High-Speed Non-Electric Locomotive Noise Measurements

HMMH Report No. 298240

October 2001

Prepared for:
Parsons Transportation Group
1133 15th Street NW
Washington, DC
20005-2701

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION AND SUMMARY

This report summarizes the methods and results of train noise measurements carried out on August 30, 2001 at the Transportation Test Center (TTC) in Pueblo, Colorado. The measurements were performed by Harris Miller Miller & Hanson Inc. (HMMH) on behalf of the Federal Railroad Administration (FRA), under subcontract to Parsons Transportation Group (PTG). The objective of the measurements was to obtain wayside noise data during the operation of the High-Speed Non-Electric Locomotive, a locomotive with a lightweight turbine engine that is less than one-tenth the size and approximately 38,000 lb lighter than a traditional diesel engine. Data were obtained for various train speeds and operating conditions during controlled demonstration tests of the locomotive. These data are compared with similar data available for other fossil fuel locomotives.

Noise measurements of the High-Speed Non-Electric Locomotive were performed in an open area adjacent to Railroad Test Track (RTT) Marker R34 at TTC in Pueblo, Colorado. The track at this location is composed of continuous welded rail (CWR) with concrete ties and ballast. The alignment is straight and approximately level. The maximum train speed measured was 130 mph. The measurement sites were on both sides of the track, with two measurement positions (50 ft and 100 ft from the track centerline) outside the loop and one measurement position (50 ft from the track centerline) inside the loop.

1.1 Noise Measurements

The following summarizes the results of the noise measurements:

- The High-Speed Non-Electric Locomotive, consisting of one power unit, generated wayside noise levels similar to those of electric-powered high speed trains such as Acela, TGV and ICE.
- The noise measurements indicated that the High-Speed Non-Electric Locomotive is in full compliance with the Federal Railroad Noise Emission Standard.
- Frequency characteristics of the noise showed no dominating pure tones that are often associated with turbine-powered engines.

2. TRAIN NOISE MEASUREMENTS

2.1 Measurement Procedures and Equipment

Wayside noise measurements of passbys of the High-speed Non-Electric Locomotive were carried out between 8:00 and 11:00 a.m. on August 30, 2001. During this period, a total of 20 passbys of the locomotive were measured. Each passby was measured under pre-determined conditions of speed, operating condition and track. The primary objective of the test was to obtain data over a wide range of train speeds in order to provide an adequate range of data for calibrating the noise model. The use of a single test locomotive under controlled conditions serves to eliminate such variables as terrain, wheel and track condition and other vehicle- and site-specific factors.

Figure 1 provides a schematic of the noise measurement setup. Microphones were positioned at 50 ft and 100 ft from the track centerline to the outside (West) of the loop, and at 50 ft from the track centerline to the inside (East) of the loop. The locomotive traveled southbound at Marker R34, in the counter-clockwise direction with respect to the total RTT loop. As a result, measurements made outside the RTT loop correspond to the right side of the locomotive and those made inside the RTT loop correspond to the left side. The RTT loop is shown in Figure 2.

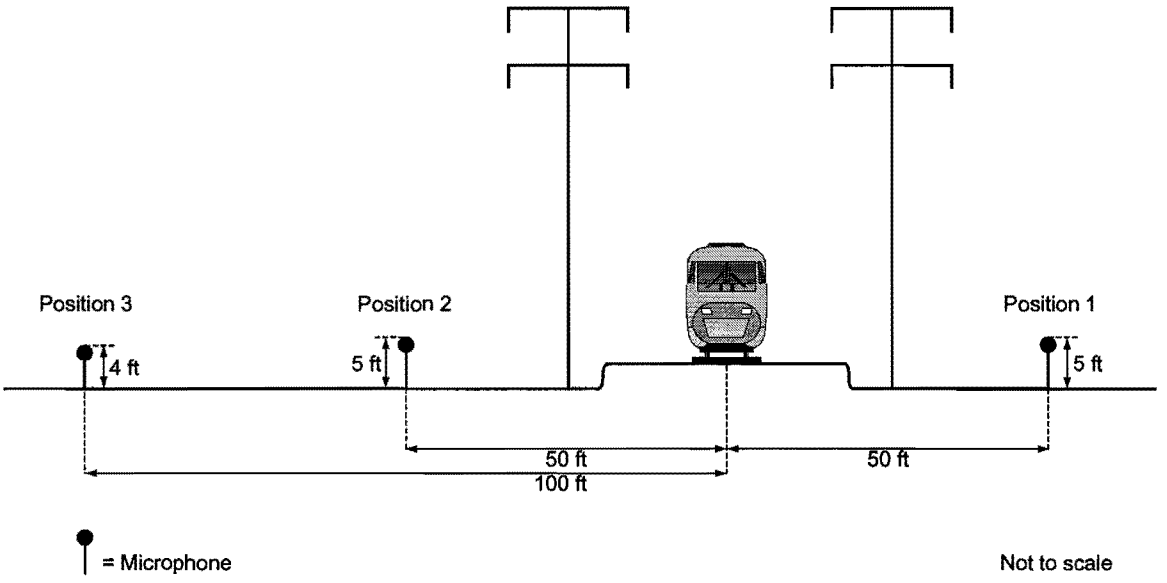


Figure 1. Schematic of Noise Measurement Test Setup

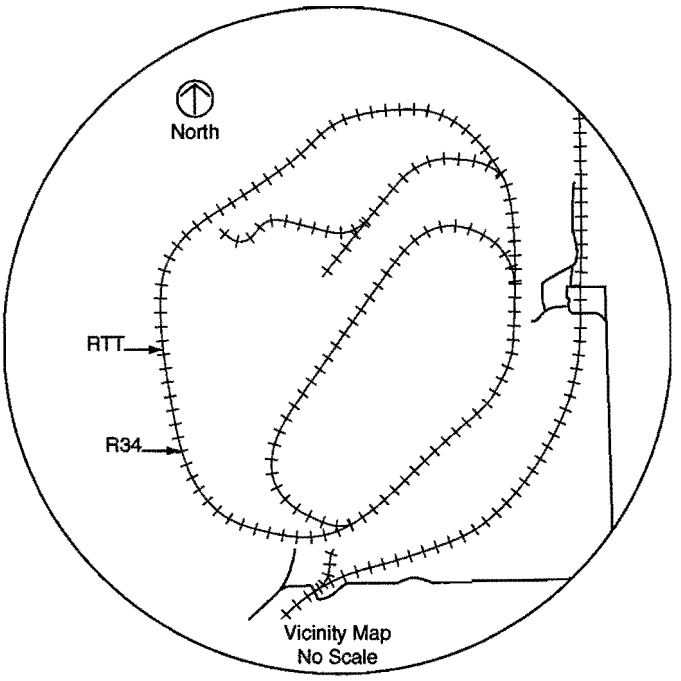


Figure 2. Marker 34 on the RTT at TTC in Pueblo, Colorado

The microphone positions are shown in Figures 3-5. At the 50 ft positions, the microphones were positioned at 5 ft (1.5 m) above the ground. This is a typical position for obtaining reference levels. At the 100 ft position, the microphone was positioned at 4 ft (1.2 m) above the ground in accordance with the measurement procedures in the Environmental Protection Agency (EPA) noise standards.[1] The 100 ft position was chosen as the reference position because it is the standard measurement distance for evaluating compliance with the Federal Railroad Noise Emission Standards.[2]

[1] EPA 40 CFR Part 201, "Noise Emission Standards for Transportation Equipment; Interstate Rail Carriers."
[2] FRA 49 CFR Part 210. "Railroad Noise Emission Compliance Regulations."

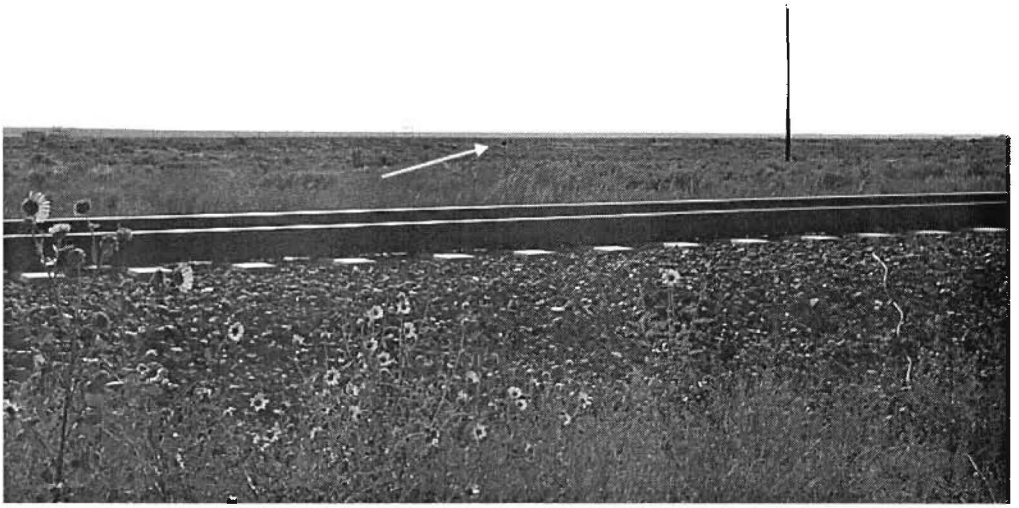


Figure 3. Microphone at Position 1, 50 ft from Centerline of Track Inside Loop

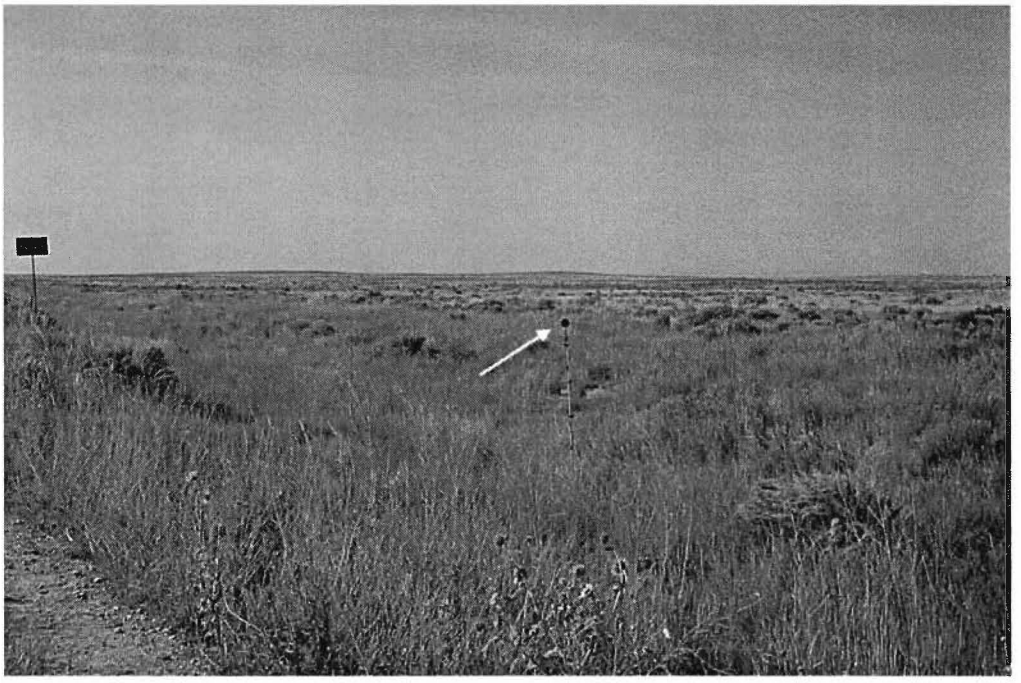


Figure 4. Microphone at Position 2, 50 ft from Centerline of Track Outside Loop

Figure 5. Microphone at Position 3, 100 ft from Centerline of Track Outside Loop

Tape recordings of the noise from each locomotive passby at the 50 ft positions were made using GenRad and G.R.A.S. one-half inch electret microphones and preamplifiers. Tape recordings of the noise at the 100 ft position were made using a Brüel & Kjaer (B&K) Type 2230 sound level meter, conforming to ANSI Standard S1.4 for precision (Type 1) sound level meters. Noise signals corresponding to all of the microphone positions were recorded on digital audio tape (DAT) using SONY recorders (Models TCD-D7PRO and TCD-D8PRO) for subsequent analysis in the HMMH laboratory. The DAT recorder provides 20 kHz of bandwidth for each of the channels of data. Train speeds were obtained using a radar speed detector and were recorded on log sheets.

Calibrations, traceable to the U.S. National Institute of Standards and Technology (NIST), were carried out before and after each set of measurements using an acoustical calibrator. A summary of the field instrumentation used for the noise measurements is provided in Table 1.

Table 1. Field Instrumentation for Noise Measurements

Equipment	Model and Serial Number		
	Position 1 50 ft Inside Track	**Position 2 50 ft Outside Track**	**Position 3 100 ft Outside Track**
Microphone	GR 1962-9810 S/N 15837	G.R.A.S. 40AQ S/N 22175	G.R.A.S. 40AQ S/N 15592
Preamplifier/ Power Supply	GR 1972-9600 S/N DA6	GR 1972-9600 S/N DA4	B&K 2230 S/N 1082194
Line Amplifier	EPAC 60/10LN S/N 090	EPAC 60/10LN S/N 223	----
Tape Recorder	SONY TCD-D7 S/N 67865		SONY TCD-D8 S/N 562675
Calibrator	GR 1987 mini-cal S/N 738262601	B&K 4231 S/N 1314603	B&K 4231 S/N 1314603

Analysis of the field data was carried out in the HMMH laboratory. Initially, the A-weighted maximum noise level (L_{Fmax}) and Sound Exposure Level (SEL) for each train event were obtained directly from the tape-recorded data using a B&K Type 2230 sound level meter. During this analysis, the "fast" response setting on the sound level meter was used as required to evaluate compliance with the Federal Railroad Noise Emission Standards.

Frequency analysis of the events was carried out using a Larson Davis (LD) 2900 Real Time Analyzer to obtain one-third octave band sound pressure level spectra averaged over intervals of maximum event noise levels.

2.2 Measurement Results and Evaluation

The results of the wayside noise measurements are listed in Appendix A, and are presented graphically in Figures 6 and 7. These figures show A-weighted noise level versus train speed at a 5 ft microphone height at the two 50 ft microphone positions in terms of SEL. Also plotted in each figure is a curve representing the mathematical model of locomotive noise as a function of speed, which is based on a standard rail noise model empirically calibrated to fit the data as described below.

Data from Figures 6 and 7 were used to develop a speed coefficient, K, describing the relationship between noise level and speed, which was used as a parameter in the development of a train noise model for the High-Speed Non-Electric Locomotive. This coefficient was calculated using a least-mean-squares regression method. The following speed adjustment to SEL at a given speed V (in mph) was found to best fit the data:

$$\Delta SEL(locomotive) = 7 \times \log\left(\frac{V}{Vref}\right)$$

where $Vref$ = a reference train speed, in miles per hour. Since the overall maximum level was caused by the locomotive (i.e. gas turbine power unit), this speed relationship applies only to locomotive noise. The relationship of SEL as a function of train speed based on a speed coefficient of 7 is shown in Figure 8.

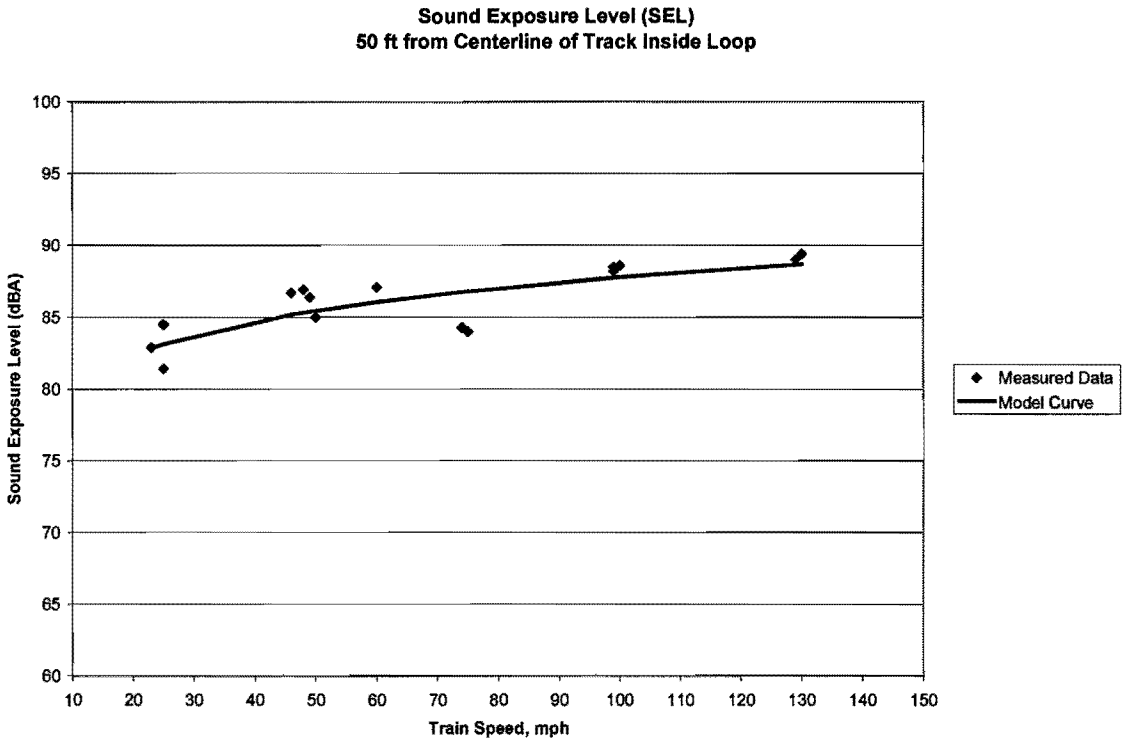


Figure 6. Measured SEL as a Function of Speed, 50 ft from Centerline of Track Inside Loop

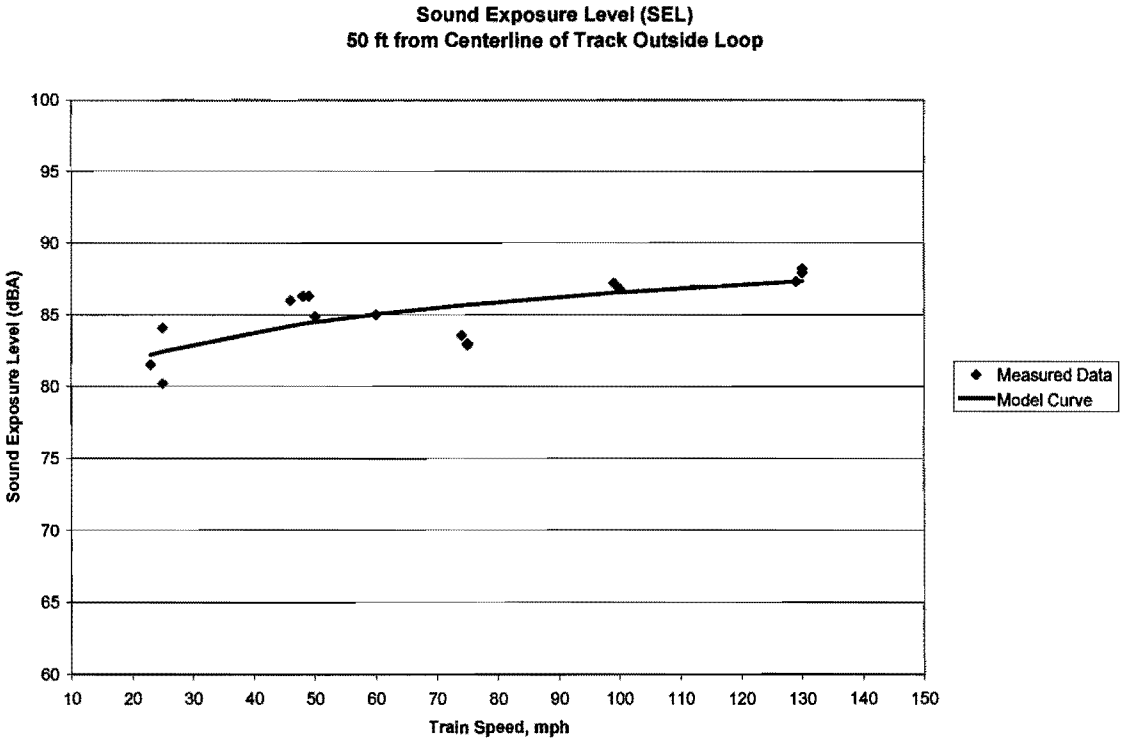


Figure 7. Measured SEL as a Function of Speed, 50 ft from Centerline of Track Outside Loop

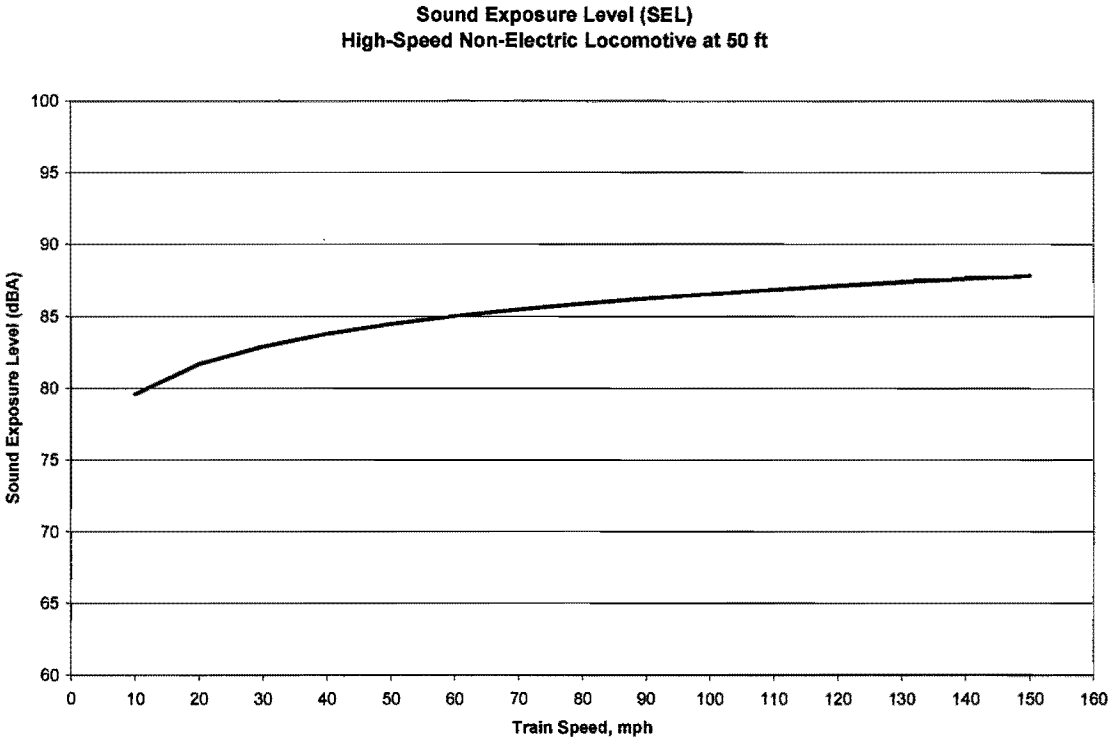


Figure 8. Relationship of SEL versus Train Speed for K=7 at 50 ft

Figures 9-14 show the noise spectra of the recorded High-Speed Non-Electric Locomotive noise data, in the form of one-third octave band sound pressure level spectra. The overall A-weighted sound level corresponding to each spectrum is also shown at the far right of each plot. Figure 9 shows the High-Speed Non-Electric Locomotive noise spectrum over a range of speeds, measured at a reference distance of 100 ft from the track. In general, the increase in speed corresponds to a broad-band increase in sound pressure level.

Figures 10-14 show examples of the High-Speed Non-Electric Locomotive noise spectra over a range of speeds, measured at 50 ft on either side of the loop and 100 ft outside of the loop. At lower speeds, low-frequency noise (31.5 to 100 Hz) makes a significant contribution to the overall level. At 100 mph and 130 mph, the noise spectra appear more evenly distributed, with significant energy at frequencies from 31.5 to 3150 Hz contributing to the overall level. At 100 mph, there is also a peak at 630 Hz, but in general, the spectra do not show a dominating pure tone often found in turbine engines.

Maximum noise spectra from all of the train passbys that were measured are provided in Appendix B.

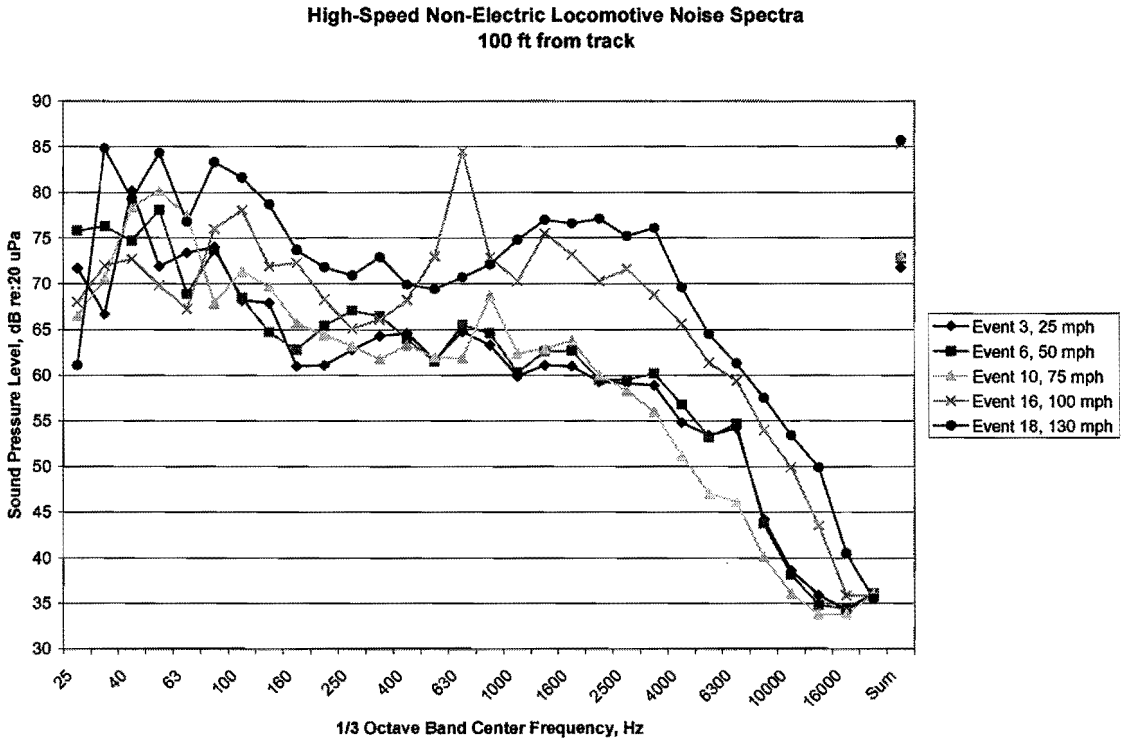


Figure 9. High-Speed Non-Electric Locomotive Noise Spectra at 100 ft

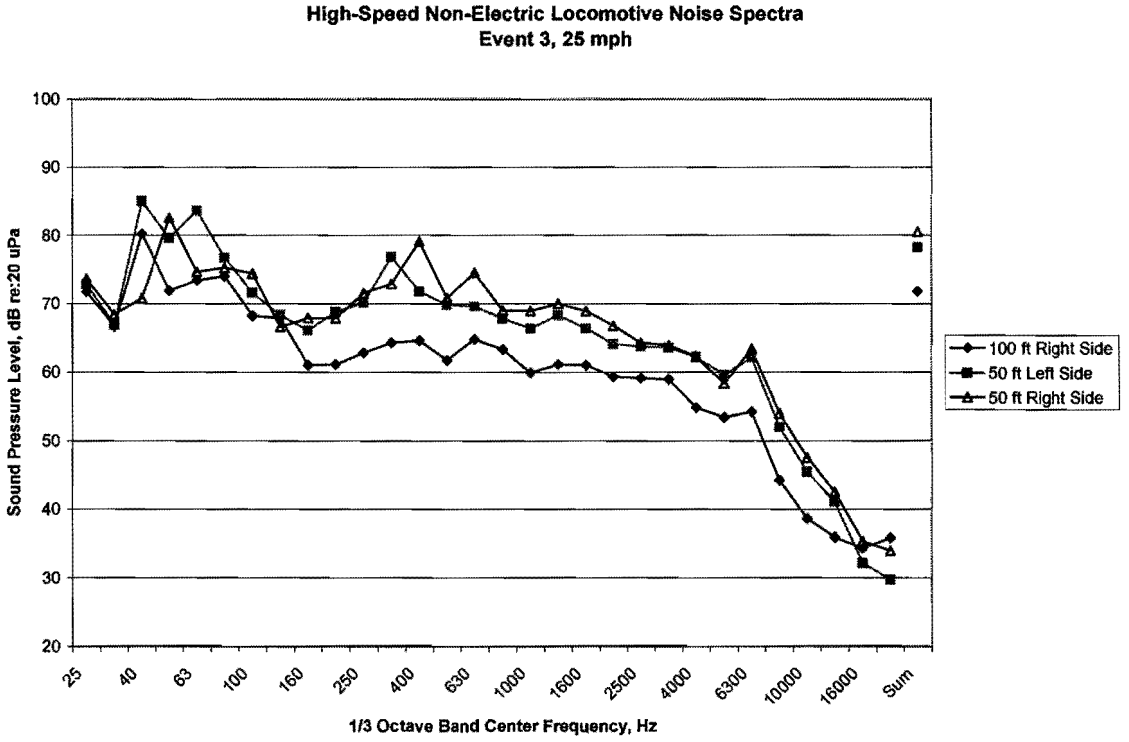


Figure 10. High-Speed Non-Electric Locomotive Noise Spectra, 25 mph

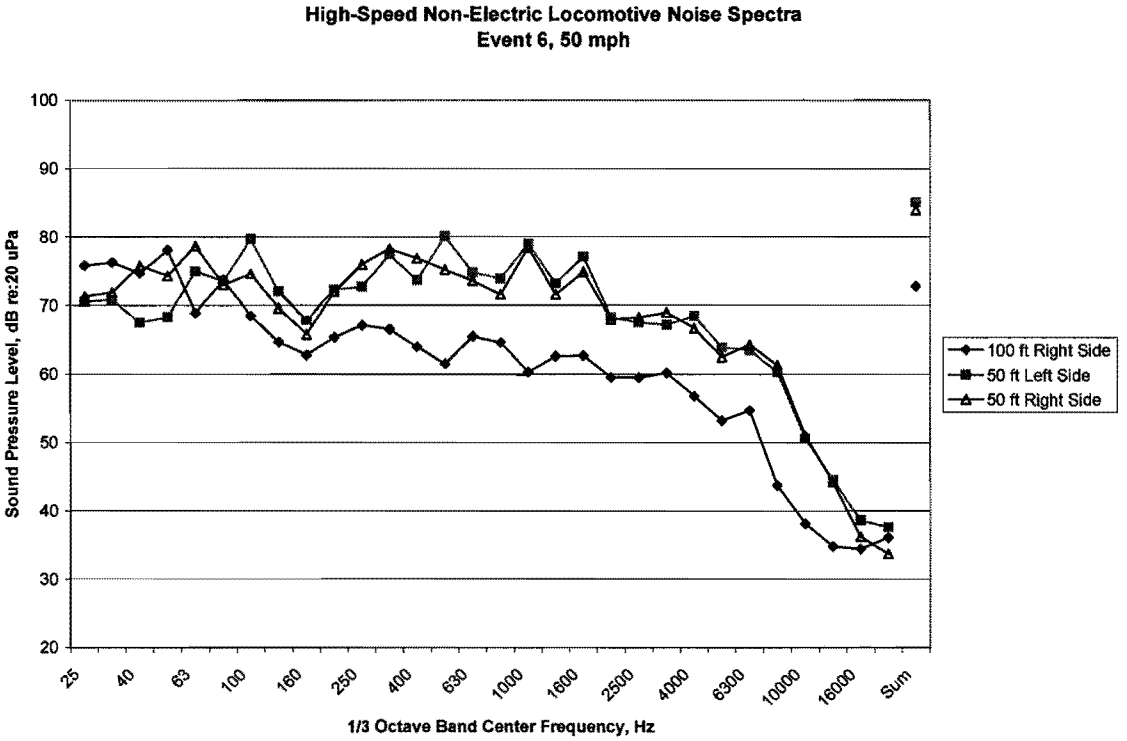


Figure 11. High-Speed Non-Electric Locomotive Noise Spectra, 50 mph

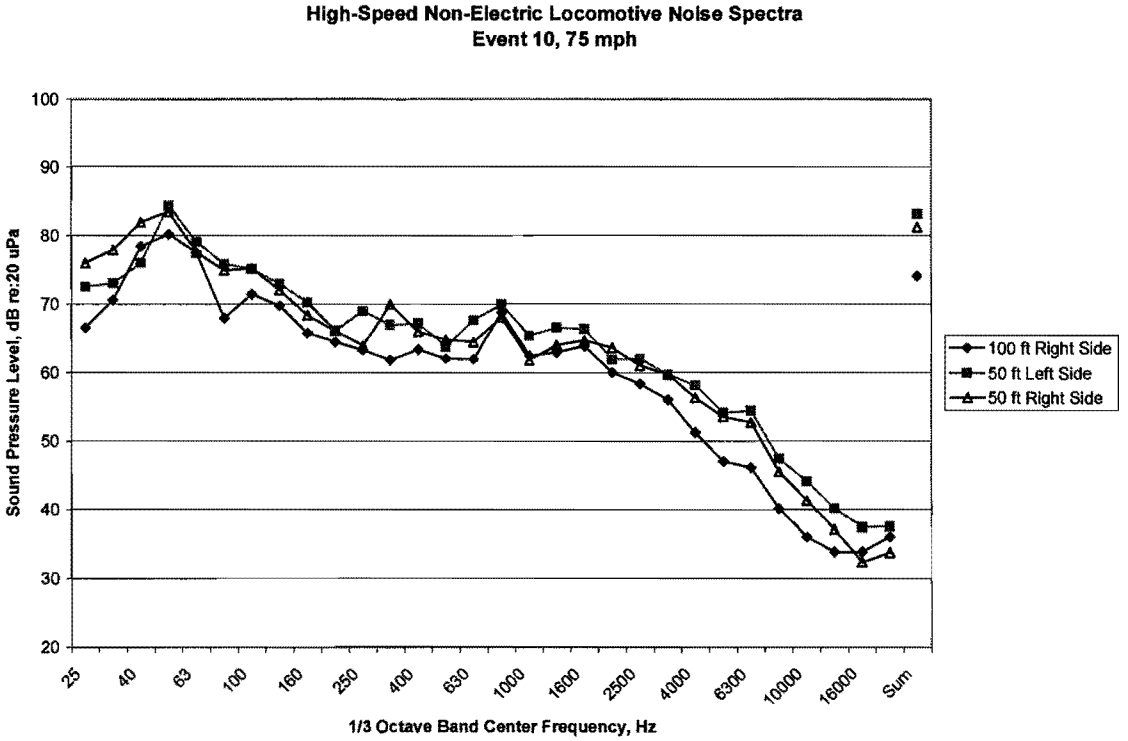


Figure 12. High-Speed Non-Electric Locomotive Noise Spectra, 75 mph

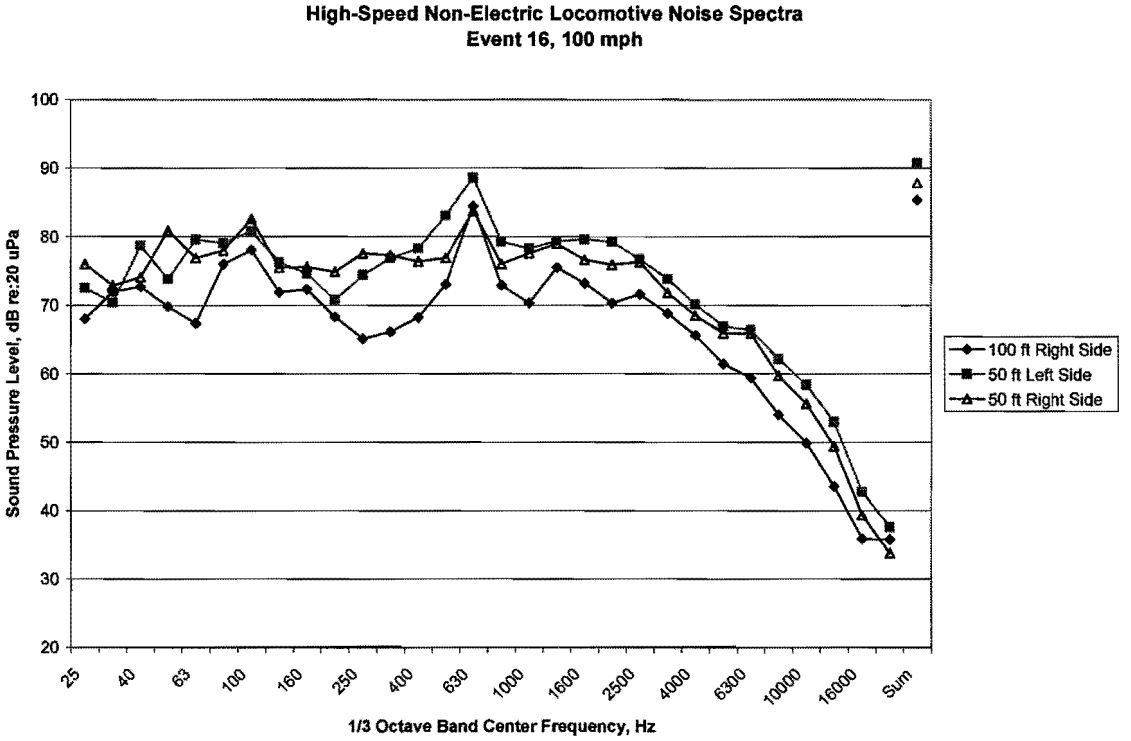


Figure 13. High-Speed Non-Electric Locomotive Noise Spectra, 100 mph

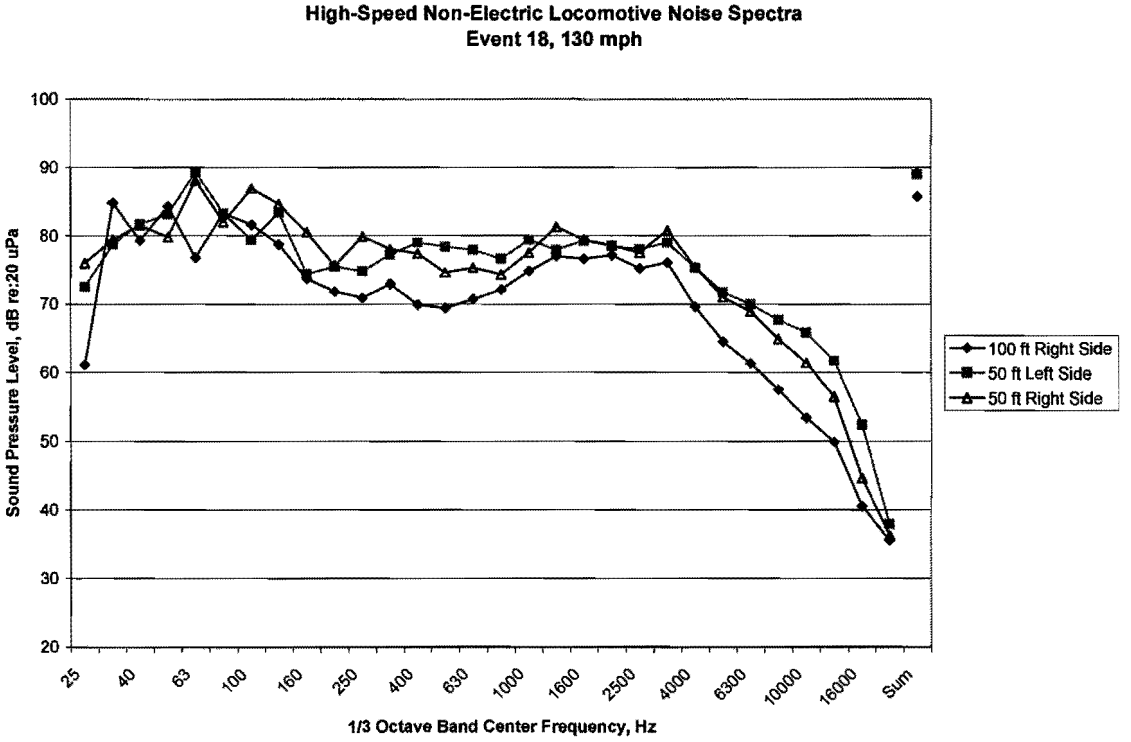


Figure 14. High-Speed Non-Electric Locomotive Noise Spectra, 130 mph

2.3 Application to FRA High Speed Rail Guidance Manual

Table 5-2 of the High-Speed Ground Transportation Noise and Vibration Impact Assessment[3] guidance manual provides source reference SELs to be used in computing noise exposure for five system categories. The levels reported in the manual are based on the results of the background measurement and research program that preceded the preparation of the manual. The program resulted in an extensive database of noise data on most existing high-speed rail systems and is reasonably accurate for the existing technologies. However, as noted in the guidance manual, when specific equipment has been selected for a project, it will be more accurate to base the impact assessment on noise measurements of that equipment.

Table 2 provides the source reference SELs at 50 ft for high-speed fossil fuel locomotives as reported in the FRA guidance manual and for the High-Speed Non-Electric Locomotive as determined from the recent measurements of the locomotive.

Table 2. Source Reference SELs for High-Speed Fossil Fuel Propulsion Units at 50 ft

System Category and Features	Example Systems	Subsource Component	Subsource Parameters		Reference Quantities			
			Length Definition, *len*	Height above rails (ft)	SEL_{ref} (dBA)	len_{ref} (ft)	S_{ref} (mph)	K
High Speed Fossil Fuel • Steel-Wheeled • High-Speed • Locomotive -Hauled • Fossil Fuel Power	RTL-2 Talgo (gas turbine)*	Propulsion	len_{power}	10	83	73	20	10
	High-Speed Non-Electric	Propulsion	len_{power}	10	82	70	20	7
*Source: Table 5-2, High-Speed Ground Transportation Noise and Vibration Impact Assessment, U.S. Department of Transportation Federal Railroad Administration, December 1998.								

As shown in Table 2, the reference SEL and K values determined for the High-Speed Non-Electric Locomotive are similar to those provided for other high speed fossil fuel propulsion units in the FRA guidance manual.

2.4 Compliance with Federal Railroad Noise Emission Standards

Pursuant to the Noise Control Act, the Environmental Protection Agency (EPA) has issued noise emission standards for specific types of railroad equipment (40 CFR Part 201). FRA has adopted these regulations for the purpose of enforcement in the FRA Railroad Noise Emission Compliance Regulations (40 CFR Part 210). The standards provide specific noise limits for stationary and moving locomotives, moving railroad cars, active retarders, car coupling and locomotive load cell test stands in terms of the A-weighted sound level at a specified measurement location. Table 3 summarizes the standards for locomotives and rail cars that are relevant to the measurements of the locomotive passby noise

[3] High-Speed Ground Transportation Noise and Vibration Impact Assessment, U.S. Department of Transportation Federal Railroad Administration, December 1998.

summarized in this report. The results obtained from these measurements were compared with the standards and allowable tolerances to determine compliance with the federal regulations

Table 3. Summary of Applicable EPA Railroad Noise Standards

Noise Source	Operating Condition	Noise Metric	Measurement Distance	Standard
Non-Switcher Locomotives built after 12/31/79	Moving	L_{max} (fast)	100 ft	90 dBA
Railroad Cars	Speed ≤ 45 mph	L_{max} (fast)	100 ft	88 dBA
	Speed ≥ 45 mph	L_{max} (fast)	100 ft	93 dBA

The noise measurements that were performed on August 30, 2001, were of the High-Speed Non-Electric Locomotive only. No cars were measured. For this reason, only the EPA standard for railroad locomotives is applicable to this measurement program. Thus, the applicable standard is an L_{Fmax} of 90 dBA for a moving locomotive at a distance of 100 ft from the receiver, plus the allowable measurement tolerance. This tolerance is defined in 49 CFR §210.25 as 2 dBA, and is intended to account for rounding errors, instrument tolerances, topographical variations, atmospheric conditions and reflected sound effects. In other words, a moving locomotive would be considered not in compliance with the Federal Noise regulation whenever the measured L_{Fmax} at a perpendicular distance of 100 ft from the track centerline exceeds 90 dBA ± 2 dBA.

The noise measurement of the High-Speed Non-Electric Locomotive were conducted using a 100 ft microphone position in compliance with the measurement procedure described in 40 CFR Part 201. Of the 20 locomotive passbys recorded at this distance in the field, all resulted in maximum noise levels below the limit described above. As shown in Figure 15, the maximum measured noise level generated by a passby at a distance of 100 ft from the track centerline is 85 dBA, which is 5 dB below the limit.

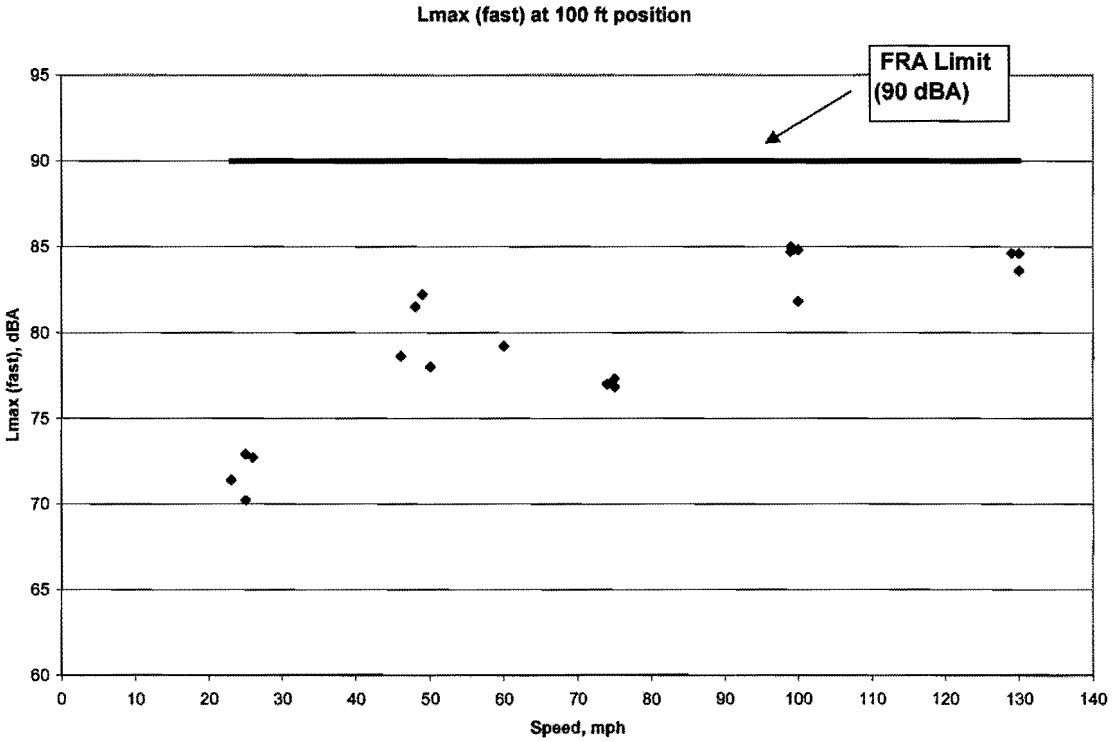


Figure 15. Measured Lmax (fast) at 100 ft

2.5 Comparison with Other High-Speed Trains

The results of the noise measurements on the High-Speed Non-Electric Locomotive at TTC are shown in Figure 16 along with a comparison with data taken for other high-speed trains. Included in Figure 16 are the Acela at TTC and the Acela on the Northeast Corridor (NEC). Also shown for comparison are plots of noise data of the Swedish X2000 and the German ICE taken several years prior at the same site on the NEC.[4]

This comparison is not strictly a fair comparison of noise since noise from the High-Speed Non-Electric Locomotive was measured without a consist of coaches. However, the comparison shown in Figure 16 indicates that the noise generated by High-Speed Non-Electric Locomotive is comparable to other high-speed trains measured in the past.

[4] Carl E. Hanson, David A. Towers, and Herbert L. Singleton. "Acela Trainset Noise and Vibration Measurements on the Northeast Corridor." HMMH Report No. 295450-3 prepared for PTG/DeLeuw Cather Inc. under FRA Task Order 205, October 2000.

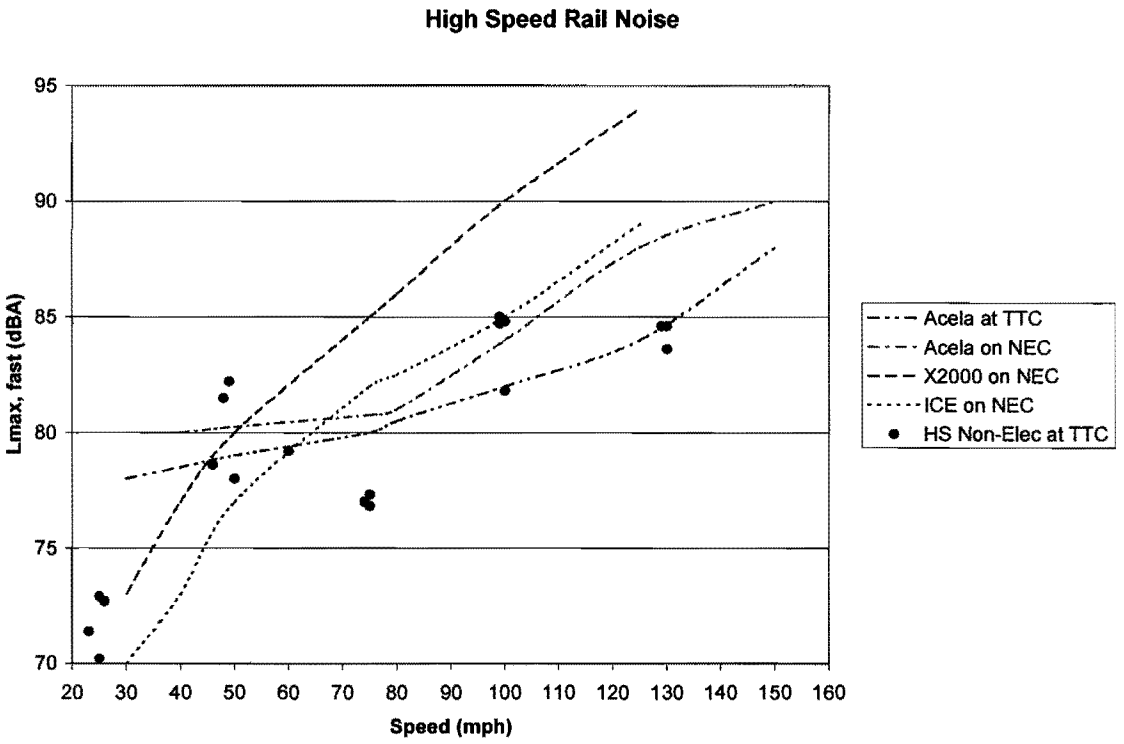


Figure 16. High-Speed Non-Electric Locomotive Noise vs. Other HSR Noise

APPENDIX

A. TRAIN NOISE DATA

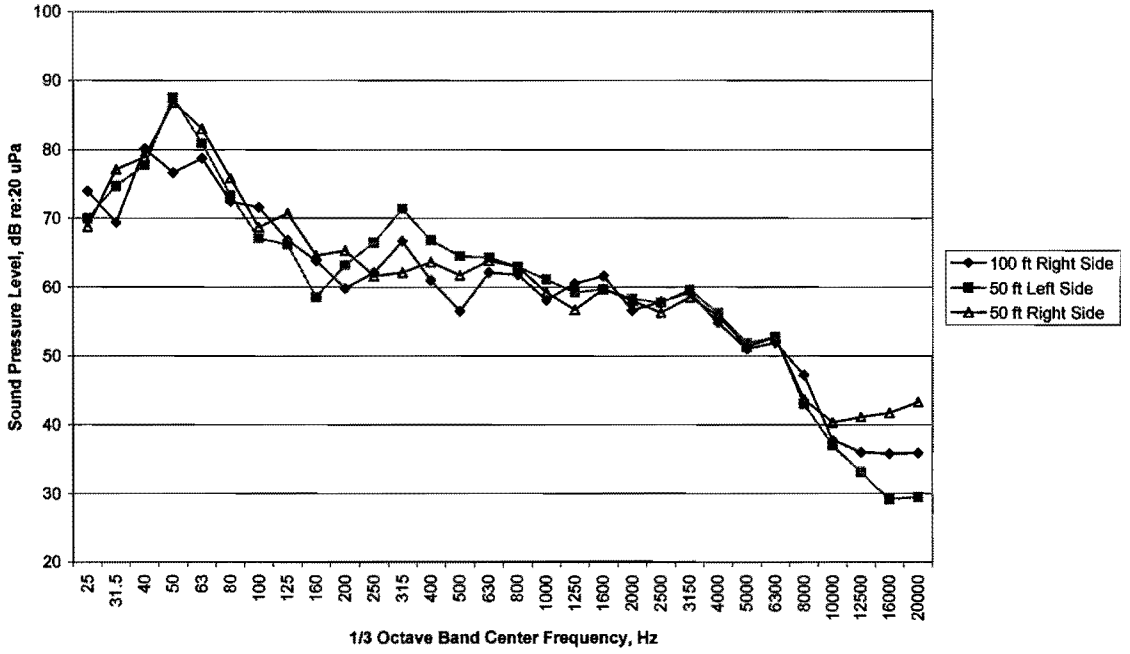
Table 4 provides a listing of the results of noise measurements performed for the High-Speed Non-Electric Locomotive on August 20, 2001 at the Transportation Test Center in Pueblo, Colorado. The results are given in terms of A-weighted Sound Exposure Level (SEL), Maximum Noise Level – fast response (L_{Fmax}) and Maximum Noise Level – slow response (L_{Smax}).

Table 4. Summary of High-Speed Non-Electric Locmotive A-Weighted Noise Level Results

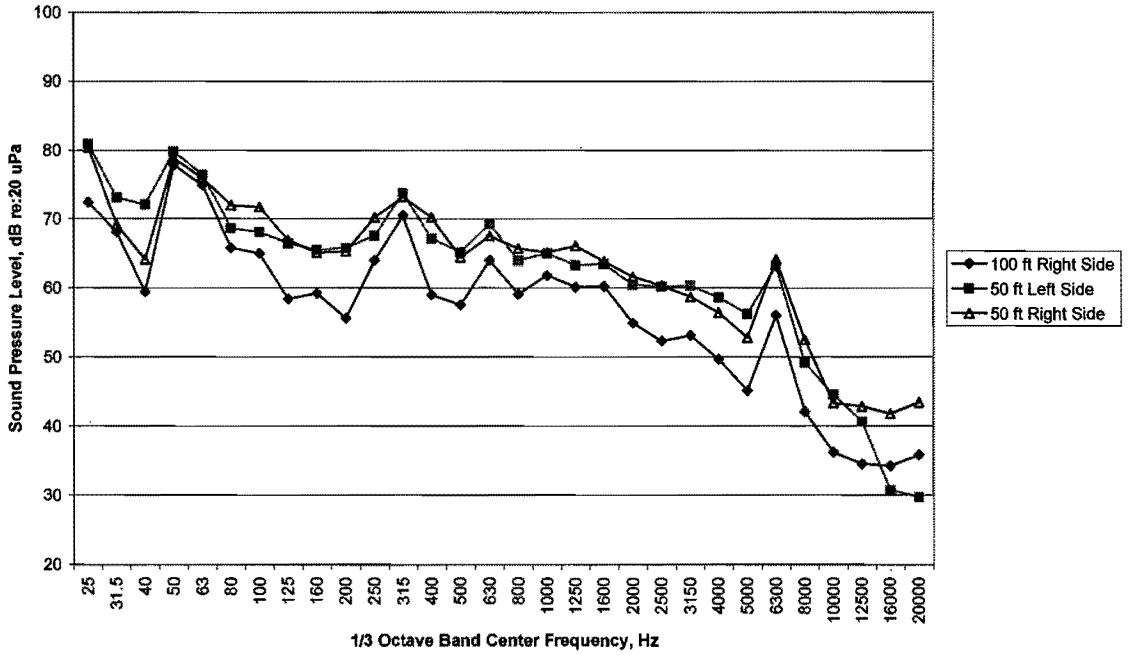
Event	Time	Speed (mph)	Position 1 (50' Left Side of Locomotive)			Position 2 (50' Right Side of Locomotive)			Position 3 (100' Right Side of Locomotive)		
			SEL	L_{Fmax}	L_{Smax}	SEL	L_{Fmax}	L_{Smax}	SEL	L_{Fmax}	L_{Smax}
1	8:53	23	82.9	78.7	77.3	81.5	77.3	76.1	77.2	71.4	70.4
2	8:57	25	81.4	78.6	76.4	80.2	77.6	75.2	75.3	70.2	68.8
2a	8:59	26	--	--	--	--	--	--	78.6	72.7	71.8
3	9:03	25	84.5	80.8	79.1	84.1	80.9	79.0	79.0	72.9	72.2
4	9:07	46	86.7	84.8	82.8	86.0	84.7	82.4	81.2	78.6	77.0
5	9:10	48	86.9	86.6	83.6	86.3	86.4	83.4	81.7	81.5	78.6
6	9:13	50	85.0	84.6	81.6	84.9	84.8	81.6	80.5	78.0	75.9
7	9:17	49	86.4	85.6	83.0	86.3	87.0	83.4	82.3	82.2	78.8
8	9:22	60	87.1	86.9	84.0	85.0	84.9	82.0	81.3	79.2	77.3
9	9:28	75	84.0	83.8	81.1	83.0	83.4	80.3	78.6	76.8	74.7
10	9:32	75	84.0	83.9	81.1	82.9	83.3	80.3	78.8	77.3	75.1
11	9:37	74	84.3	84.8	81.6	83.6	84.5	80.8	78.9	77.0	74.9
12	9:42	Accel from stop	91.0	80.5	79.5	90.1	78.5	77.8	84.5	73.1	72.0
13	9:44	Idle	94.9	81.4	79.2	94.6	79.7	78.9	87.2	73.2	72.3
14	9:47	Accel from 25 mph	84.8	81.1	79.5	84.4	80.2	78.7	79.2	73.2	72.3
15	10:01	99	88.2	90.5	86.0	87.2	88.7	85.0	84.2	84.7	81.5
15a	10:09	100	--	--	--	--	--	--	82.0	81.8	79.0
16	10:16	100	88.6	90.8	86.5	86.8	88.4	84.6	84.8	84.8	81.4
17	10:23	99	88.5	90.1	86.2	87.2	88.8	84.9	84.3	85.0	81.4
18	10:30	130	89.4	91.0	87.2	88.2	90.2	86.4	83.8	84.6	81.6
19	10:37	130	89.4	91.3	87.3	87.9	90.0	86.0	83.5	83.6	81.0
20	10:45	129	89.0	90.6	86.8	87.3	89.3	85.4	83.8	84.6	81.4

B. TRAIN NOISE MAXIMUM SPECTRA

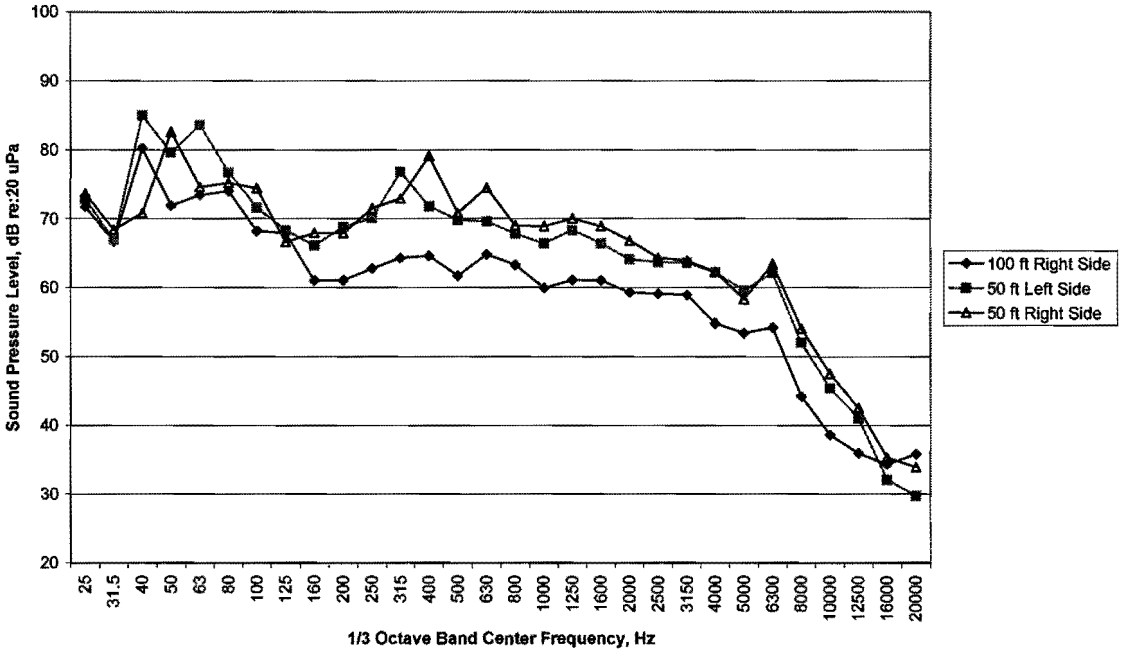
High-Speed Non-Electric Locomotive Noise Spectra
Event 1, 23 mph



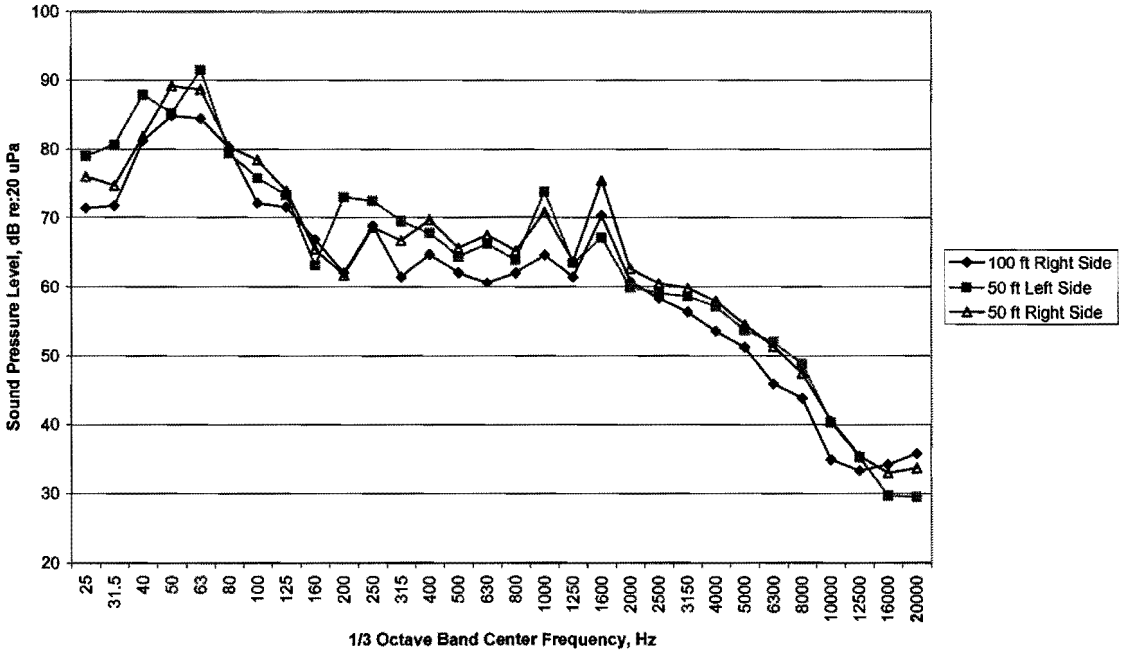
High-Speed Non-Electric Locomotive Noise Spectra
Event 2, 25 mph



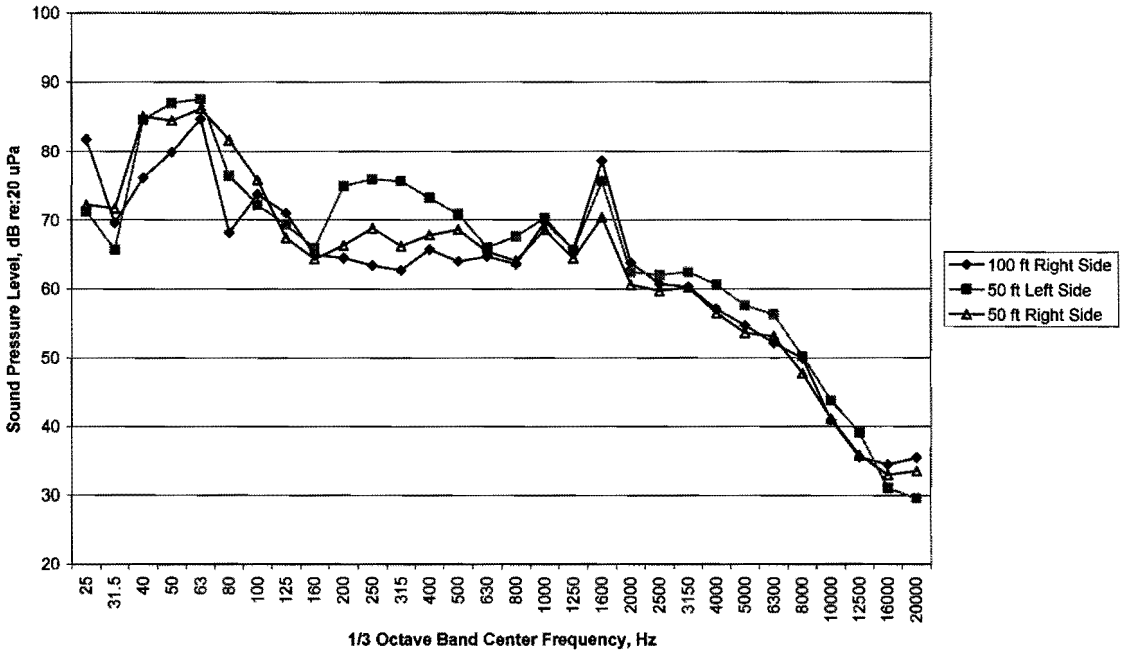
High-Speed Non-Electric Locomotive Noise Spectra
Event 3, 25 mph



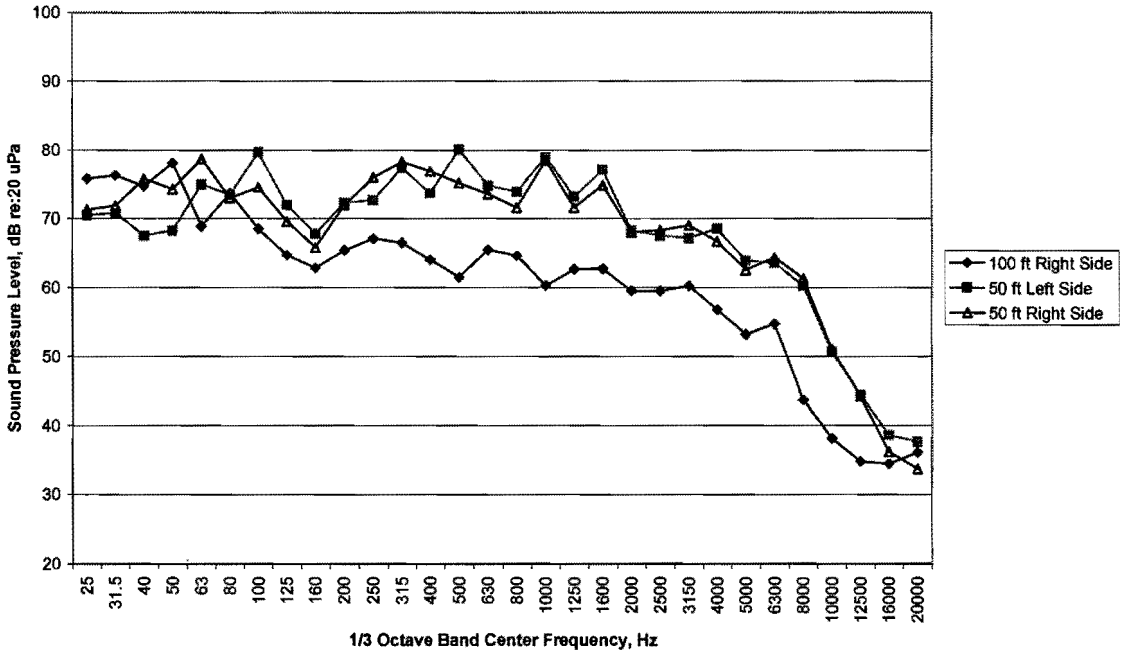
High-Speed Non-Electric Locomotive Noise Spectra
Event 4, 46 mph



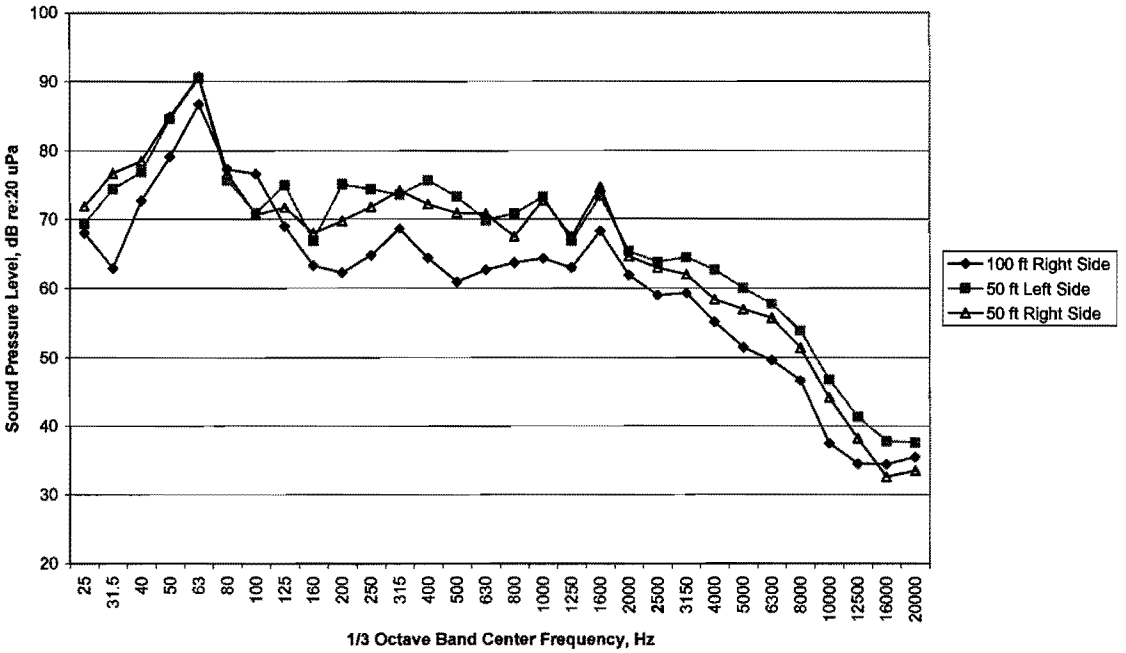
High-Speed Non-Electric Locomotive Noise Spectra
Event 5, 48 mph



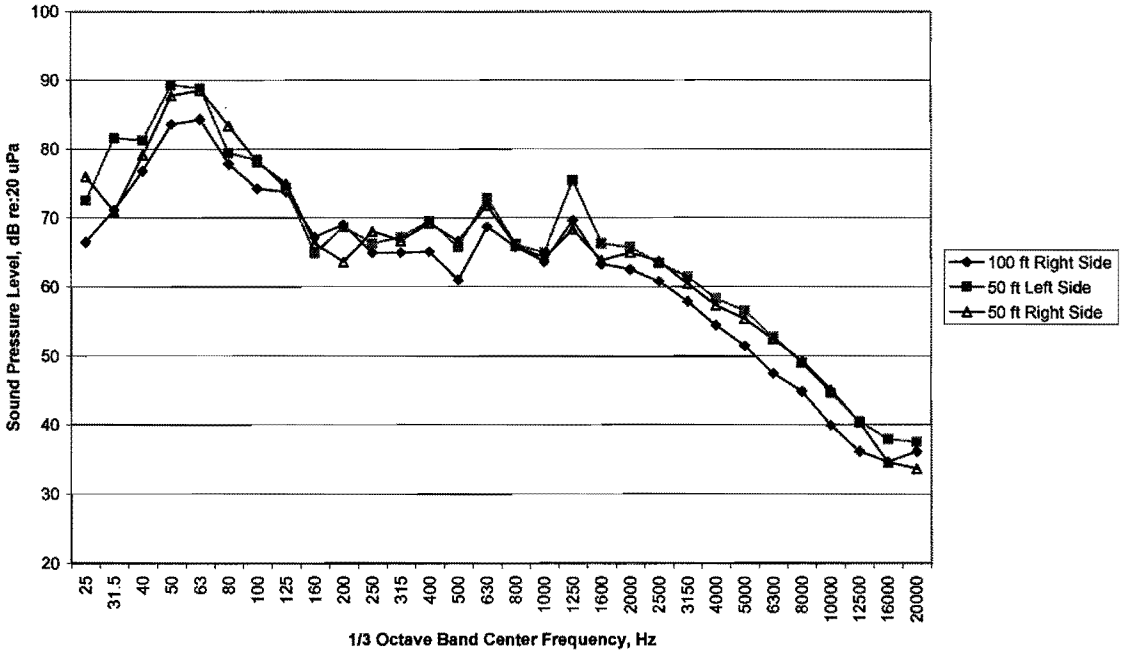
High-Speed Non-Electric Locomotive Noise Spectra
Event 6, 50 mph



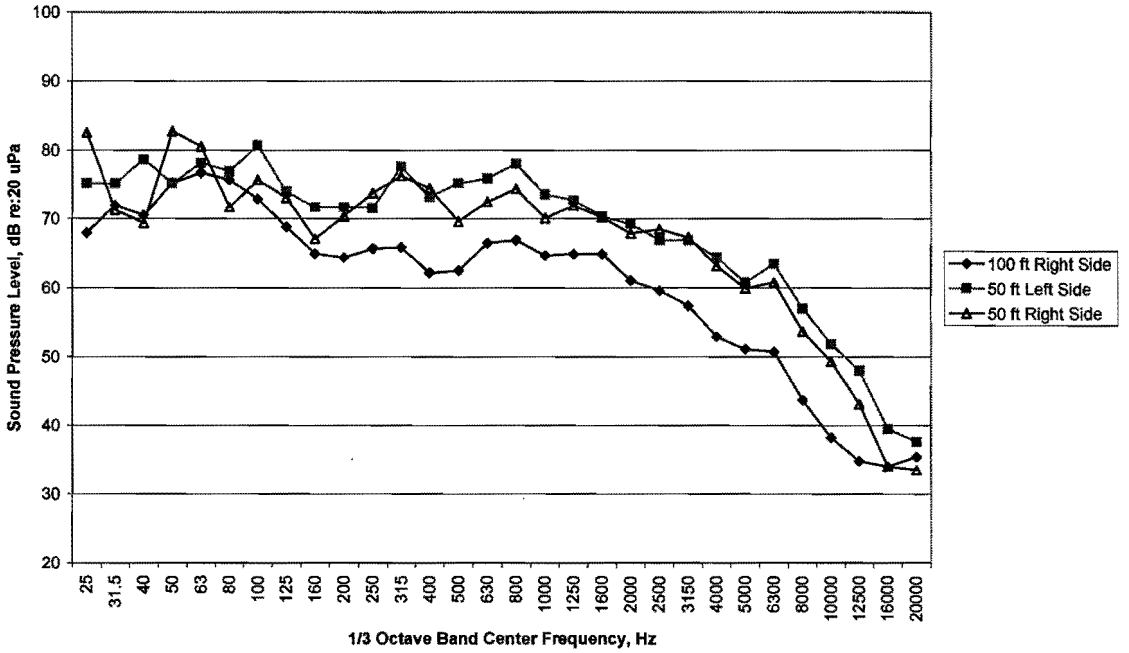
High-Speed Non-Electric Locomotive Noise Spectra
Event 7, 49 mph



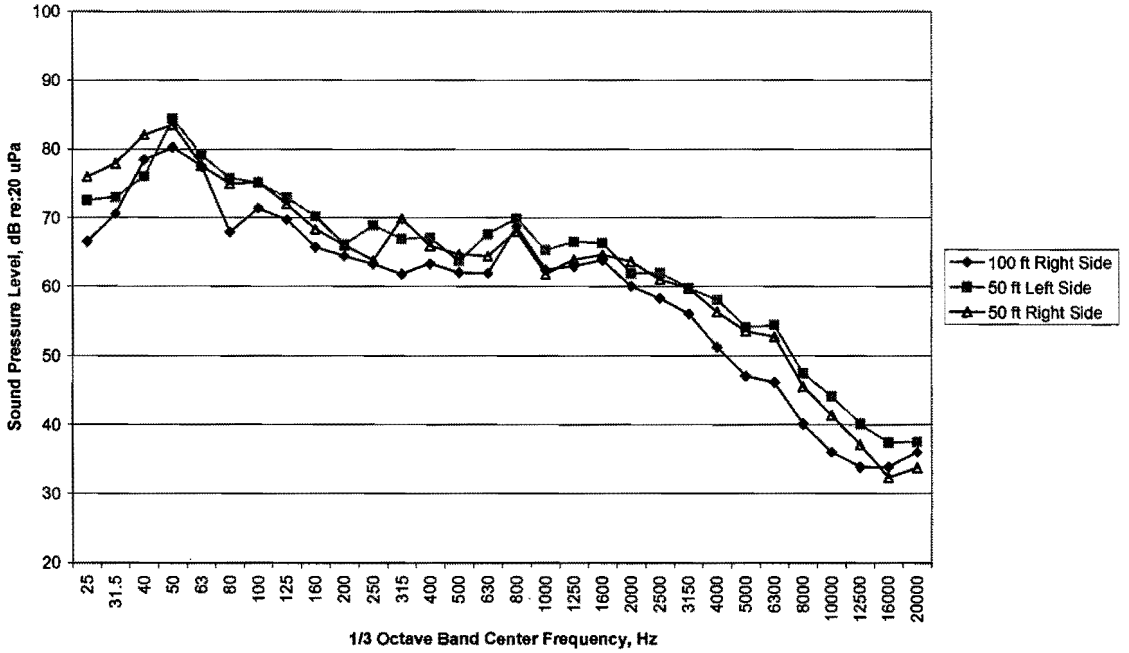
High-Speed Non-Electric Locomotive Noise Spectra
Event 8, 60 mph



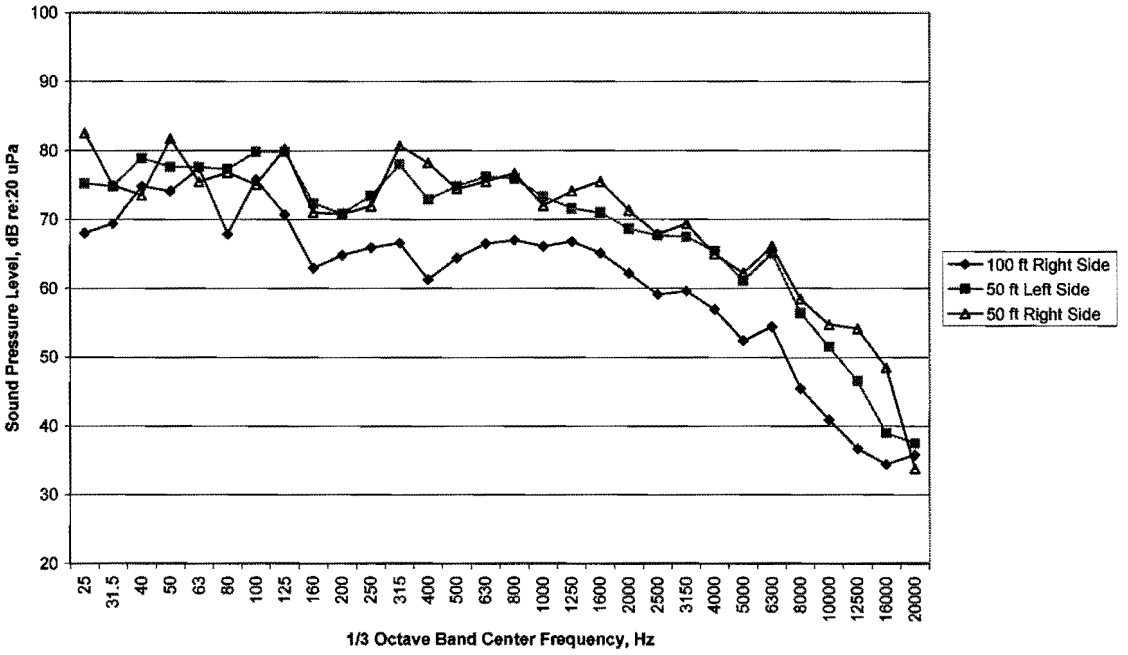
High-Speed Non-Electric Locomotive Noise Spectra
Event 9, 75 mph



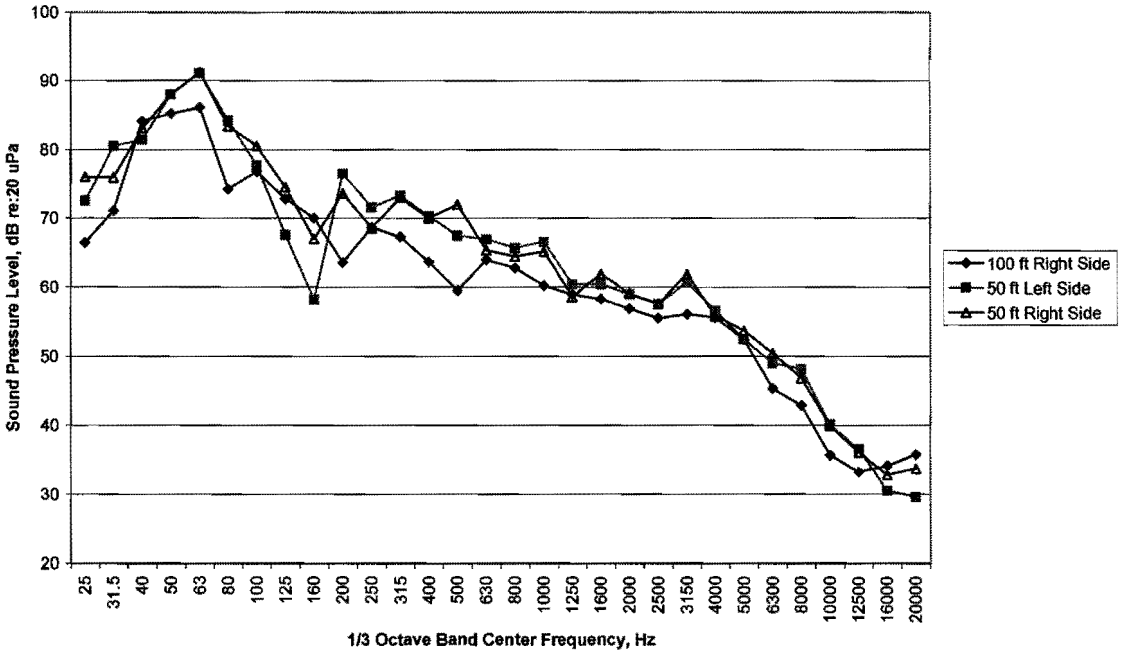
High-Speed Non-Electric Locomotive Noise Spectra
Event 10, 75 mph



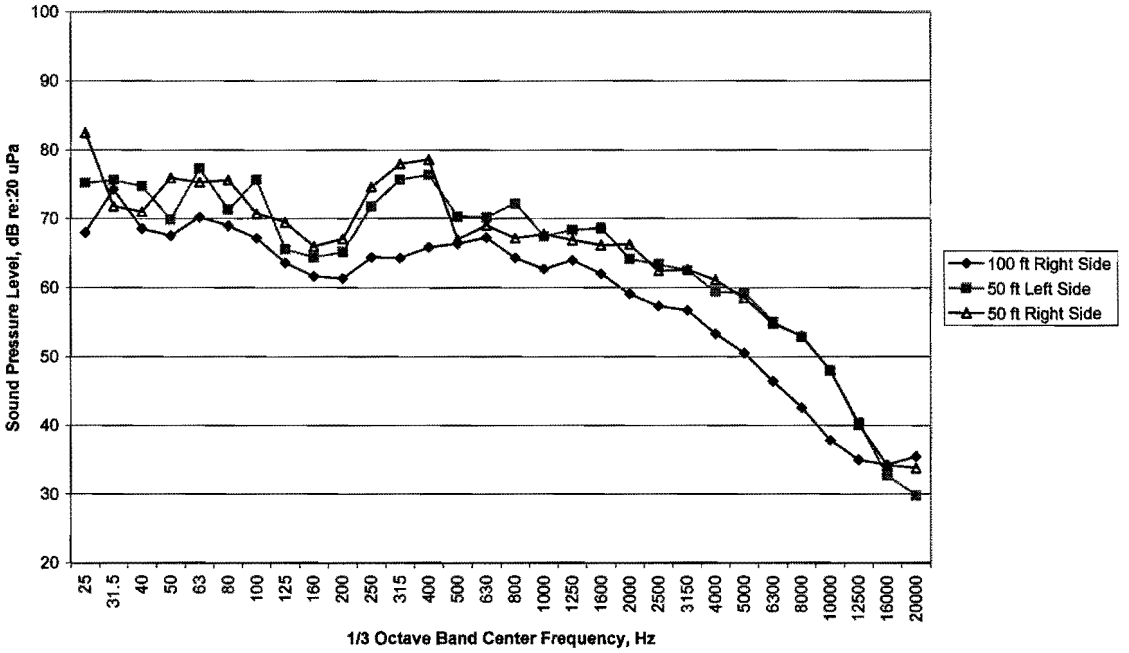
High-Speed Non-Electric Locomotive Noise Spectra
Event 11, 74 mph



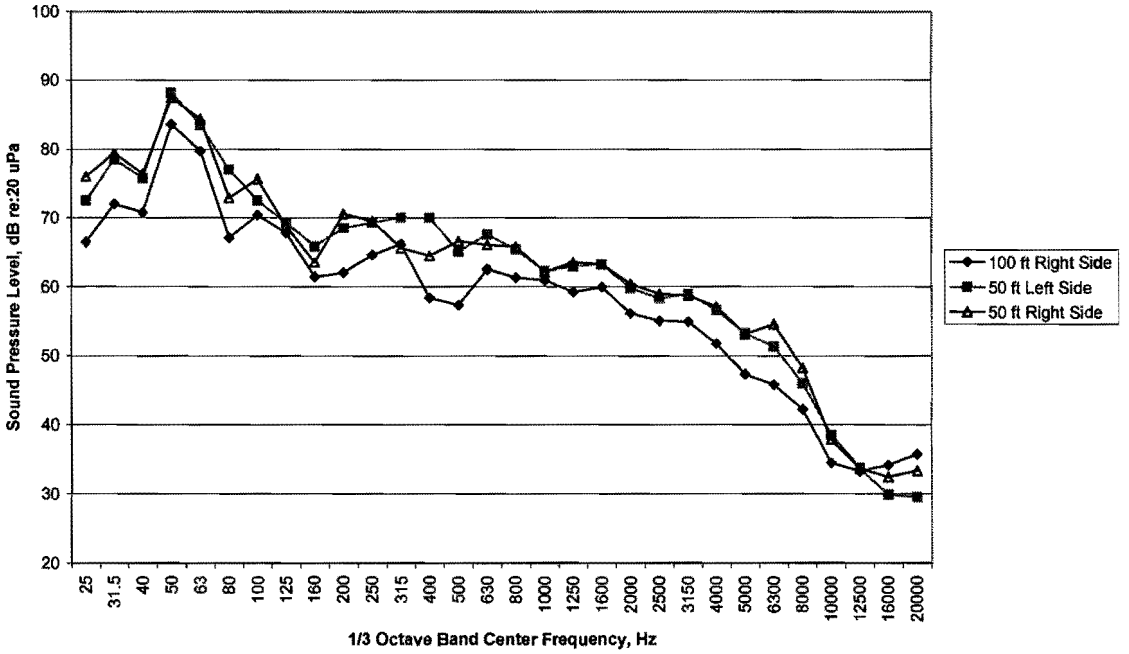
High-Speed Non-Electric Locomotive Noise Spectra
Event 12, Accelerating from Stop



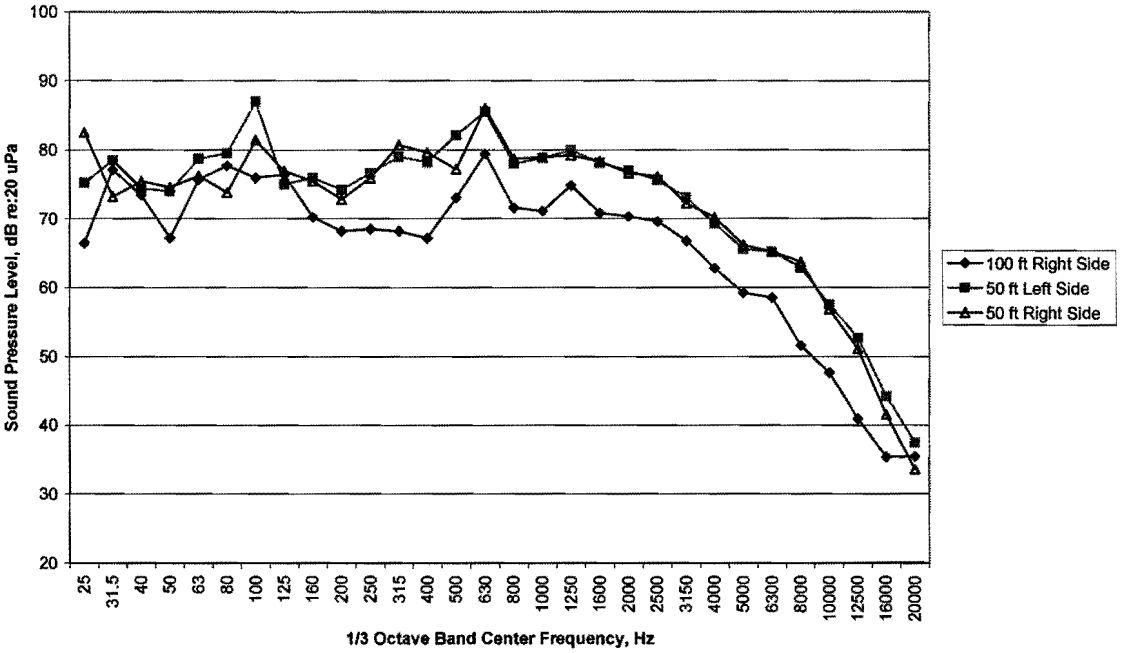
High-Speed Non-Electric Locomotive Noise Spectra
Event 13, Locomotive Idling



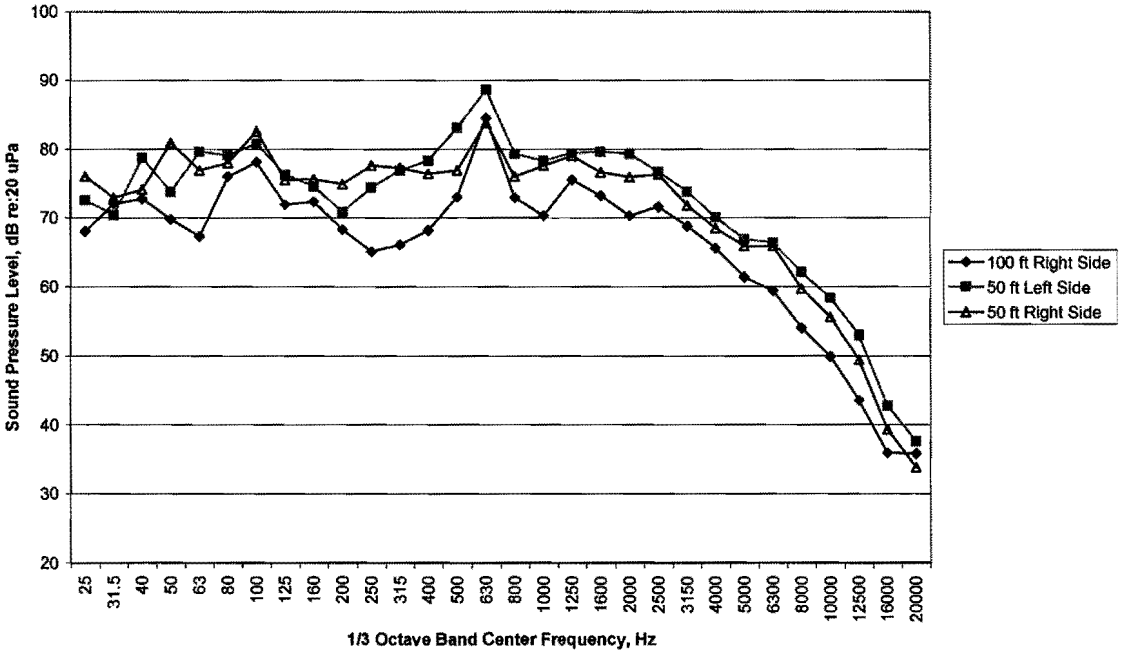
High-Speed Non-Electric Locomotive Noise Spectra
Event 14, Accelerating from 25 mph



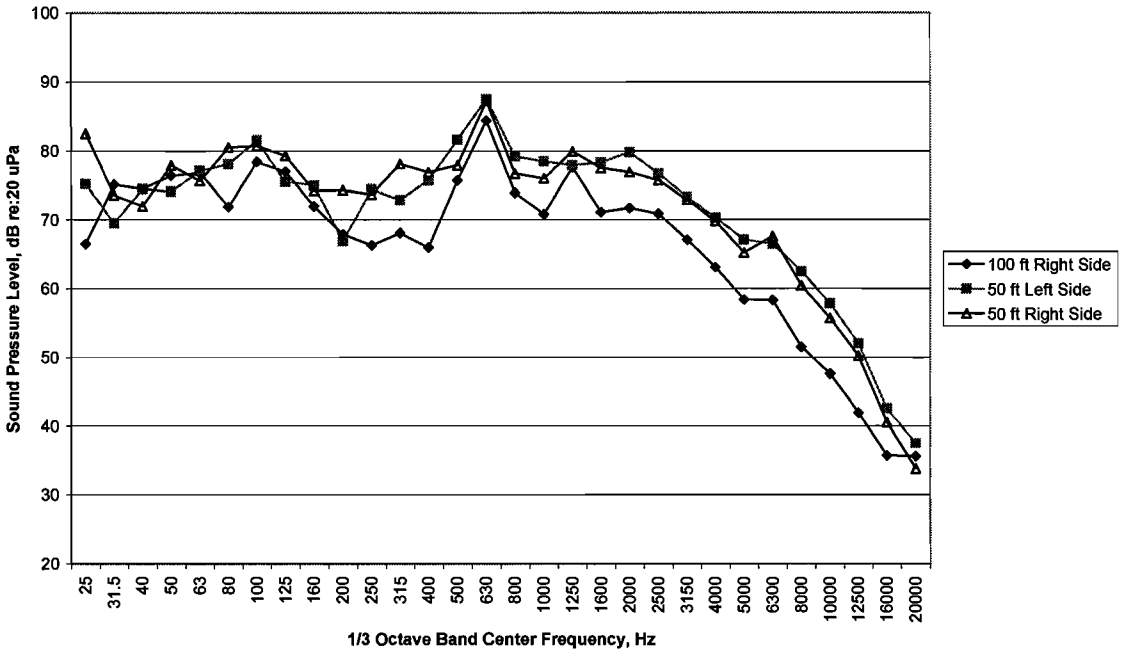
High-Speed Non-Electric Locomotive Noise Spectra
Event 15, 99 mph



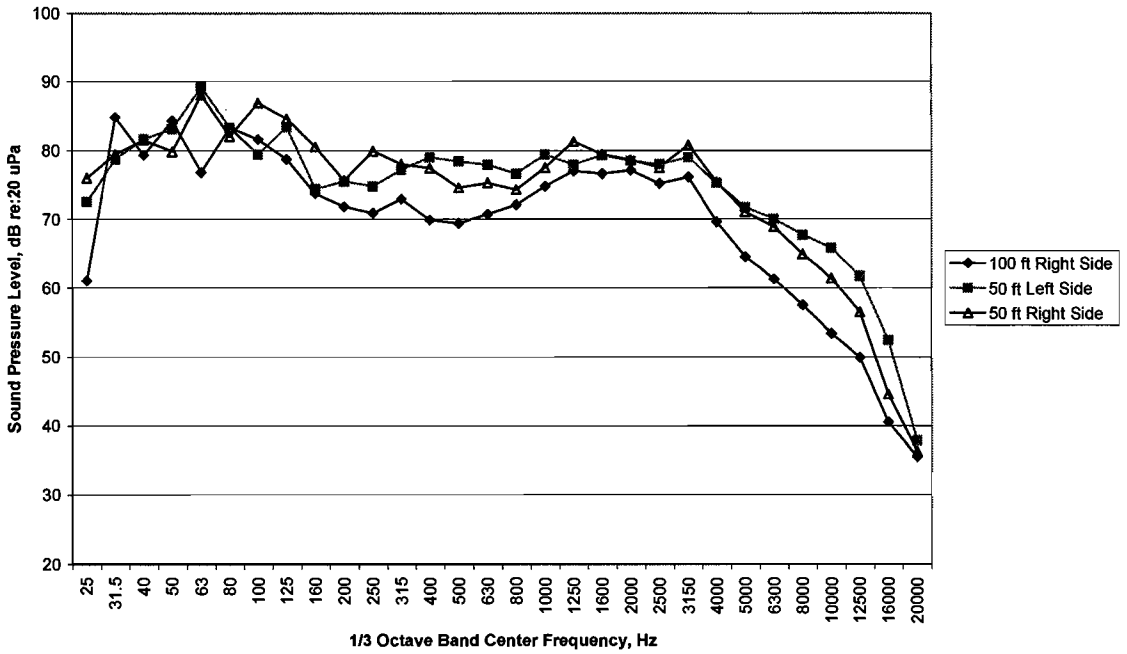
High-Speed Non-Electric Locomotive Noise Spectra
Event 16, 100 mph



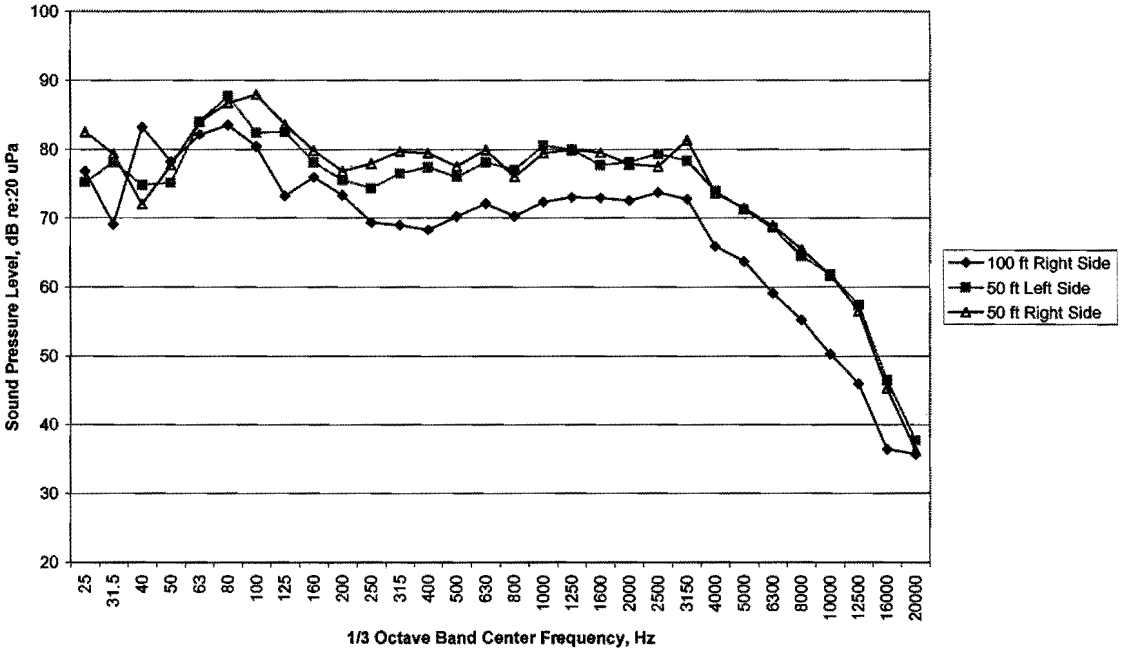
High-Speed Non-Electric Locomotive Noise Spectra
Event 17, 99 mph



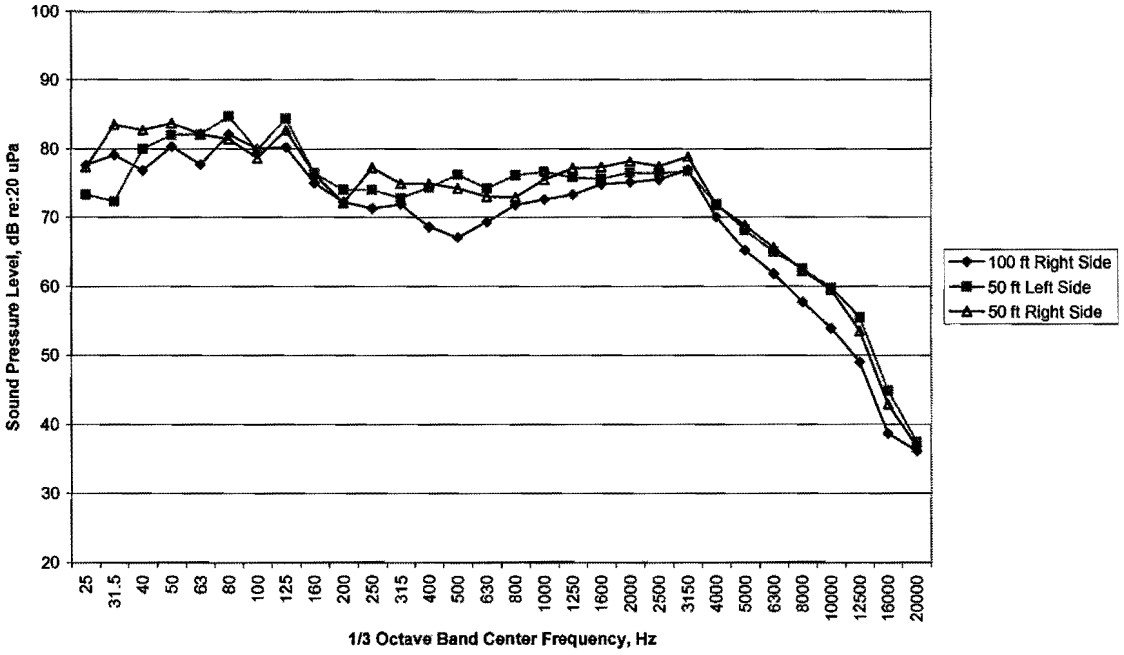
High-Speed Non-Electric Locomotive Noise Spectra
Event 18, 130 mph

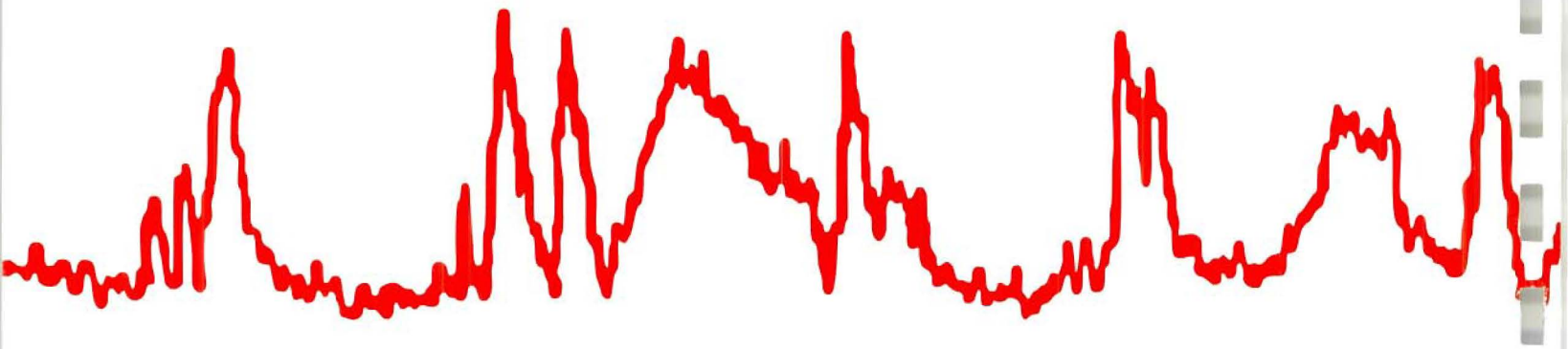


High-Speed Non-Electric Locomotive Noise Spectra
Event 19, 130 mph



High-Speed Non-Electric Locomotive Noise Spectra
Event 20, 129 mph





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