.7	52.1	53.3
1250	54.6	55.9	57.0	52.8	53.1
1600	54.2	57.5	57.3	52.4	50.7
2000	54.2	57.3	56.9	52.1	50.7
2500	53.8	57.4	55.9	51.4	48.9
3150	53.3	56.1	55.0	50.8	48.4
4000	51.7	55.6	54.2	49.3	45.8
5000	50.6	55.1	54.8	47.3	46.0
6300	48.7	52.6	52.9	44.9	43.7
8000	48.5	51.5	51.8	48.7	43.4
10000	44.1	47.8	47.8	43.6	40.3

B.3 Spectral Sound Levels for Cruiser Category

Table 10 shows the one-third octave band sound levels at the time of L_{Amax} for the cruiser motorcycle category. The sound levels are graphically represented in Figure 9. The results are divided into three broadband level categories: greater than 77 dBA, between 70 and 77 dBA, and less than 70 dBA.

Table 10. Cruiser category: spectra grouped by broadband levels (and shape).

Frequency (Hz)	Motorcycle Type: Cruiser		
	$L_{Amax} \geq 77$ dBA	$70 \leq L_{Amax} < 77$ dBA	$L_{Amax} < 70$ dBA
25	27.6	27.3	28.6
32	28.2	28.5	30.3
40	31.1	34.4	32.8
50	39.1	39.1	39.2
63	44.4	48.1	44.4
80	51.6	56.0	49.9
100	63.2	60.9	54.4
125	66.4	62.3	56.3
160	67.2	65.1	57.3
200	69.6	65.3	56.1
250	70.6	63.0	54.0
315	70.3	61.5	53.2
400	64.7	57.1	49.6
500	61.3	53.5	47.5
630	59.7	54.2	48.2
800	60.7	55.1	49.0
1000	59.5	55.5	50.4
1250	58.8	55.5	50.8
1600	58.4	55.0	50.7
2000	58.1	54.8	51.0
2500	56.6	54.6	50.9
3150	56.9	53.8	50.4
4000	55.0	52.4	48.8
5000	54.0	51.3	47.8
6300	52.2	49.3	45.9
8000	51.8	49.3	45.4
10000	46.7	44.6	41.8

APPENDIX C. SOUND LEVEL RESULTS – FULL THROTTLE CONDITION

Preliminary results for motorcycles under full throttle conditions are found in this appendix; further analysis will need to be conducted in order to determine if the full throttle events are statistically different or if they should be grouped with the cruise condition events.

C.1 Linear Regression of L_{Amax} Values by Motorcycle Type

A linear regression analysis was performed for L_{Amax} as a function of the log of speed for each motorcycle type, and the data are shown in Figure 21 and Table 11. The regression line equation was then used to determine the sound level for each motorcycle type for 30, 40, and 50 mph (48, 64, and 80 km/h) and the average for the three speeds for each type are plotted in Figure 22. In addition to the levels for each motorcycle type measured in this study, Figure 22 also shows the sound level for the general motorcycle category in the national database [Fleming 1996] for comparative purposes.

The regression line coefficients for each motorcycle type are given below:

Cruiser	8.2075x + 64.982
Sport	36.88x + 7.9711
Dual Purpose	32.323x + 15.231
Touring	27.856x + 21.175
Moped/Scooter	no data available

where $x = \log_{10}(\text{speed in mph})$.

The following observations can be made when examining the data. All of the motorcycle categories show an increase in sound level as a function of speed (the moped/scooter category is not shown because there were no data). The sound levels averaged from 30-50 mph (48-80 km/h) indicate the following ranking in motorcycle types, from loudest to quietest: cruiser (78.1 dBA), sport and dual purpose (66.7 dBA), touring (65.5 dBA), with cruisers being substantially louder than the other types (about 11-13 dBA) and the national general category being about 6 dBA lower (72.7 dBA) than the cruiser category.

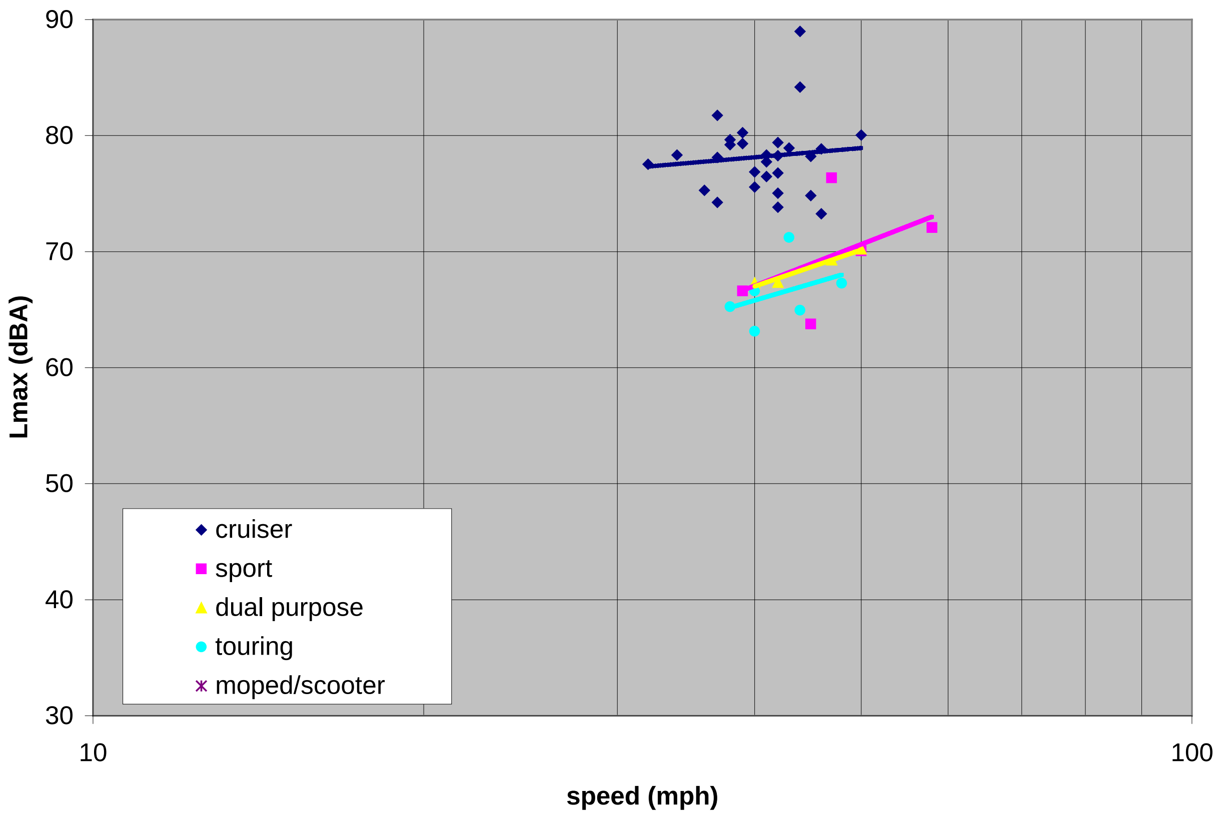

Figure 21. Sound levels as a function of speed for all data points with regression lines for each motorcycle type (full throttle condition).

Table 11. L_{Amax} and speed for all data points, listed by motorcycle type (full throttle condition).

Cruiser		Sport		Dual Purpose		Touring		Moped/Scooter	
Speed (ft)	L_{Amax} (dBA)	Speed (ft)	L_{Amax} (dBA)	Speed (ft)	L_{Amax} (dBA)	Speed (ft)	L_{Amax} (dBA)	Speed (ft)	L_{Amax} (dBA)
44	89.0	47	76.4	50	70.2	43	71.2	no data available	
44	84.2	58	72.1	47	69.3	48	67.3		
37	81.7	50	70.1	42	67.4	40	66.6		
39	80.3	39	66.6	40	67.3	38	65.2		
50	80.1	45	63.8			44	65.0		
38	79.6					40	63.1		
42	79.4								
39	79.3								
38	79.2								
43	78.9								
46	78.9								
41	78.3								

34	78.3								
42	78.3								
45	78.2								
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40	75.6								
36	75.3								
42	75.0								
45	74.8								
37	74.2								
42	73.8								
46	73.3								

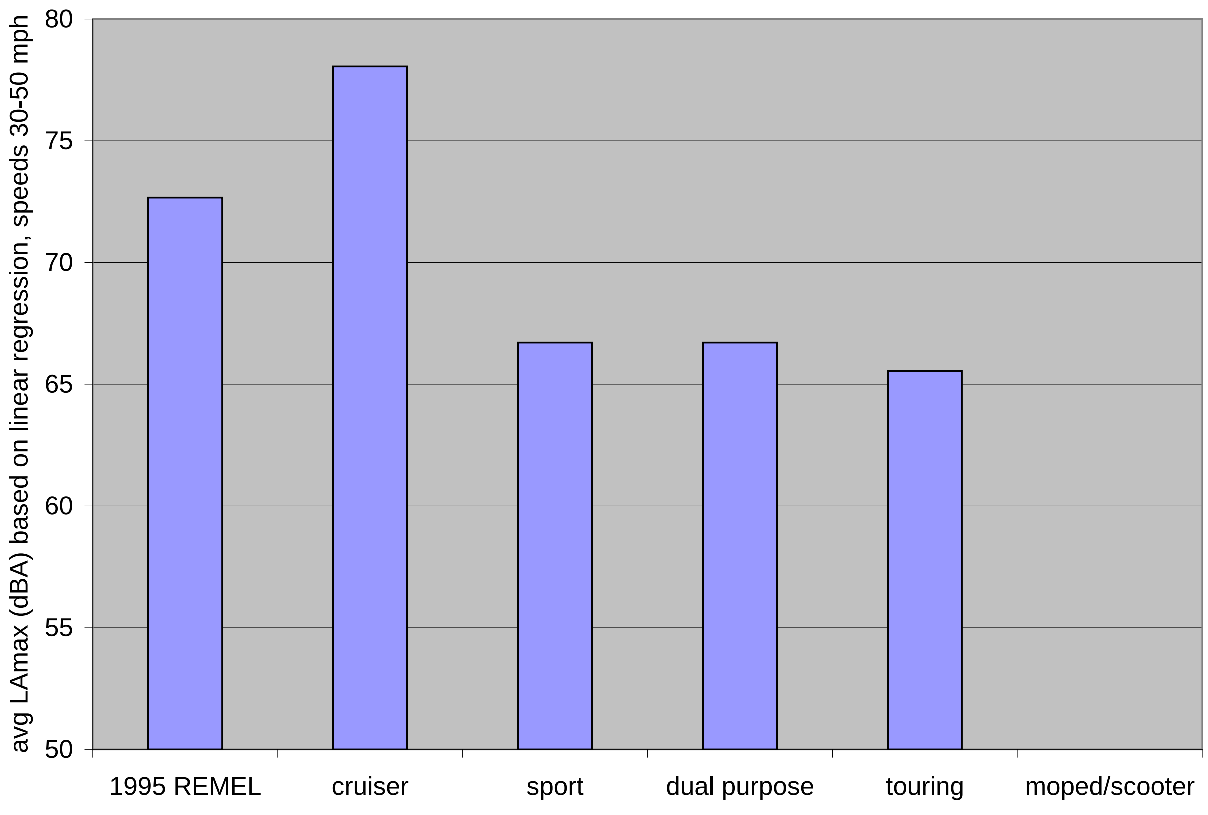

Figure 22. Average sound levels between 30 and 50 mph for each motorcycle category (full throttle condition) and for the general motorcycle category in the 1995 REMELs.

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