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THE MEASUREMENT OF LOCOMOTIVE NOISE AT EXISTING RAILROAD TEST SITES

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16. Abstract

A study was undertaken to examine the feasibility of accurately measuring the noise from locomotives at existing load cell sites in the absence of sites conforming with U.S. Environmental Protection Agency standards. It was found through measurments at seven typical sites and one conforming load cell test site involving ten locomotives that reasonably accurate measurements were possible for the locomotive operating fully loaded at throttle 8. Errors, when they occurred, were due primarily to sound reflecting off nearby buildings. Measurements with the locomotive in idle were generally difficult because of high background noise at these sites. A passby test procedure was also examined and found to provide reasonably accurate measurement of locomotive noise at throttle 8, full load.

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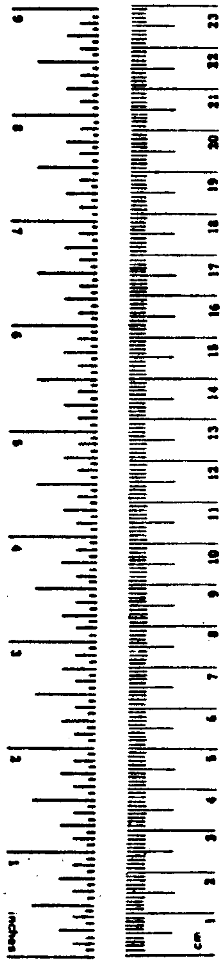
PREFACE

The testing program described in this report was carried out by Bolt Beranek and Newman Inc., (BBN) under contract to the U.S. Department of Transportation and in cooperation with the Association of American Railroads (AAR) and the Chessie System. The work was technically coordinated at the Transportation Systems Center by Mr. Robert Mason. The initial contact with the Chessie System was made by Mr. C. Furber and Mr. P. Conlan of the AAR. Mr. W.F. Liebenow of the Chessie System coordinated all railroad services, including providing us with locomotives, test sites, and railroad personnel to assist in the testing. The bulk of the testing occurred at the Cumberland, Maryland locomotive shop where Mr. C. Shafer, Mr. H. Livingood and Mr. S. Benson were principally responsible for providing us with the services and equipment required from the Chessie. Messrs. J. Vallus and D. Goding of the Electro-Motive Division of General Motors provided guidance in the design of the test plan, and Mr. Fred Stein of General Electric provided us with information on the load cells. We are grateful to all of these people, for without their help and cooperation this program could not have been carried out.

METRIC CONVERSION FACTORS

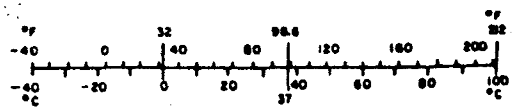
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

1.1 BACKGROUND

On December 31, 1976, locomotive noise emissions standards issued by the U.S. Environmental Protection Agency became effective [*1*]. Those standards include requirements for stationary test sites that are difficult to satisfy on most railroad properties in the U.S. The fact that test sites conforming to the standards are rare presents a serious problem for the U.S. Department of Transportation, which is charged by the Noise Control Act of 1972 with ensuring compliance with these standards. The railroads also are faced with a serious problem since they must make provision to comply with DOT regulations based on the EPA standards.

1.2 OBJECTIVE

The purpose of the program described in this report is to provide DOT and the railroads with additional information to ease the process of compliance with the EPA standards. Most railroads have numerous resistor bank load cells suitable for stationary test of locomotives under loads simulating line-haul operation. The difficulty is that these load cells are commonly found in locations where background noise, reflecting objects (buildings, other locomotives, etc.), and the noise from the load cell itself might contaminate the measurement of noise from locomotives operated at these sites. During the program, the noise from ten locomotives was measured at a site conforming with the EPA standards, as well as up to seven other sites that did not conform but were typical of locomotive load cell test sites. The goal was to provide guidelines for the acceptability of these sites. In addition, alternative test procedures were examined that would eliminate the need for a load cell and, hence, increase the availability of acceptable noise test sites.

1.3 PROGRAM OVERVIEW

This program consisted of a measurement phase and an analysis phase. The measurement phase was carried out in cooperation with the Chessie System at four of their locomotive maintenance centers located in Cumberland, Maryland; Clifton Forge, Virginia; Huntington, West Virgina; and Russell, Kentucky. At Cumberland, Maryland, where the bulk of the testing was carried out, a load cell test site conforming with EPA standards was constructed. The noise from nine locomotives, obtained on an opportunity basis at Cumberland, was measured at that site as well as one "typical" load cell test site. In addition, the noise from another locomotive dedicated to the program was measured at the above two sites and at six other "typical" load cell sites. Finally, the noise from all ten locomotives was measured using a passby procedure in which the locomotives were accelerated down a test track at throttle 8 with full service brake application, thereby obtaining full power at low speed.

During the analysis phase of the program, the influence of the test site on the measurement of noise was examined. A number of factors such as ground reflections, reflections from large surfaces like buildings, meteorological effects, background noise, and load cell noise were all examined. Primary factors were identified, and guidelines for testing at nonconforming sites were developed.

1.4 ORGANIZATION OF THE REPORT

Details of the test program and test results are provided in Section 2, and the analysis phase is described in Section 3. Section 4 presents conclusions and a detailed listing of measured data is presented in Appendix A. Appendix B discusses ground interaction effects.

2. TEST PROGRAM

The locomotive noise measurement program spanned the period from September 11, 1978 through October 27, 1978. That period included an approximately three-week hiatus in testing due to a railroad strike that began about the middle of September. In this section, we describe the test sites, test locomotives, test procedures, instrumentation, and test results.

2.1 TEST SITES

The eight load cell test sites used during this test program are listed in Table 1. In addition to tests at these stationary sites, passby tests were run on the test track located approximately 300 ft north of the main shop at the Cumberland, Maryland locomotive repair facility.

TABLE 1. LOAD CELL TEST SITES

Test Site	Load Cell Type	Location	Type of Site
1	General Electric Model EM 99	Approximately 200 ft north of the northwest corner of the main shop, Cumberland, MD	Typical site; used for all locomotives
2	General Electric Model EM 89	In the storage yard southeast of the main shop, Cumberland, MD	Conforming site; used for all locomotives
3	General Electric Model EM 55	Approximately 300 ft northwest of the northwest corner of the main shop Cumberland, MD	Typical site; used only for the "dedicated" locomotive tests
4	General Electric Model EM 89	East of the main shop against the north wall of load box testing shed, Cumberland, MD	Typical site; used only for "dedicated" locomotive tests
5	General Electric Model EM 55	Portable load box located approximately 150 ft east of the main shop on track No. 1, Cumberland, MD	Typical site; used only for "dedicated" locomotive tests
6	General Electric Model EM 99	Russell, Kentucky	Typical site; used only for "dedicated" locomotive tests
7	General Electric Model EM 55	South load box east of the main shop, Huntington, WVA	Typical site; used only for "dedicated" locomotive tests
8	2-General Electric EM 55s	West load box, Clifton Forge, VA	Typical site; used only for "dedicated" locomotive tests

Most of the testing was carried out at Cumberland, where five of the eight load cell sites and the passby site were located. The remaining three load cell test sites were at the Chessie locomotive repair facilities at Clifton Forge, Virginia; Huntington, West Virginia; and Russell, Kentucky. Figure 1 is a map of a portion of the Cumberland facility showing most of the test sites. Figure 2 shows the salient features of Test Site No. 1. When features of the sites allowed it, we placed microphones at 50, 100 and 200 ft from the centerline of the locomotive. At Site No. 1, the most distant microphone could be placed only 144 ft away. All locomotives were tested at this site and at the conforming site (No. 2) in order to compare noise measurements at a so-called "typical" site with measurements at a conforming site. Conditions at Site No. 1 were generally favorable for noise measurements with considerable open area around the site. The load cell was mounted close to the ground (Fig. 2d) thus maximizing the shielding effect of the locomotive body on the noise from the load cell blower. The major difficulty with this site was that the tracks shown in Fig. 2a were the main access tracks to the turntable (Fig. 1). As a result, there always were many idling locomotives in the area, and special effort has to be made to clear the tracks near the microphones before any measurements could be taken. The need to move idling locomotives sometimes resulted in considerable testing delays and inconvenience for the railroad. Those delays and inconveniences would impact on the utility of this site if the railroad were to use it on a regular basis for noise testing. Also, the proximity of these idling locomotives resulted in high background noise that precluded the accurate measurement of idle noise.

Site No. 2 was set up to conform with the EPA standards. It was located approximately 500 ft southeast of the main shop at Cumberland in a storage yard. A location was selected in the

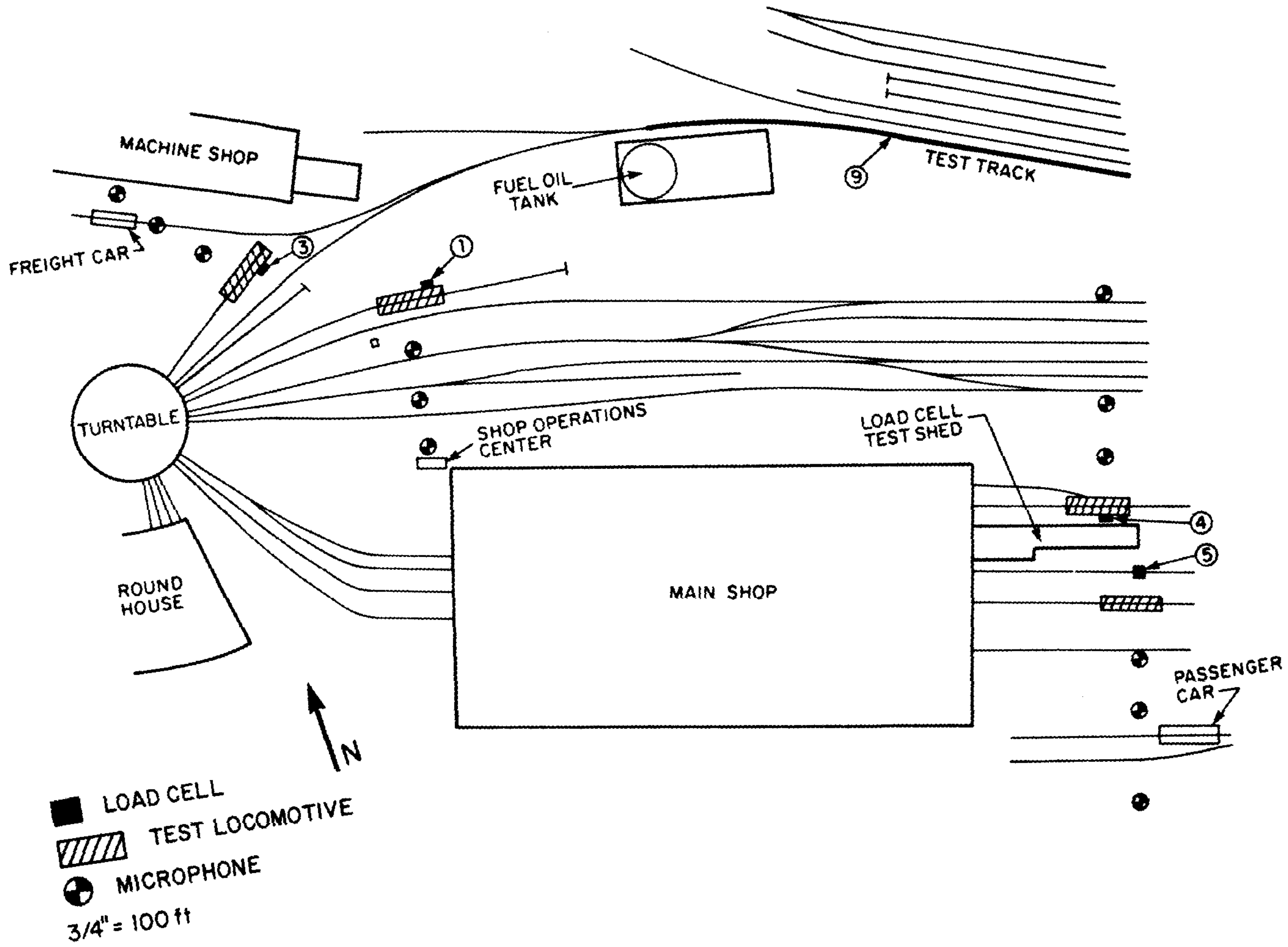
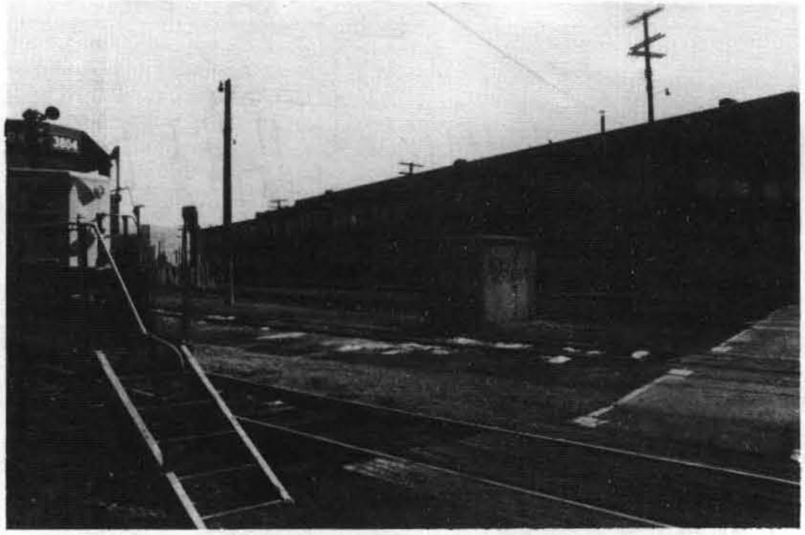
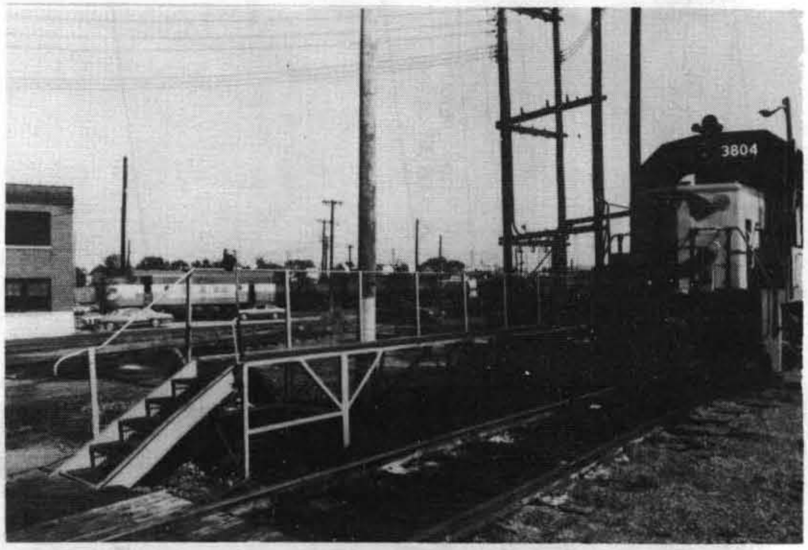


FIG. 1. TEST SITES AT CUMBERLAND, MARYLAND



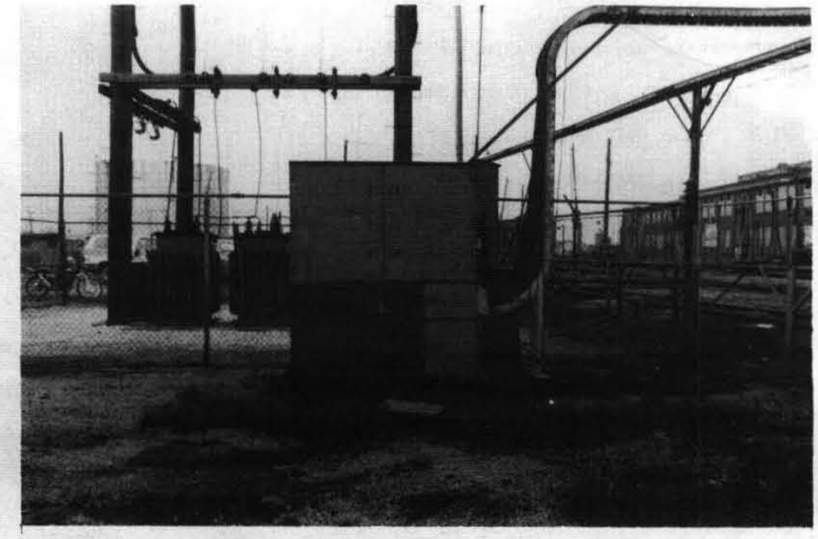
(a) Looking Southeast With the Test Locomotive at the Left and the Microphone Array to the Right



(b) Looking East With the Test Locomotive on the Right and the Load Cell located Near the Base of the 4 Poles Just to the Left of the Locomotive

FIG. 2. TEST SITE NO. 1

(c) Looking North from the Most Distant Microphone Toward the Test Locomotive



(d) Looking East at the Load Cell; the Test Locomotive is Out of the Picture to the Right

FIG. 2. (Continued)

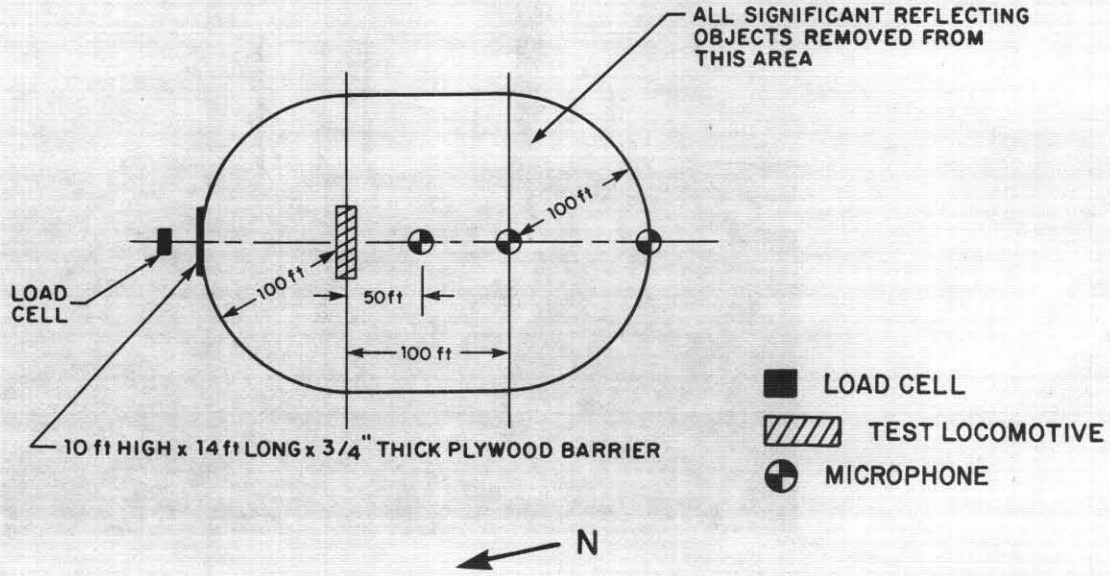


FIG. 3. CONFORMING SITE GEOMETRY

yard such that when it was cleared of all locomotives, freight cars, and passenger cars, there were no significant reflecting objects within an area shown in Fig. 3. A portable load cell was placed just outside that area as shown in the figure, and a barrier was constructed between the load cell and test locomotive as shown in Fig. 4. Figure 5 shows a number of photographs of the test site. The ground within the clear area was a mixture of tall weeds, bare ground and short grass. There were also a

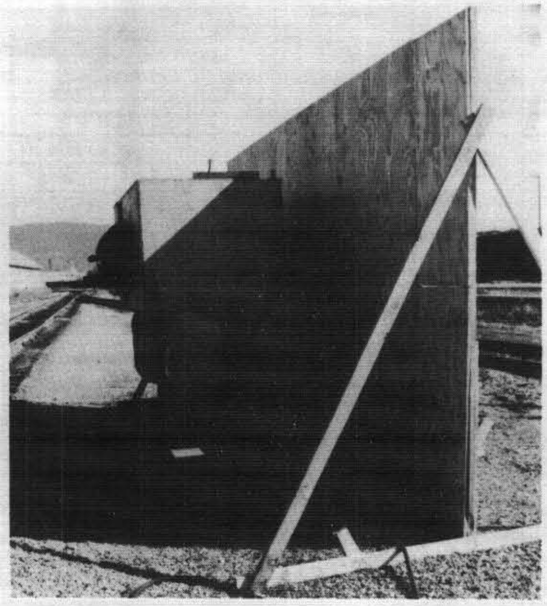
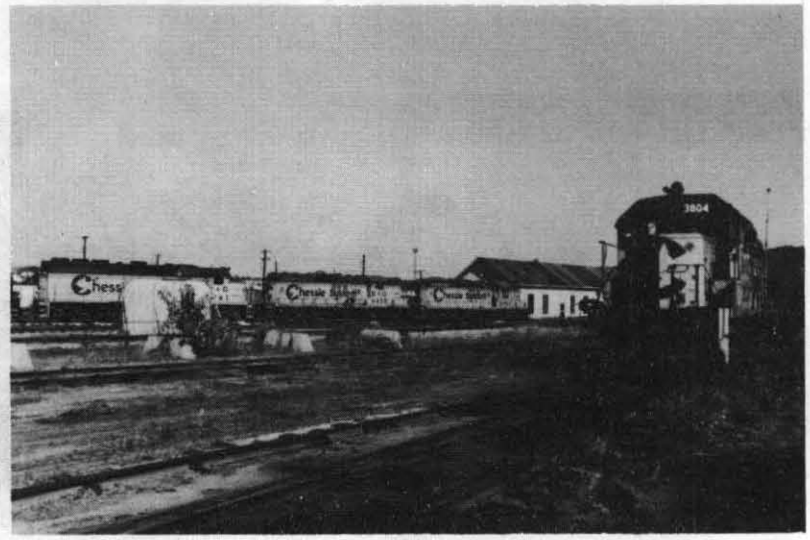


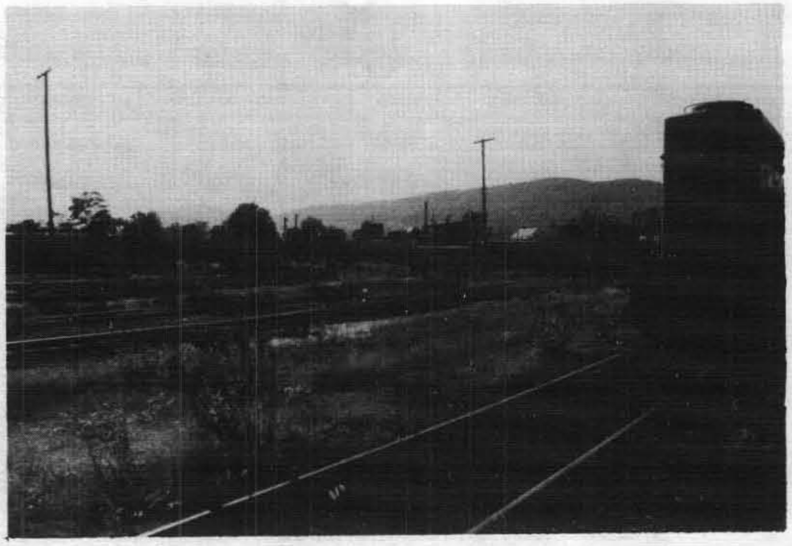
FIG. 4. CONFORMING SITE (SITE NO. 2) LOAD CELL INSTALLATION WITH BARRIER



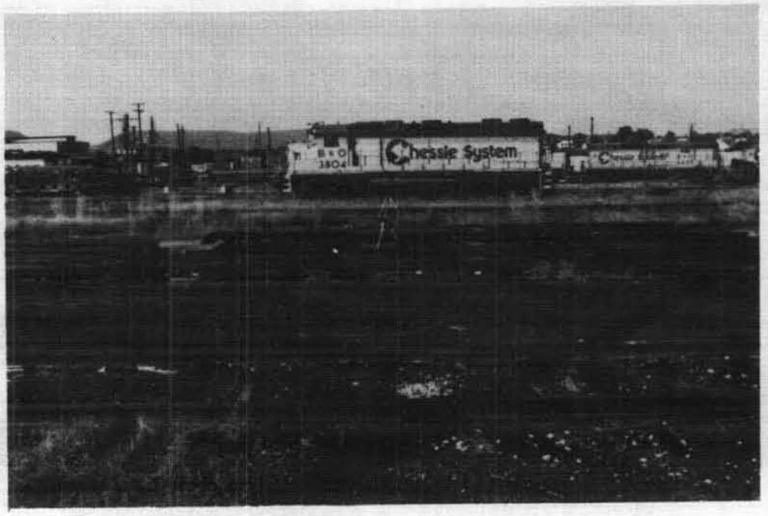
(a) Looking Northeast, the Load Cell Barrier Can Be Seen to the Left and the Test Locomotive on the Right

(b) Looking Southeast, the Test Locomotive is on the Left and the Microphone Array Stretches to the Right

FIG. 5. TEST SITE NO. 2 – THE CONFORMING SITE



(c) Looking Southwest, the Test Locomotive is to the Right and the Microphones are to the Left



(d) Looking North Toward the Test Locomotive the 50 and 100 Ft Microphones Can Be Seen.

FIG. 5. (Continued)

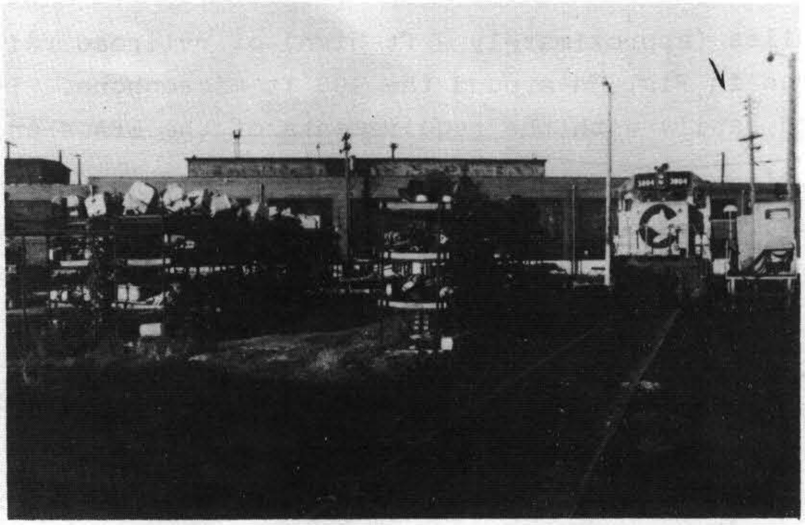
few piles (approximately 2 ft high) of railroad rails which can be seen in Fig. 5d around the 100 ft microphone. The site conformed easily with the requirements of the EPA standards.

Site No. 3 is shown at the upper left hand corner of Fig. 1. Because of space restriction, the most distant microphone was only 150 ft from the centerline of the locomotive rather than the desired 200 ft. Figure 6 contains a number of photographs of the site. It is clearly a cluttered area. Note especially that the 100-ft microphone is only some 40 ft in front of a freight car used for semi-permanent storage.

Site No. 4 is shown in the lower right hand corner of Fig. 1, and photographs of the site are shown in Fig. 7. The site is noteworthy in that the load cell is mounted against the wall of a building used for indoor load testing of locomotives and the locomotive is parked on a siding also adjacent to that same wall as shown in Fig. 8.

Site No. 5 is also shown in the lower right hand corner of Fig. 1 and photographs of the site can be found in Fig. 9. A portable load cell stored at Cumberland was used at this site. As indicated in Fig. 1, the load cell was located on the first track south of the load cell test shed, and the test locomotive was located on the adjacent track between the load cell and the microphones.

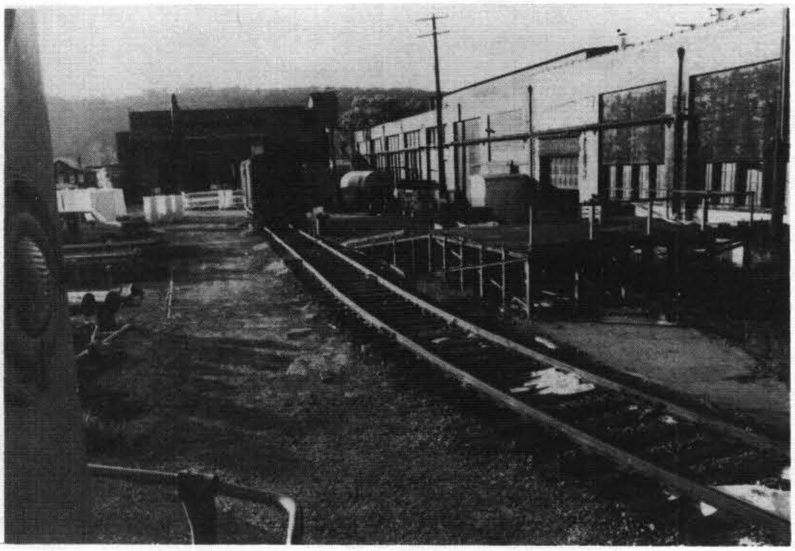
Site No. 6 was located at the Chessie locomotive repair facility in Russell, Kentucky. Figure 10 is a map of the facility showing the test site. A number of photographs of the site may be found in Fig. 11. The most prominent feature of this site is the very high exhaust from the load cell blower as shown in Fig. 11a. Figure 11b shows the somewhat cluttered nature of the site not apparent in Fig. 10. Because of the fuel tanks and trash containers distributed about the area, as shown in Fig 11b, it was



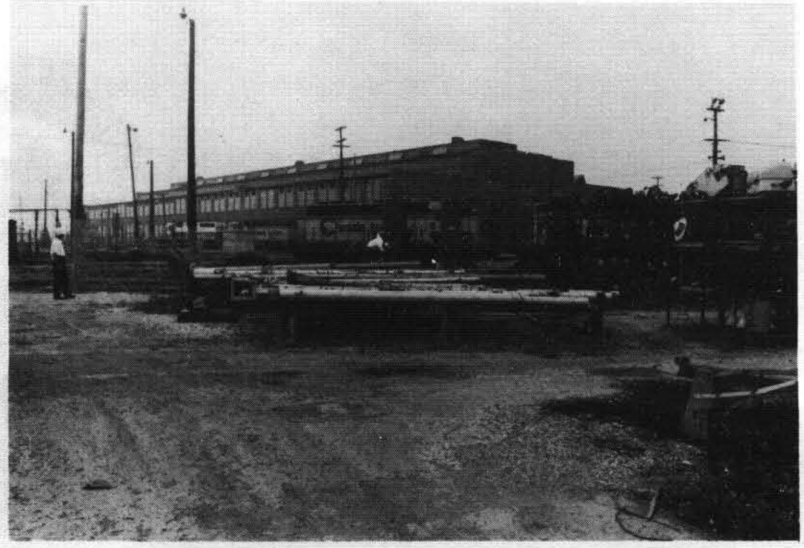
(a) Looking Northeast, the Test Locomotive is on the Right and to the Right of it is the Load Cell

(b) Looking West, the Test Locomotive is on the Left and the Microphone Array Stretches to the Right

FIG. 6. TEST SITE NO. 3

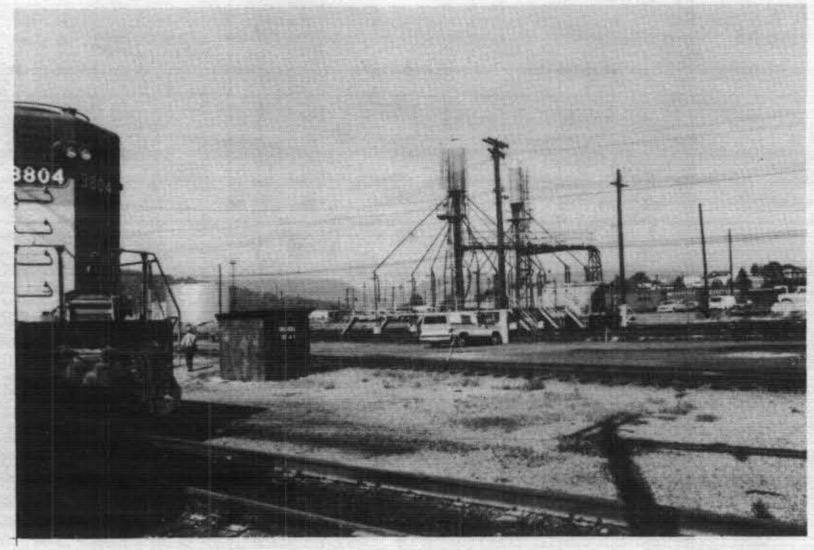


(c) Looking to the West From the Test Locomotive at the Three Microphones

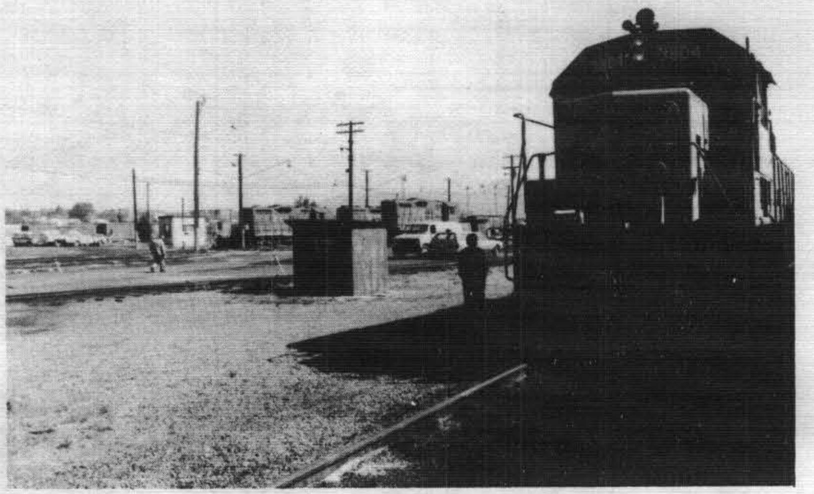


(d) Looking Southeast From the 100 Ft Microphone Position at the Load Cell Prior to Arrival to the Test Locomotive or Installation of the Instrumentation

FIG. 6. (Continued)

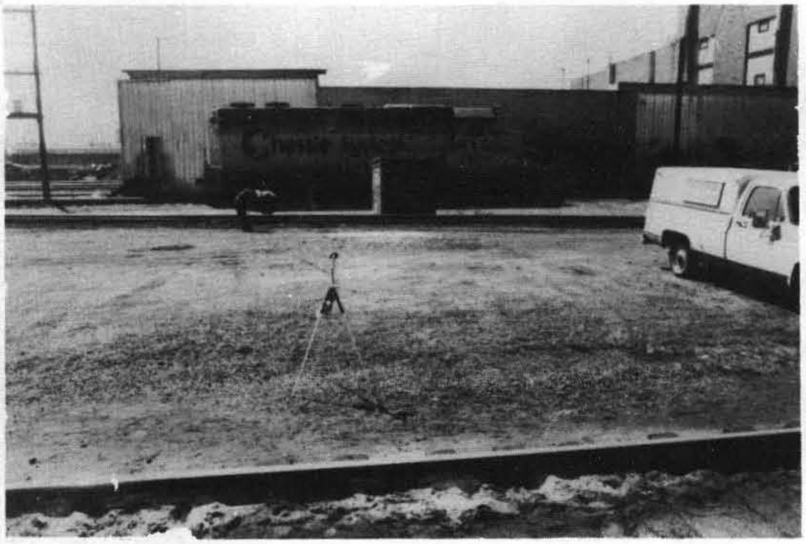


(a) Looking Northwest With the Test Locomotive to the Left and the Microphone Array Stretching to the Right



(b) Looking Northeast With the Test Locomotive to the Right and the Microphones Stretching to the Left

FIG. 7. TEST SITE NO. 4



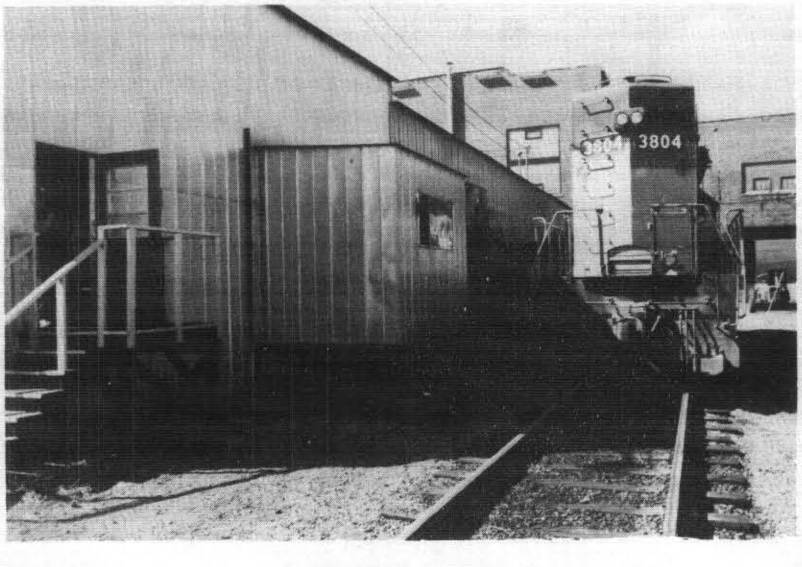
(c) Looking South at the Test Locomotive From Just Behind the 100 Ft Microphone

FIG. 7. (Continued)

not possible to place the microphones on a line perpendicular to the locomotive. Instead, they had to be placed on a line at about a 30° angle to the perpendicular towards the rear (cooling fan end) of the locomotive.

Site No. 7 was located at the locomotive repair facility in Huntington, West Virginia. Figure 12 shows a map of the test area, and photographs can be found in Fig. 13. It was not possible to locate a 200 ft microphone at this site because such a microphone would have had to be placed in the mainline right of way. The site is somewhat cluttered, as shown in Fig. 13; but as Fig. 13c and d show, there is a clear line-of-sight to the microphone.

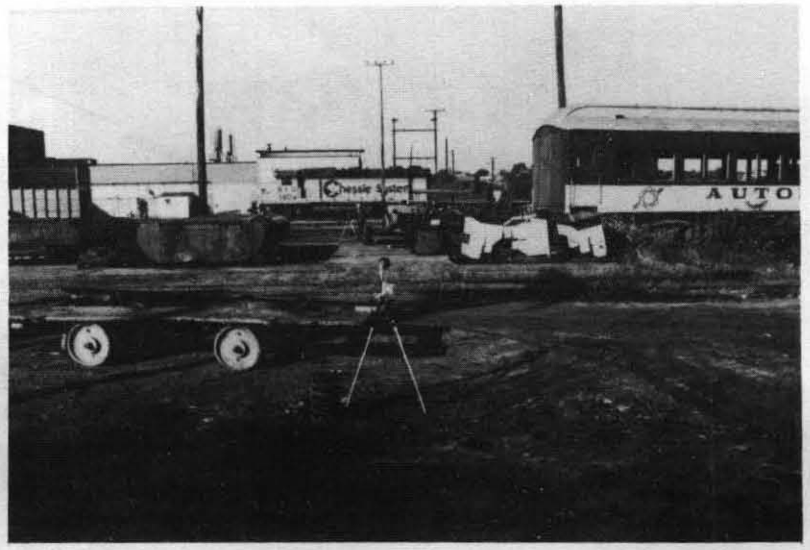
(a) Looking South at the Load Cell



(b) Looking West at the Test Locomotive With the Load Cell Against the Wall to the Left

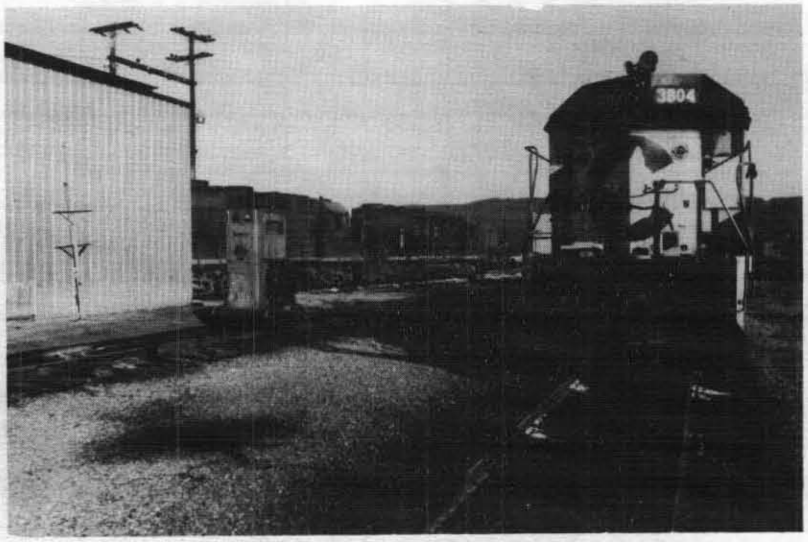
FIG. 8. SITE NO. 4 — LOAD CELL

(a) Looking Southeast, the Test Locomotive is to the Left and the Three Microphones Can Be Seen Stretching off to the Right

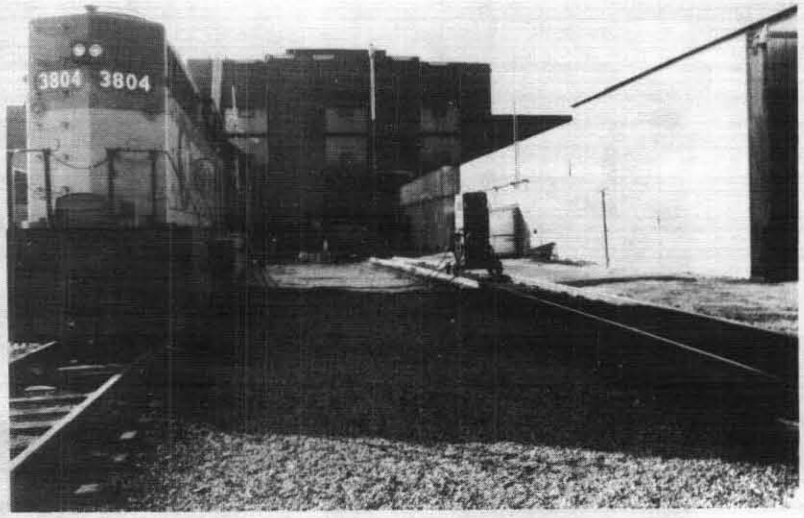


(b) Looking North at the Test Locomotive from the 200 Ft Microphone

FIG. 9. TEST SITE NO. 5



(c) Looking East the Test Locomotive is on the Right, the Portable Load Cell is on the Track to the Left.



(d) Looking West at the Main Shop, the Test Locomotive is to the Left and the Portable Load Cell is to the Right.

FIG. 9. (Continued)

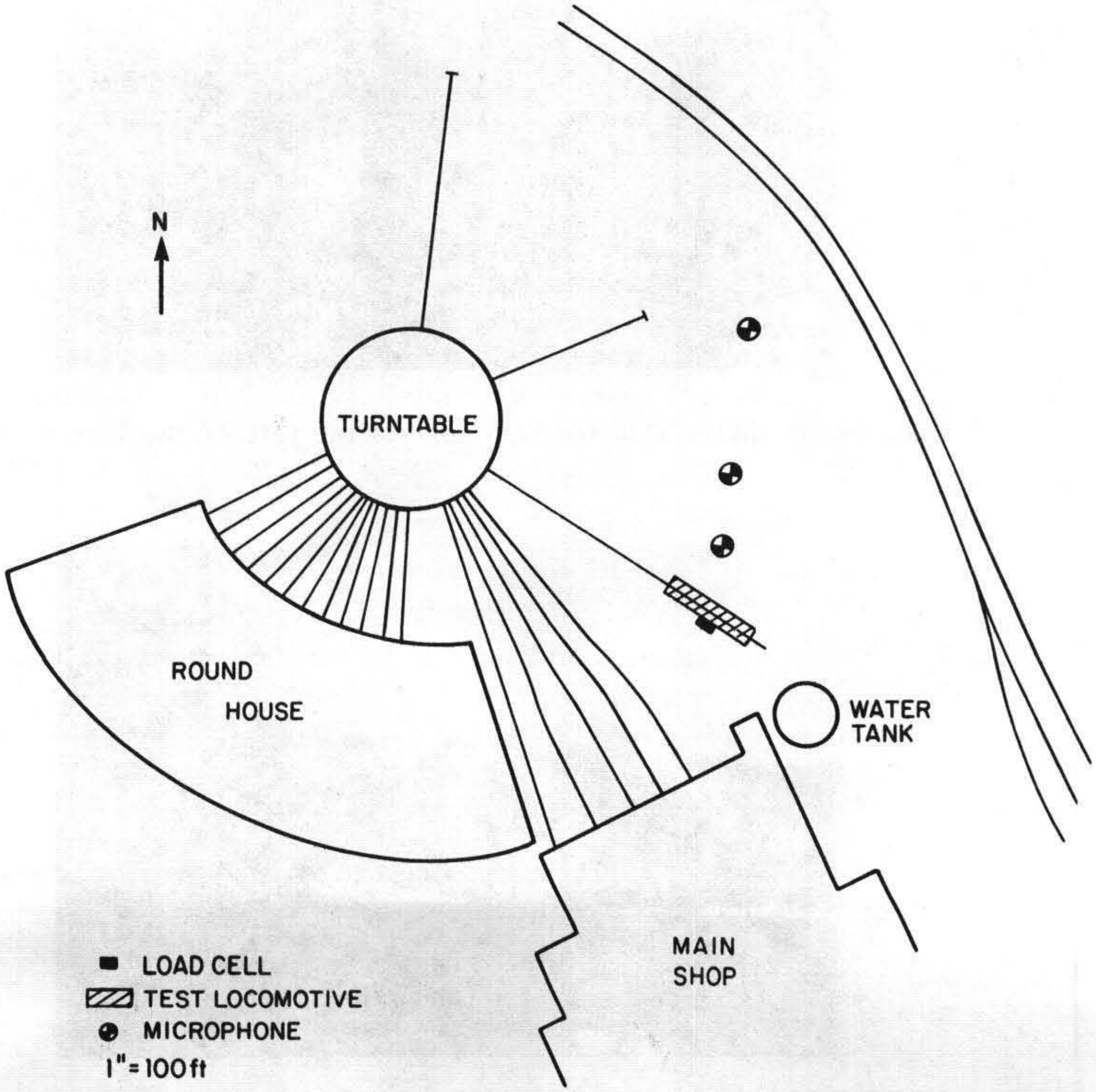
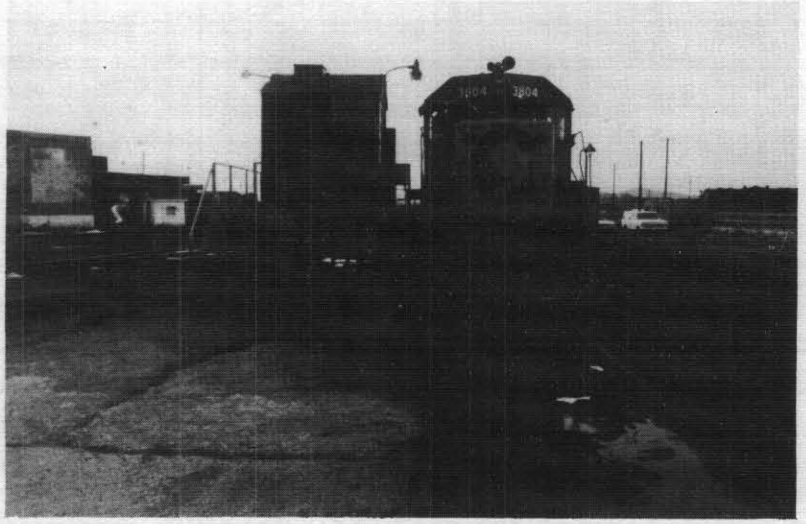
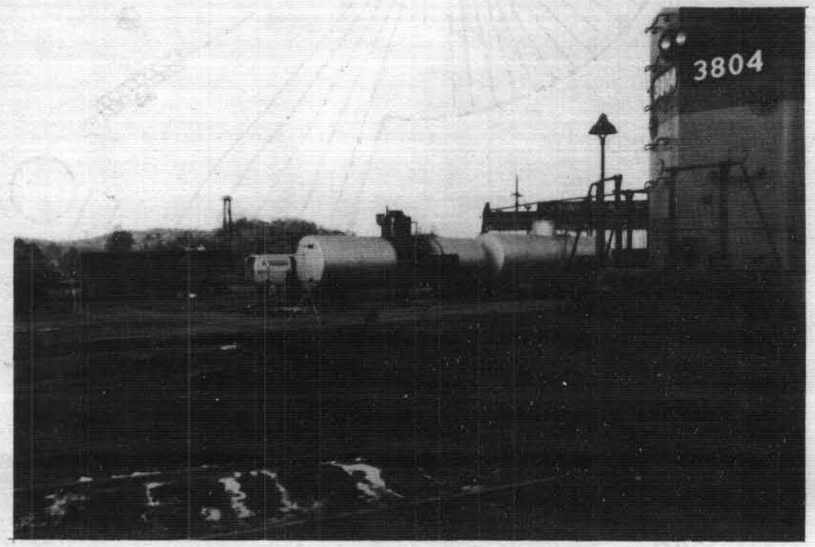


FIG. 10. RUSSELL FACILITY — TEST SITE NO. 6

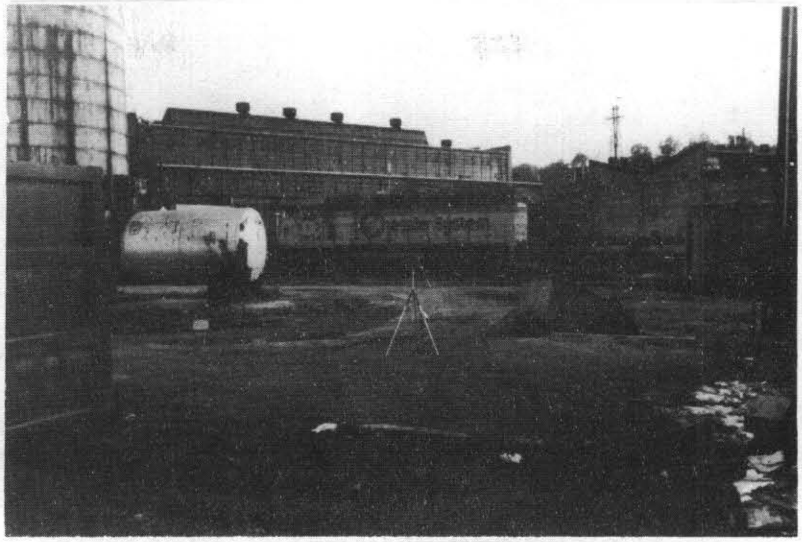


(a) Looking Northeast With the Load Cell to the Left of the Test Locomotive

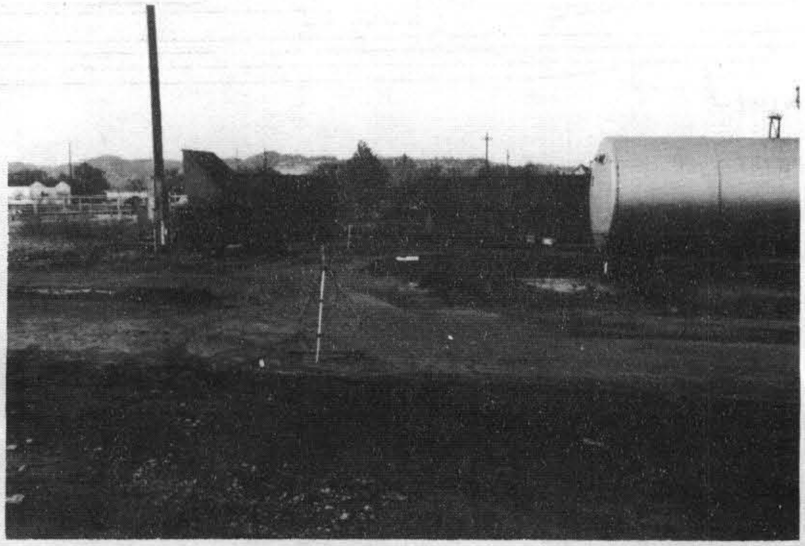


(b) Looking Northwest, the Test Locomotive is on the Right With the Microphones Extending to the Left.

FIG. 11. TEST SITE NO. 6 — RUSSELL, KENTUCKY



(c) Looking South at the Test Locomotive from Just Behind the 100 Ft Microphone



(d) Looking North From the Locomotive at the Line of Microphones

FIG. 11. (Continued)

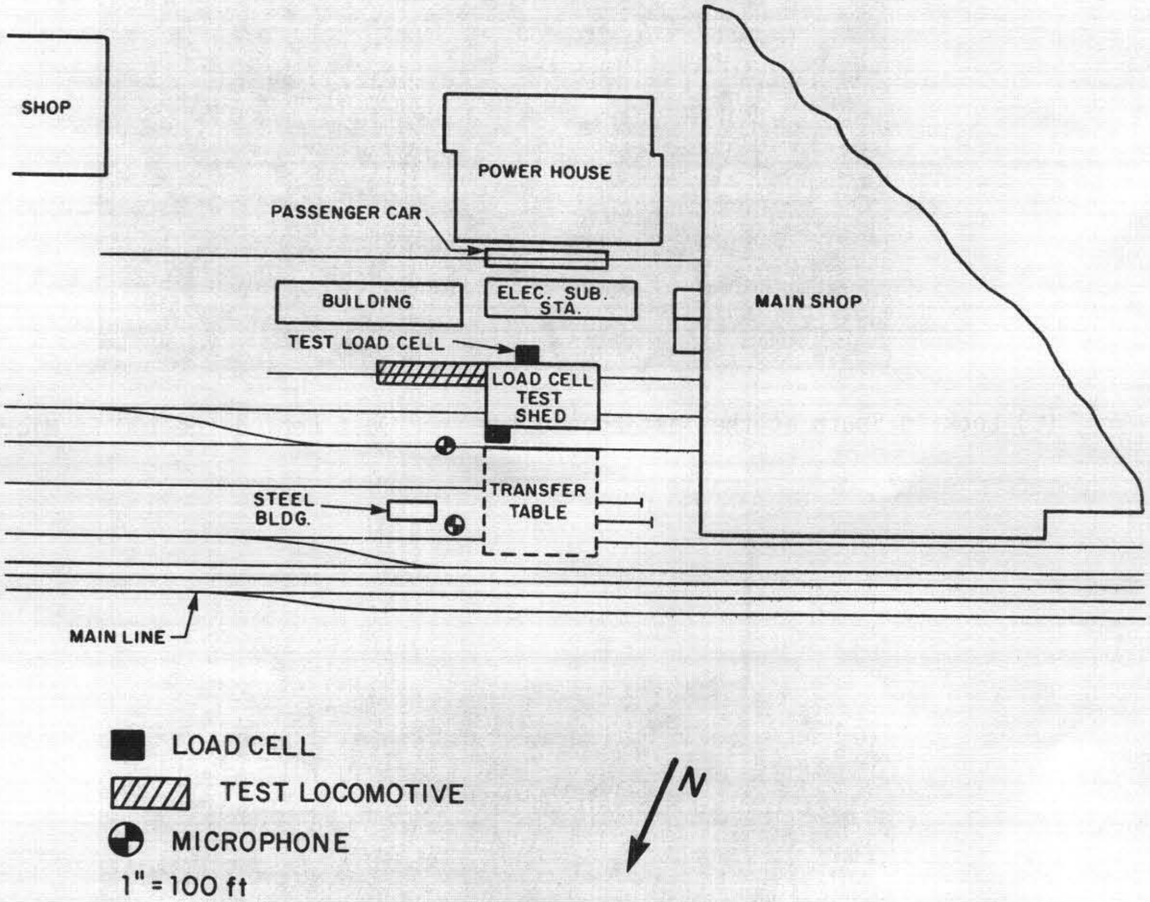
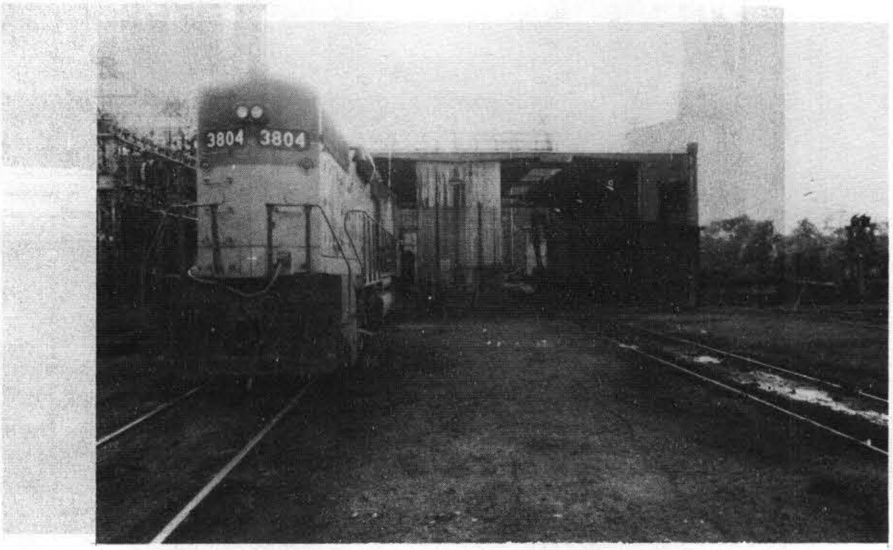


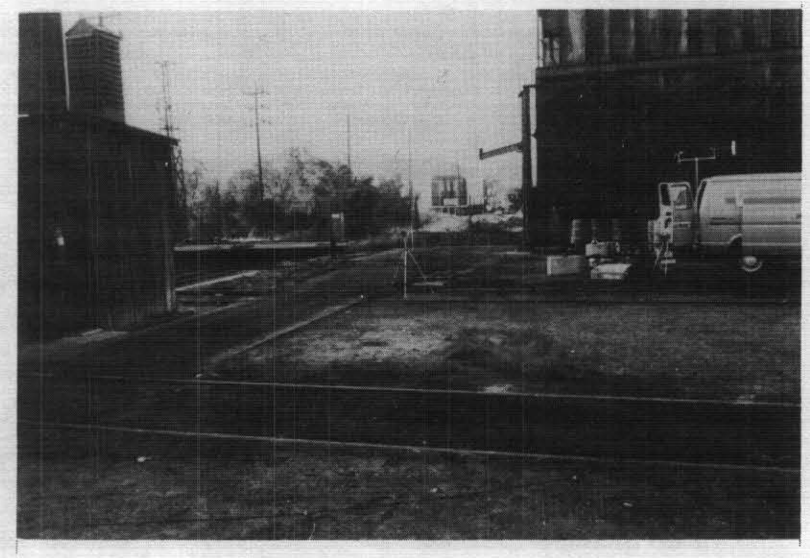
FIG. 12. HUNTINGTON FACILITY TEST SITE NO. 7



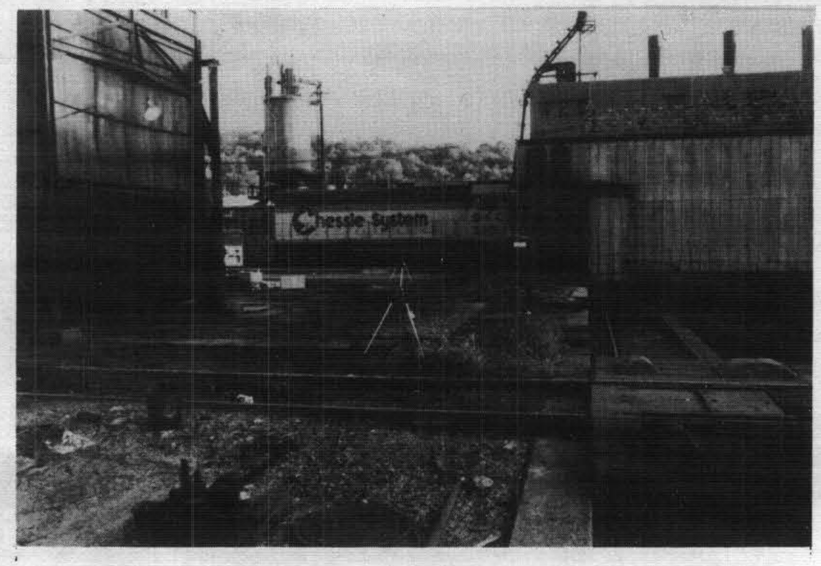
(a) Looking West at the Load Cell Test Shed With the Test Locomotive on the Left

(b) Looking West, the Load Cell Can Be Seen to the Left and Forward of the Test Locomotive.

FIG. 13. TEST SITE NO. 7 — HUNTINGTON, WEST VIRGINIA



(c) Looking Northwest from the Test Locomotive, a Second Load Cell *not* Used in the Tests Can Be Seen to the Left.



(d) Looking Southeast at the Test Locomotive from Just Beyond the 100 Ft Microphone

FIG. 13. (Continued)

Test Site No. 8 was at the Chessie's Clifton Forge, Virginia locomotive repair facility. Figure 14 shows a map of the area, and photographs are found in Fig. 15. This site is about as close to a conforming site as one will find anywhere in the railroad industry. The only reflecting objects within the area specified in the EPA standards (Fig. 3) are the two load cell structures. The load cell between the test locomotive and the microphones was not used in the tests. Of course, even with the microphone being shielded from the load cell by the locomotive, one would expect some contamination of the locomotive noise by the load cell noise.

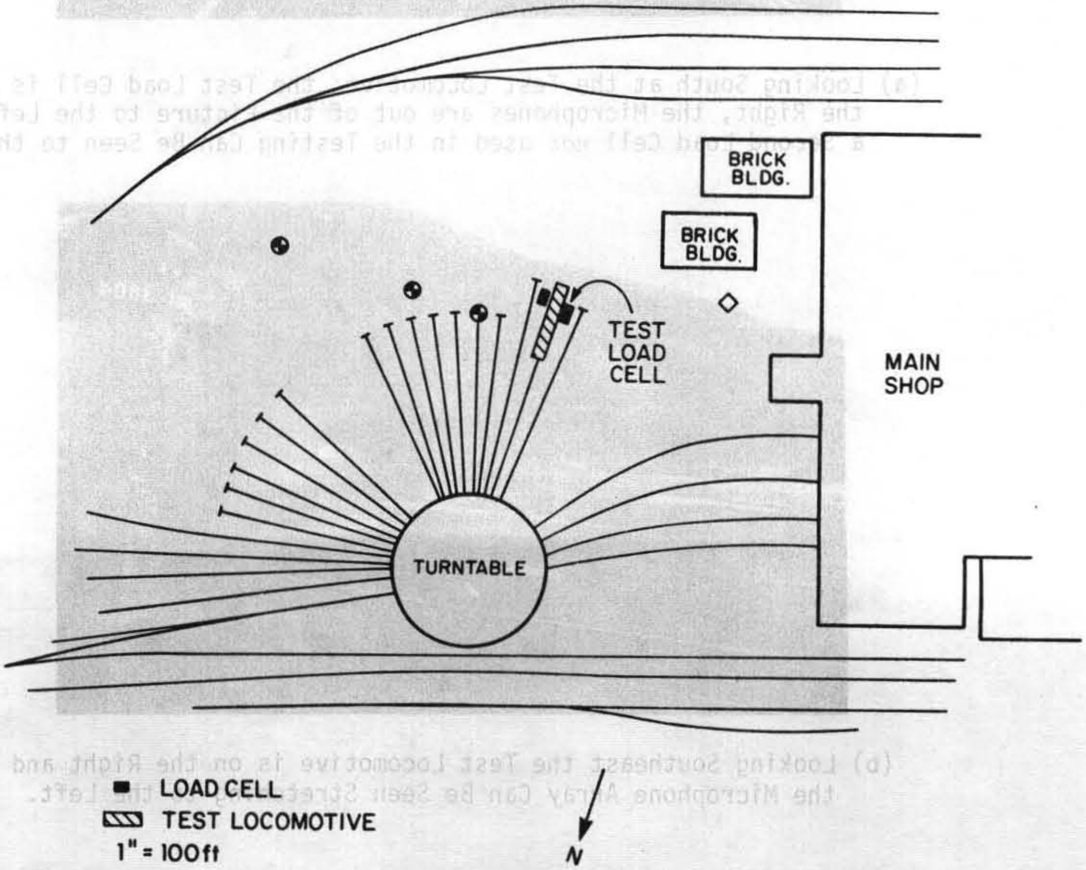
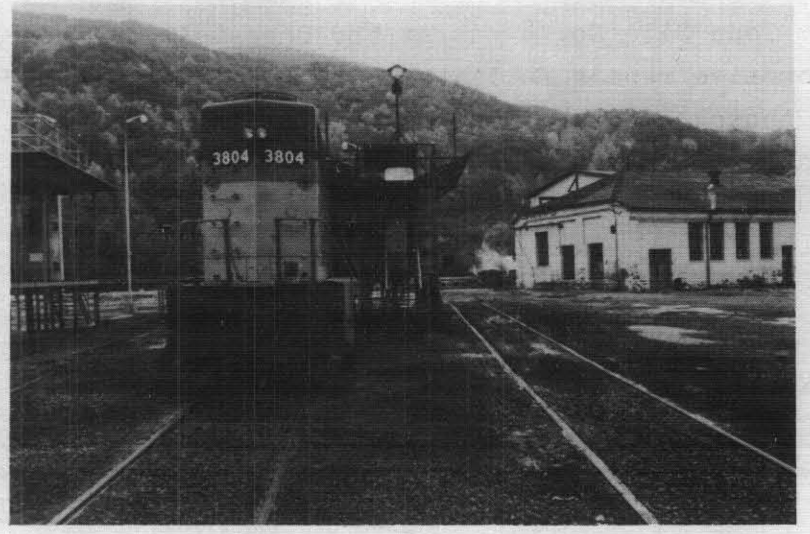
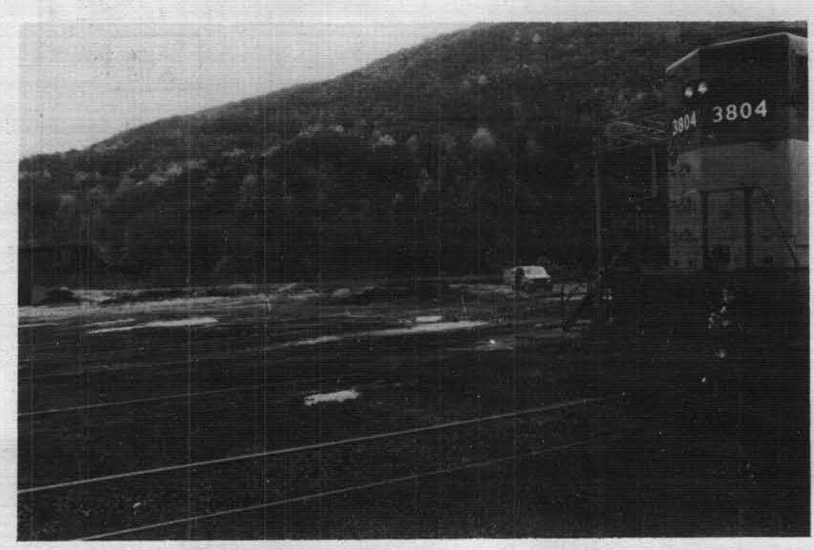


FIG. 14. CLIFTON FORGE FACILITY – TEST SITE NO. 8

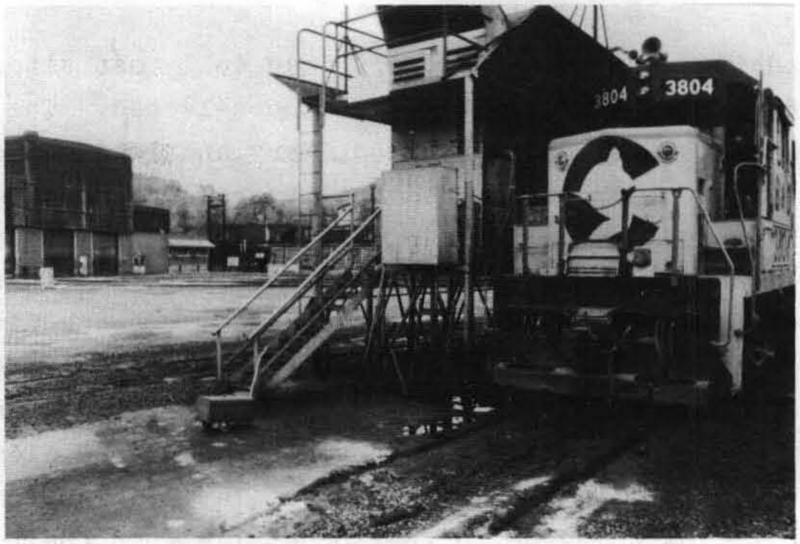


(a) Looking South at the Test Locomotive; the Test Load Cell is on the Right, the Microphones are out of the Picture to the Left; a Second Load Cell *not* used in the Testing Can Be Seen to the Left.



(b) Looking Southeast the Test Locomotive is on the Right and the Microphone Array Can Be Seen Stretching to the Left.

FIG. 15. SITE NO. 8 — CLIFTON FORGE, VIRGINIA



(c) Looking Northwest at the Main Shop, the Test Locomotive and Load Cell are on the Right.

(d) Looking West at the Test Locomotive from the 100 Ft Microphone

FIG. 15. (Continued)

In addition to the stationary load cell test sites, a site for making passby measurements was also selected. The passby site was located at the Cumberland, Maryland locomotive repair facility. A test track of good quality rail used for dynamic load testing of locomotives was selected for the passby tests. A portion of that track is visible in Fig. 1. A map of the site and photographs are found in Figs. 16 and 17, respectively. The site was cleared of freight cars as shown in Fig. 16 so as to conform with the site requirements in the EPA standards. However, a parking lot south of the test track could not be cleared of automobiles and light trucks (see Fig. 17a). These vehicles were sufficiently low compared to the locomotive that their effect on the locomotive noise measured at the microphones located on the other side of the locomotive was negligible.

2.2 TEST LOCOMOTIVES

Locomotives for testing were obtained at the Cumberland facility on two bases. A "dedicated" locomotive was assigned to the program for several weeks. That locomotive was tested at all eight load cell test sites and the passby site. The "dedicated" locomotive was a General Motors Electro-Motive Division (EMD) GP38, Serial No. 3804.

In addition to the "dedicated" locomotive, nine locomotives were obtained on an opportunity basis at Cumberland. These opportunity locomotives were tested at Site No. 1, the conforming site, and at the passby test site. All were EMD locomotives since these were the only type serviced at Cumberland. These locomotives are listed in Table 2.

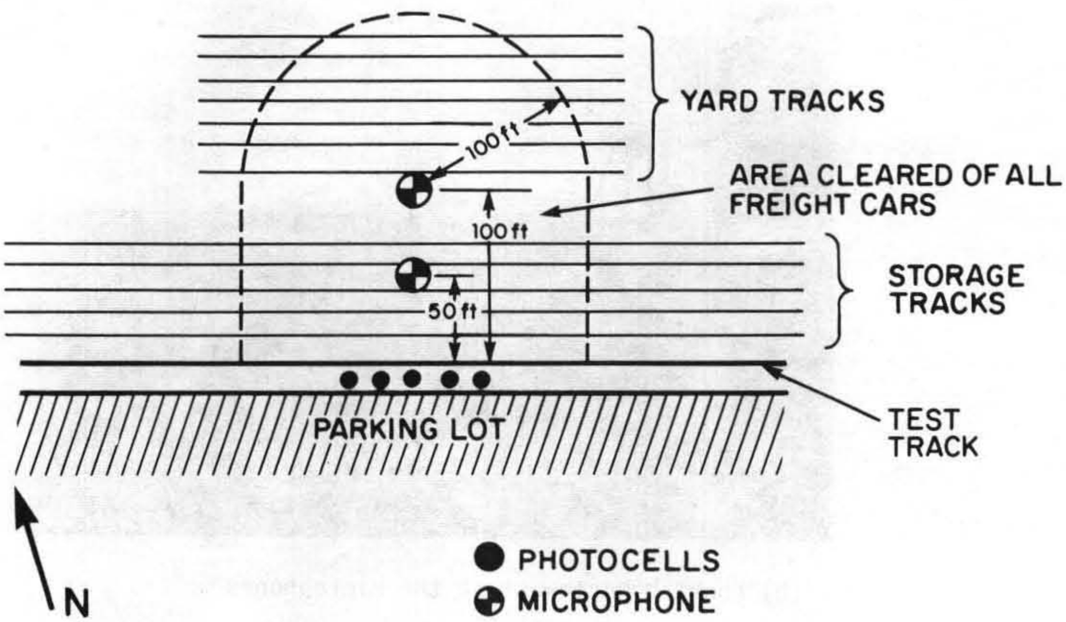
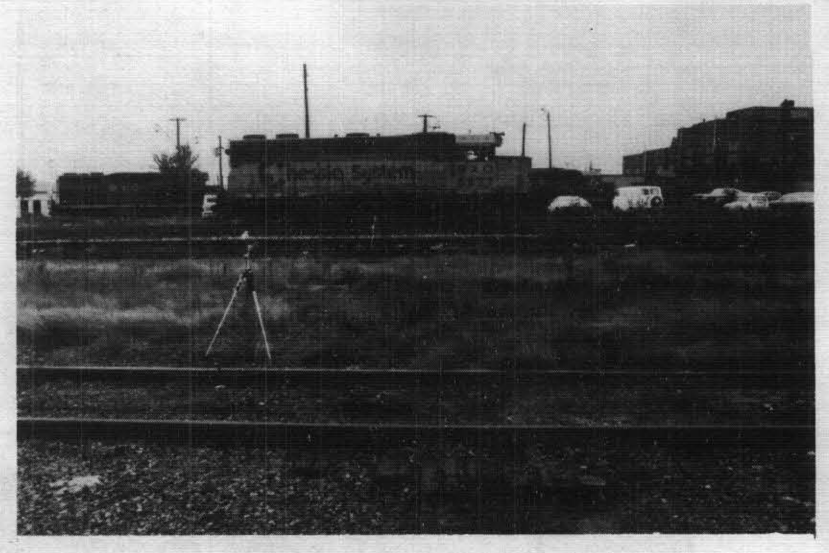


FIG. 16. PASSBY TEST SITE.

(a) Looking West at the Test Locomotive; the Parking Lot is to the Left and the Microphones are to the Right.

FIG. 17. PASSBY TEST SITE — CUMBERLAND, MARYLAND

(b) Looking Northwest at the Microphones



(c) Looking South at the Test Locomotive from Behind the 100 Ft Microphone

FIG. 17. (Continued)

TABLE 2. TEST LOCOMOTIVES

Railroad	Manufacturer	Model	Serial No.	Type
Chessie	EMD	GP38	3804	Dedicated
Chessie (Baltimore & Ohio)	EMD	GP40-2	4143	Opportunity
Chessie (Western Maryland)	EMD	GP40	3797	Opportunity
Chessie	EMD	GP40-2	4147	Opportunity
Chessie	EMD	GP40	3784	Opportunity
Chessie	EMD	GP35	3515	Opportunity
Chessie	EMD	SD35	7419	Opportunity
Chessie	EMD	GP30	6915	Opportunity
Chessie	EMD	GP9	6482	Opportunity
Chessie	EMD	GP38	3827	Opportunity

2.3 INSTRUMENTATION

Two independent instrumentation systems were used during the test program: an on-board instrumentation system used at both load cell and passby test sites and a wayside instrumentation system. Figure 18 shows the on-board instrumentation system. Two microphones were used: one in the cab approximately 6 in. from the engineer's left ear and one outside the locomotive mounted on a pole attached to the railing of the locomotive. This latter microphone was mounted at the height of the exhaust stack halfway between the exhaust stack and the cooling fans. The output of a time code generator along with the microphone signals was recorded on a seven channel FM tape recorder operating at 30 ips intermediate band. We also attempted to record main generator current and voltage, but continued failure of the buffering amplifiers (Gould, Model 13-4215-92) made this impossible. Instead, we

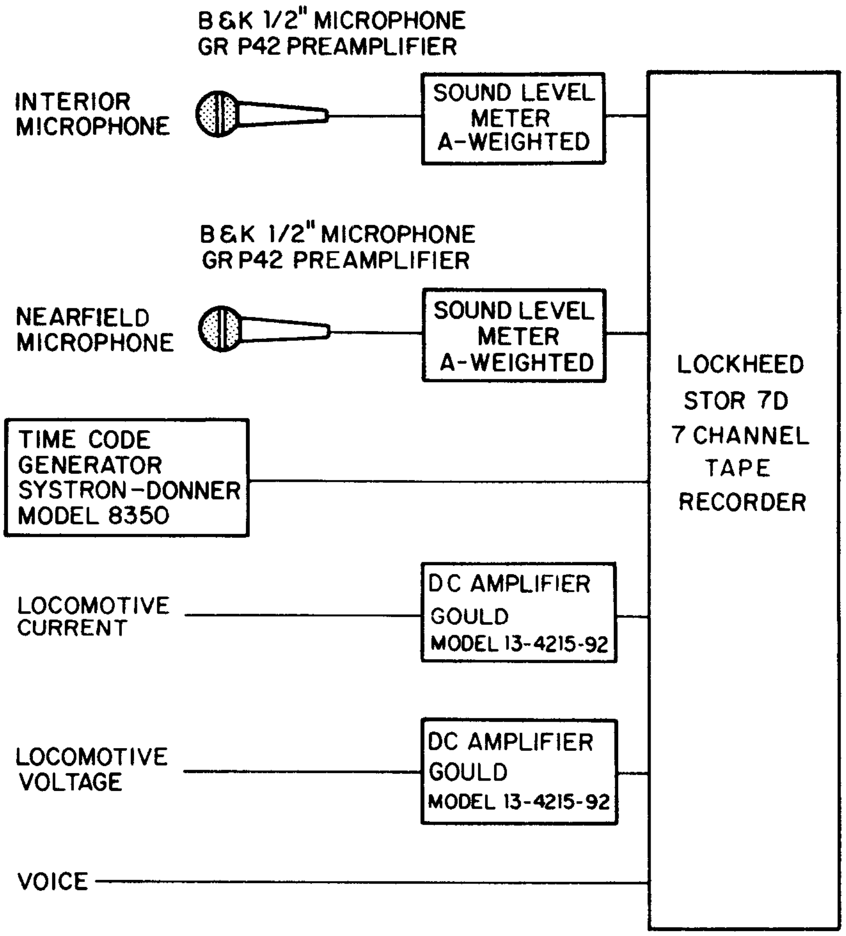


FIG. 18. ON-BOARD INSTRUMENTATION

used a Westinghouse power meter provided by Chessie and noted in the data logs the power levels achieved under each operating condition.

The wayside instrumentation for the load cell test sites is shown in Fig. 19. Up to three wayside microphones, the output of a time code generator, and wind speed and direction from a Climatronics Weather System were recorded on the same model tape recorder as in the on-board system. During all testing, the

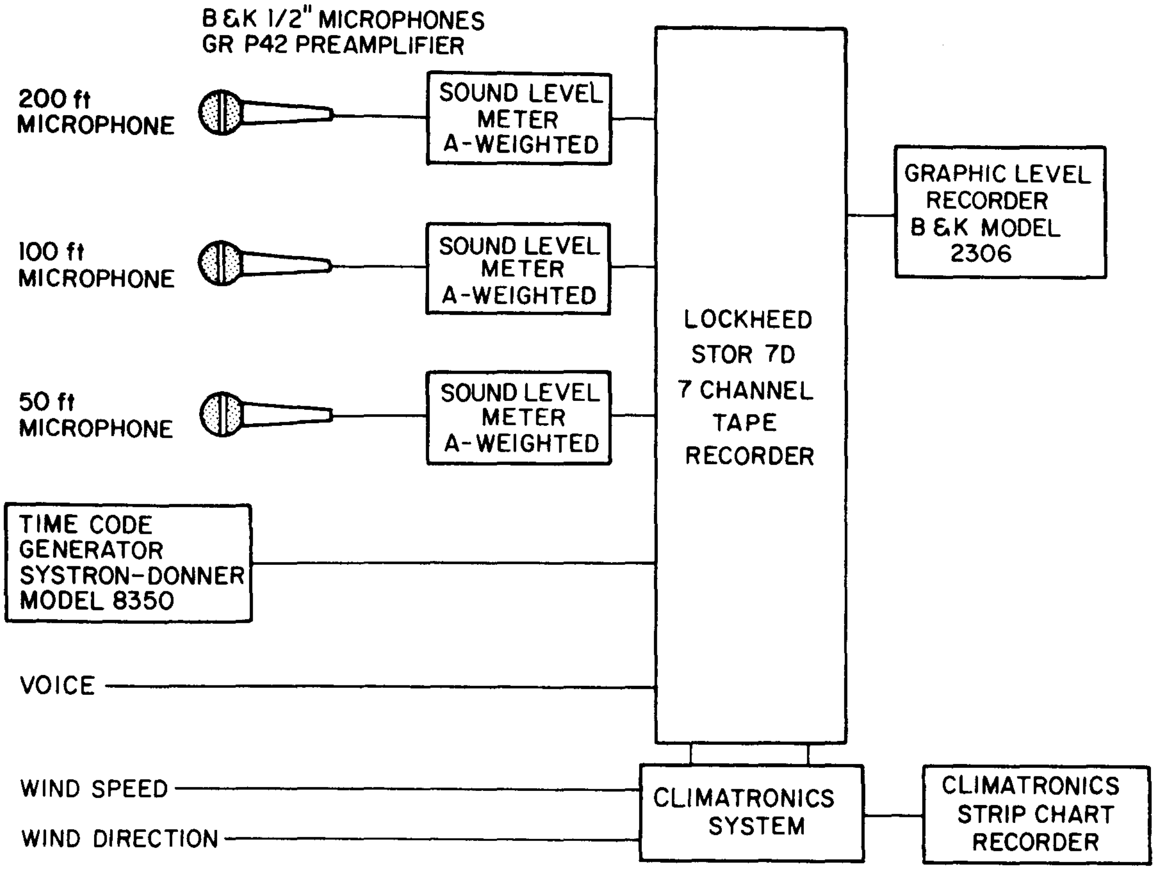


FIG. 19. WAYSIDE INSTRUMENTATION USED AT THE LOAD CELL TEST SITES

wayside and on-board time code generators were synchronized so that the signals recorded on the two separate systems could be synchronized for comparison purposes.

The wayside instrumentation system used at the passby site is shown in Fig. 20. It is essentially the same as the system used at the load cell test sites except that in place of the most distant microphone, the output of a series of photocells were recorded. These photocells were located at 20 ft intervals at trackside in the vicinity of the microphones. An automotive headlight mounted on the locomotive was directed downward at the

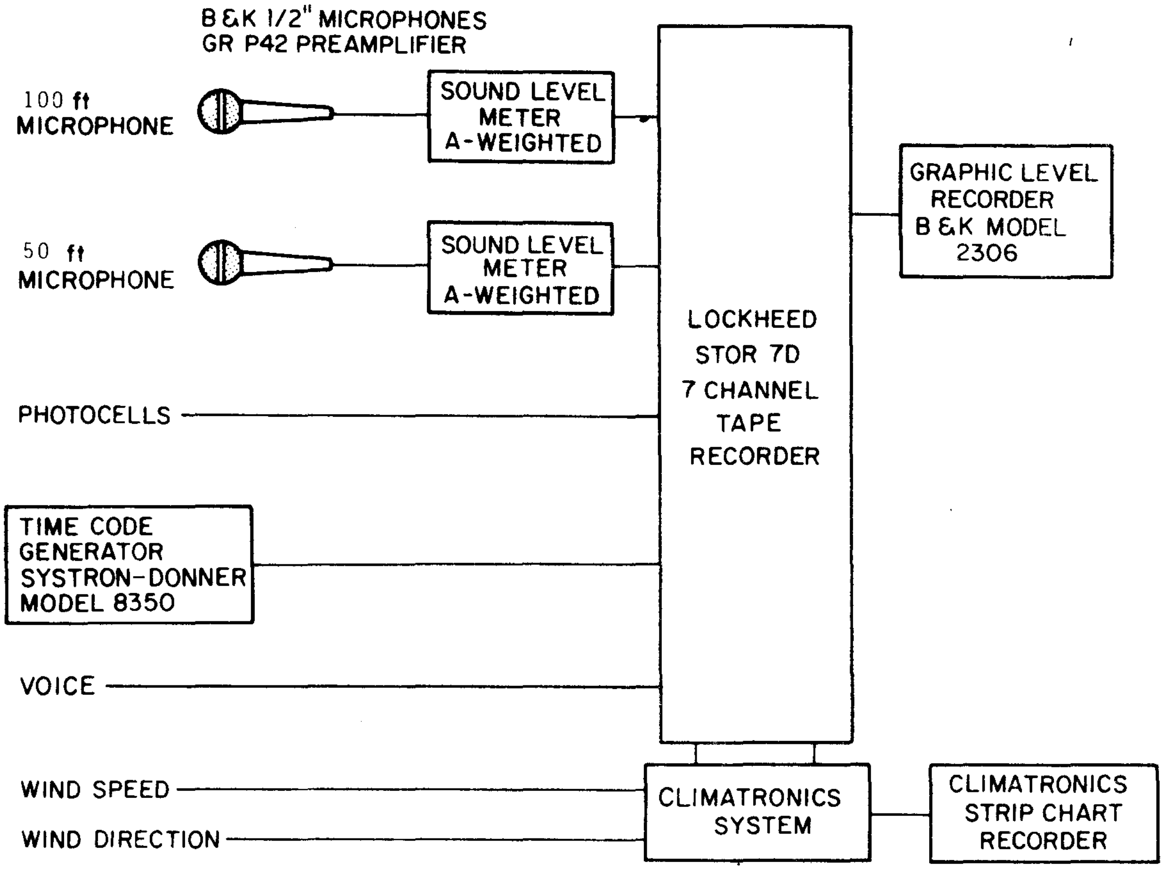


FIG. 20. WAYSIDE INSTRUMENTATION USED AT THE PASSBY TEST SITE

photocells. When light passed over any of the photocells, an electrical pulse was generated at the output of the photocell system that was recorded on the tape recorder. From the resulting sequence of recorded pulses, locomotive position and speed could be determined.

2.4 TEST PROCEDURE

2.4.1 "Opportunity" Locomotive

The "opportunity" locomotives were tested at Site No. 1 (the "typical" site), Site No. 2 (the "conforming" site), and the passby site.

Stationary Tests

At the two load cell test sites, the locomotive was connected to the load cell. After warming up, a number of tests were performed while noise at each of the microphones and the wind speed and wind direction at one location were recorded on magnetic tape. In addition, readings of locomotive power were noted in the data logs for each operating condition: the tests performed were as follows:

- *Throttle notch tests:* Idle and throttle settings 1 – 8, each held until the locomotive stabilized with all radiator cooling fans in operation.
- *Throttle wipe tests:* Throttle movements 1 – 4, 4 – 8, 8 – 6, 6 – 8, 8 – 1, 1 – 8. With a delay after each throttle change to allow the locomotive to stabilize.
- *Radiator cooling fan tests:* With the locomotive in throttle 8, the radiator cooling fans were operated in all combinations encountered in normal operation.

The *throttle notch*, *throttle wipe*, and *radiator cooling fan tests* were all performed with the locomotive both loaded by the load cell and unloaded. The *radiator cooling fan tests* were performed on only two of the opportunity locomotives. Background levels were recorded at the conclusion of the test after the locomotive was shut down.

Passby Tests

All "opportunity" locomotives were tested at the passby test site. After warming up, the locomotive was positioned at one end of the test track as far from the microphones as possible. The locomotive was placed in throttle 8 (all fans operating) with the main generator de-energized. With a full service brake application the main generator was energized, and the locomotive was allowed to accelerate past the microphone. By means of this procedure the locomotive achieved full load at low speed (~20 mph). Without the service brake application, full load could not be achieved until speeds of 40 - 60 mph. The test was then repeated, accelerating in the opposite direction.

To determine the contribution of braking noise and wheel/rail noise to the noise measured with the locomotive accelerating past the microphones, a braking test was performed. The locomotive was accelerated in throttle 8 from one end of the test track towards the microphones. Before reaching the microphones, the locomotive was placed in idle, and a full service brake application was made. This test was repeated in both directions several times so as to achieve the same speed passing the microphones as was obtained during the acceleration tests.

2.4.2 "Dedicated" Locomotive

The "dedicated" locomotive was tested at all load cell test sites and the passby test site. *Throttle notch tests, throttle wipe tests* and *radiator cooling fan tests* were performed at all load cell test sites using the test procedure just described. Passby tests were also performed using the same test procedure as for the "opportunity" locomotives.

2.4.3 Load Cell

All the load cells in this test program were air cooled resistor bank load cells manufactured by General Electric. All used forced air ventilation blowers to cool the resistors. In all cases, the blowers were wired into the resistor bank circuits and, hence, were powered by the main generator of the test locomotive. As a result, blower speed increased with increasing locomotive power.

The noise from these blowers can be substantial and can contaminate the measurement of noise from the locomotive. As a result, efforts were made to quantify the noise contribution from the load cell at each test site. The procedure used was to power the blower in each load cell directly from the locomotive. This involved either connecting the blower leads directly to the output leads of the locomotive main generator or connecting the locomotive normally to the load cell and then cutting out as many resistors as possible by opening the appropriate relays on the load cell. In this way full blower speed could be achieved at low locomotive throttle settings.

The proper blower speed was obtained by first measuring the voltage across the blower leads at each throttle setting with the load cell operating normally. The load cell was then set up as described above and the locomotive set in a low throttle (usually throttle 2 or 3). The "hump control" on the locomotive was then adjusted to produce the desired voltage across the load cell blower to simulate blower operation at each throttle setting. The "hump control" on the locomotive is a rheostat-like device that allows the engineer to gradually and continuously energize the main generator in each throttle setting from fully de-energized to fully energized. All Chessie locomotives are equipped with this option.

The resulting measurements of load cell noise are, of course, contaminated to some degree by the noise from the locomotive. This contamination has been minimized, however, because a very low throttle setting* is used. We have attempted to correct for this contamination by taking the measurements of locomotive noise with the locomotive operating unloaded in the throttle settings

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*Much lower than required to drive the blower during normal testing.

used to power the blower and subtracting these from the measurements of load cell noise. These estimates along with other test results are found in the next section.

2.5 TEST RESULTS

After the field testing was completed, all of the data tapes were played back through a six-channel strip-chart recorder to obtain A-weighted sound levels, wind speeds and directions, locomotive power, etc. Information extracted from these strip chart recordings is provided in detail in Appendix A. In this section we highlight the most important conclusions to be derived from that data.

2.5.1 Site Effects

The changes in the noise measured from the dedicated locomotive at the 8 load cell test sites are summarized in the bar charts of Fig. 21. The numbers in the bars refer to the load cell test site numbers in Table 1 and Sec. 2.1. At the end of the test program the locomotive was retested (approximately 1 month later) at the conforming site (Site No. 2). The data for Site No. 2 in Fig. 21 shows the change in noise level when retested. Both idle and throttle 8 sound levels are seen to be within ±1/2 dBA of the original levels. From this one would expect to be able to measure the noise from a given locomotive with an accuracy of ±1/2 dBA.

For the measurements of the noise at throttle 8, the sound levels measured at the nonconforming sites were found on the average to be 1/2 dBA above the level measured at the conforming site with a standard deviation of 0.91 dBA. On the average, this accuracy is almost as good as one could expect from a conforming site. As we shall show in the next section, the largest errors at Sites No. 1, 6 and 7 are due primarily to extraneous

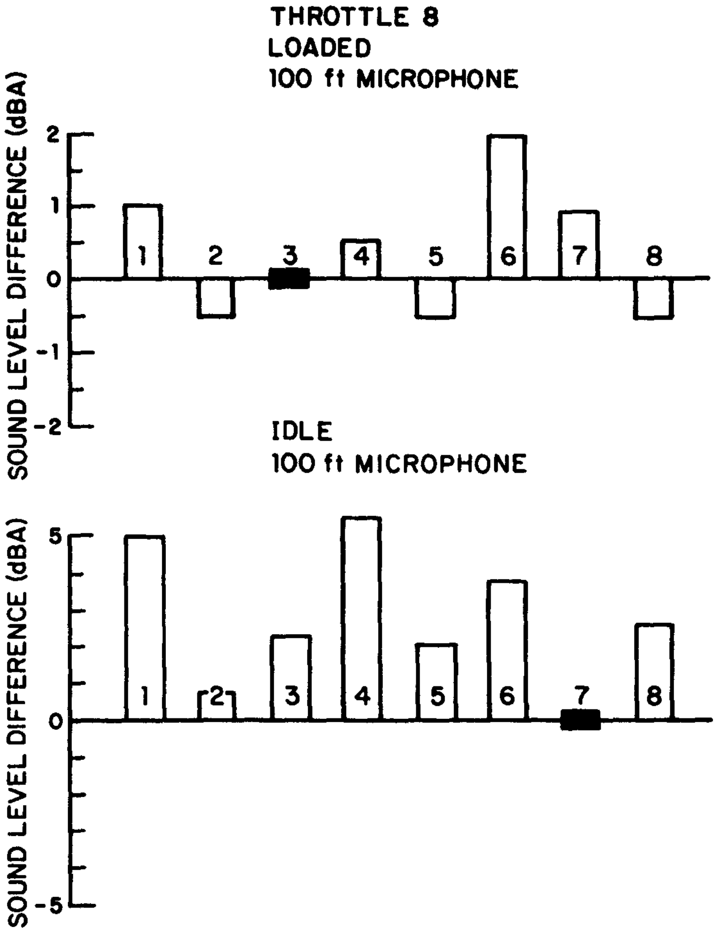

FIG. 21. DIFFERENCE BETWEEN THE SOUND LEVELS MEASURED FROM THE DEDICATED LOCOMOTIVE AT THE TYPICAL TEST SITES AND THE SOUND LEVELS MEASURED AT THE CONFORMING SITE; I.E., TYPICAL SITE SOUND LEVEL - CONFORMING SITE SOUND LEVEL. (The numbers refer to the load cell test sites in Table 3. The heavy bars for Sites 3 and 7 indicate no difference in sound level at the two sites.)

reflections from buildings and other large flat surfaces with smaller contributions from background noise and load cell noise.

The results are very encouraging because they indicate that reasonably accurate measurements of locomotive noise at throttle 8 can be obtained at commonly existing load cell test sites.

The picture for idle noise measurement is less encouraging. The idle sound levels at the nonconforming sites were on the average 2.7 dBA higher than the conforming site with a standard deviation of 1.9 dBA. The primary source of these errors is the background noise at the test sites. Table 3 compares measured idle sound levels and background noise levels at each of the sites during the days the dedicated locomotive was tested. The background noise was typically measured after the locomotive was shut down at the completion of testing. Unfortunately, the background levels at all of the typical sites were highly variable due to the movement of idling locomotives in and out of the vicinity of the test sites. As a result, the background levels in Table 3 are, at best, only a general indication of the background levels obtained at each site. We attempted to minimize background interference by suspending testing when idling locomotives or other noise sources got too close to the test site. For example, in the table test site 1 and test site 4 show idle levels below the reported background. This anomaly is due

TABLE 3. COMPARISON OF DEDICATED LOCOMOTIVE IDLE SOUND LEVELS AND BACKGROUND SOUND LEVELS AT EACH OF THE LOAD CELL TEST SITES AT THE 100 FT MICROPHONE

Test Site	Idle Sound Level (dBA)	Background Sound Level (dBA)
1	69.5	74 - 78
2	66.5	61.5
3	69.5	64
4	72.5	74.5
5	68.5	64
6	70.5	61 - 63
7	66.5	53 - 61
8	69	65 - 74.5

primarily to having restricted our testing to periods of lower background levels.

Figure 22 shows the increase in noise levels when testing each locomotive at Test Site No. 1, a typical site, as compared to the noise levels obtained at the conforming site. For throttle 8 operation the average increase is 0.45 dBA with a standard

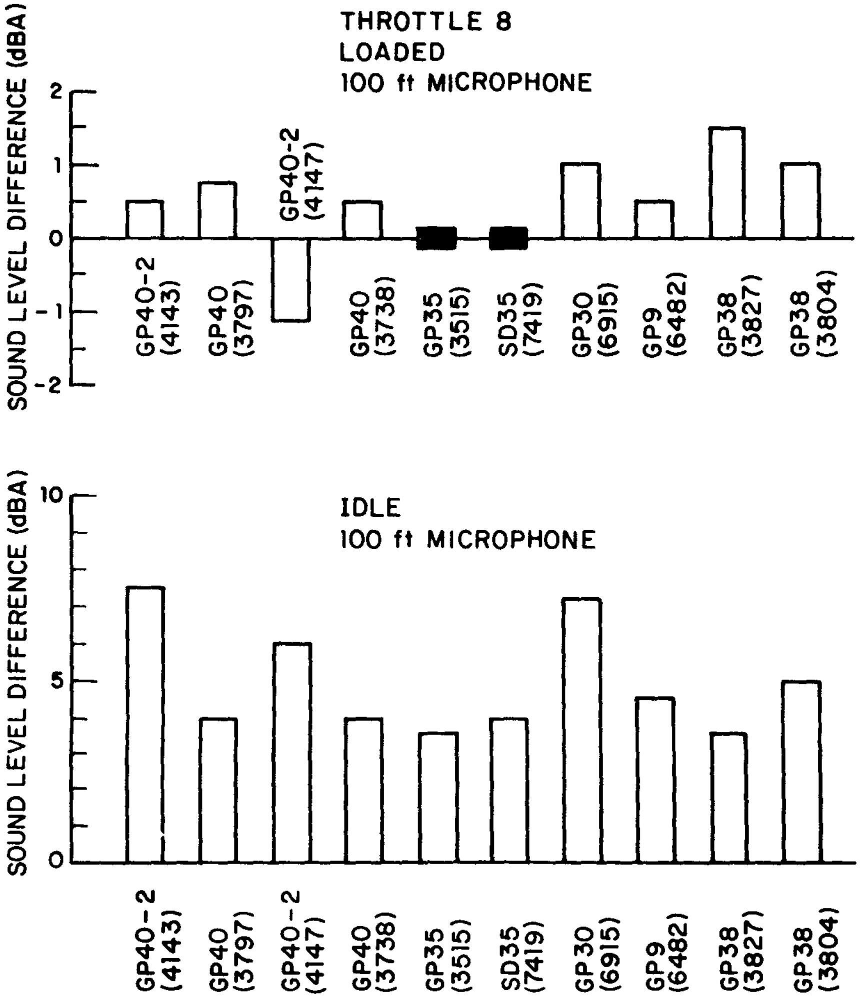

FIG. 22. DIFFERENCE BETWEEN THE SOUND LEVELS AT SITE NO. 1 AND THE CONFORMING SITE FOR EACH TEST LOCOMOTIVE; I.E., SITE NO. 1 SOUND LEVEL - CONFORMING SITE SOUND LEVEL. (The heavy bars for the GP35 and SD35 indicate that no difference in sound level was measured at the two sites.)

deviation of 0.75 dBA, indicating as before that reasonably accurate measurements of locomotive noise at throttle 8 can be obtained at nonconforming test sites.

The measurement of idle noise levels is not so encouraging. The average increase in these levels is 4.9 dBA with a standard deviation of 1.4 dBA. Again, the discrepancy is due primarily to background noise levels at Site No. 1 as indicated in Table 4. Again, there are anomalies in the table in which idle levels are below background levels due to the highly variable nature of the background noise. In general, the most that can be said is that the background varied between 68 - 78 dBA at Site No. 1 and that site could not be used to measure locomotive idle noise levels on any regular basis.

TABLE 4. COMPARISON OF IDLE NOISE LEVELS AND BACKGROUND NOISE LEVELS MEASURED AT SITE NO. 1 (100 Ft Microphone Position)

Locomotive		Idle Noise Level (dBA)	Background Noise Level (dBA)
Type	Serial No.		
GP40-2	(4143)	75	69 - 72
GP40	(3797)	76	75
GP40-2	(4147)	74.5	74
GP40	(3784)	73	70.5
GP35	(3515)	71.5	73
SD35	(7419)	70	72 - 76
GP30	(6915)	72	70 - 74
GP9	(6482)	72	73 - 80
GP38	(3827)	67	68 - 77
GP38	(3804)	69.5	74 - 78

2.5.2 Load Cell Noise

A serious concern at the beginning of the program was the contribution of the noise from the load cell blower to the noise of a locomotive operating loaded at throttle 8. Table 5 shows in all cases that the load cell noise was at least 10 dBA below the measured locomotive noise. The "upper bound" estimate of load cell noise in the table was obtained by taking the noise levels measured with the load cell driven by the locomotive with most of the load cell resistors cut out of the circuit. In this way the voltage across the blower motor achieved with the locomotive driving the load cell normally at throttle 8 could be obtained with the locomotive in a much lower throttle setting. The "best estimate" in the table was obtained by logarithmically subtracting the noise from the locomotive operating in that throttle setting from the "upper bound" estimate. Only at Site No. 6, where the exhaust from the load cell was very high, does the load cell contribution come within 10 dBA of the locomotive noise in throttle 8.

TABLE 5. COMPARISON OF DEDICATED LOCOMOTIVE NOISE AT THROTTLE 8 AND LOAD CELL NOISE AT 100 FT

Site No.	Locomotive Noise (dBA)	Load Cell Noise (dBA)	
		Best Estimate	Upper Bound
1	89.5	74	78
2	88.5/88	-	66
3	88.5	69	73
4	89	68	75
5	88	-	71.5
6	91.5	80	81
7	89.5	69	73
8	88	71.5	75

2.5.3 Passby Test Procedure

An alternate test procedure to the stationary load cell test was examined during this program. The purpose of the new test procedure was to allow for fully loading the locomotive at throttle 8 at locations where the noise from the locomotive could be measured without contamination by high background noise, large reflecting surfaces, load cell noise, etc. – problems associated with most existing load cell test sites. A passby test procedure fully described in Sec. 2.4 was used in which the locomotive, with a full service brake application, was accelerated at throttle 8 past a microphone at the wayside 100 ft from the track centerline. In all cases, we had no difficulty in achieving full power from the locomotive at speeds of 20-30 mph after accelerating from rest over distances of less than 200 yds. Figure 23 compares the noise from the 10 test locomotives measured using the passby test

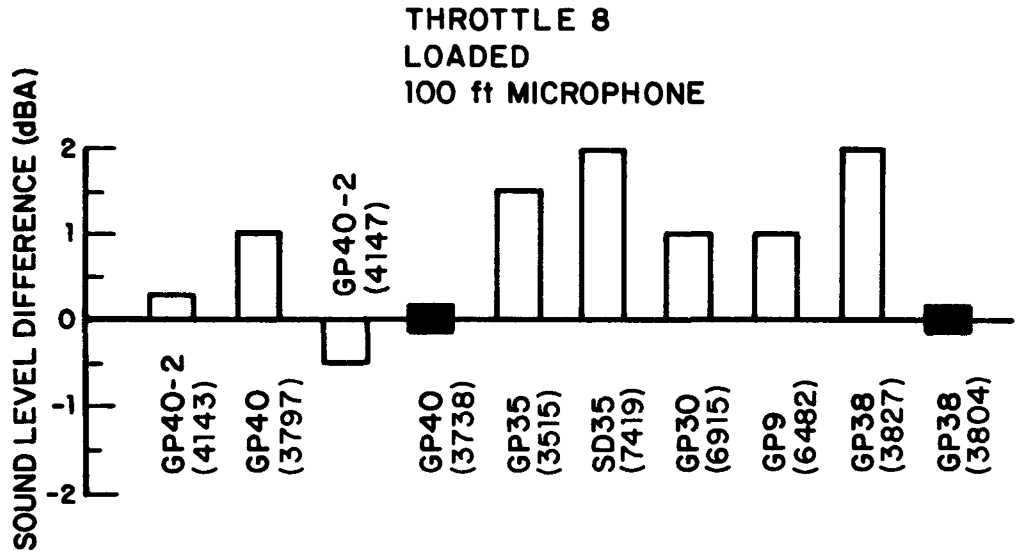

FIG. 23. DIFFERENCE BETWEEN LOCOMOTIVE NOISE LEVELS AT THROTTLE 8 AND 100 FT MEASURED USING THE PASSBY TEST PROCEDURE AND THOSE NOISE LEVELS MEASURED AT THE CONFORMING SITE WITH THE LOCOMOTIVE STATIONARY AND ATTACHED TO THE LOAD CELL; I.E., PASSBY SOUND LEVEL - CONFORMING SITE SOUND LEVEL.

procedure at Site No. 9 with the noise measured from those locomotives at the conforming site. The two test procedures agree quite closely. The passby test procedure gives noise levels on the average 0.83 dBA higher than the stationary test procedure with a standard deviation of 0.87 dBA.

2.5.4 Throttle Wipe Tests

All locomotives were tested using the throttle wipe procedure described in Sec. 2.4. It was felt that during rapid throttle changes, sound levels exceeding those achieved at throttle 8 full load might be obtained. For all the locomotives tested, the maximum A-weighted sound level was achieved during operation at throttle 8 full load.

2.5.5 Radiator Cooling Fan Contribution

All of the locomotives tested had electric-powered demand-actuated radiator cooling fans. Since these fans can be easily turned off and on, it was possible to examine the cooling fan contribution to the noise from each of the test locomotives during load cell testing. Table 6 summarizes the results of these tests. It shows the change in noise from the locomotive at 100 ft operating fully loaded in throttle 8 as each fan is turned on. The fans were turned on in the same sequence in which they would be turned on automatically in normal operation as cooling water temperature increases. As Table 6 indicates, the fans generally contribute significantly to the total noise at throttle 8.

TABLE 6. INCREASE IN LOCOMOTIVE NOISE AT THROTTLE 8 AT 100 FT DUE TO RADIATOR COOLING FANS (dBA)

Locomotive Type	Serial No.	No. of Fans				
		0	1	2	3	4
GP38	3804	85	88.5	88.5	-	-
Retest		86	87	88	-	-
GP40-2	4143	84	86	86	87	-
GP40	3797	-	-	-	89	-
GP40-2	4147	86.5	87.5	88	89	-
GP40	3784	-	84	85	87	-
GP35	3515	81	84.5	84.5	86.5	-
SD35	7419	78	82	83	86	-
GP30	6915	81	83	84	85	-
GP9	6482	88.5	89	89	89	89
GP38	3827	83	84	85	-	-

3. ANALYSIS OF SOUND PROPAGATION AT THE LOCOMOTIVE TEST SITES

The difference between the noise from a locomotive measured at one of the typical sites and that noise measured at the conforming site was due to a number of factors such as background noise, load cell noise, changes in the noise produced by the locomotive, and acoustic propagation effects. All but the last, propagation effects, have been considered in Sec. 2. In this section we develop an analytical model of the propagation of sound from a locomotive, focusing on the sound at 100 ft from a locomotive operating at throttle 8 under full load. Our purpose here is to estimate the increase or decrease in sound measured at each of the typical test sites as compared to that measured at the conforming site.

3.1 ACOUSTIC PROPAGATION EFFECTS CONSIDERED

The following factors contributing to excess attenuation are usually [2] considered for outdoor noise propagation.

1. Temperature, humidity, and atmospheric pressure.
2. Rain, fog, mist.
3. Barriers.
4. Vegetation.
5. Turbulence and wind/temperature gradients.
6. Ground effects.
7. Reflections off solid surfaces.

This is a general list of factors to consider in any type of outdoor noise propagation situation. However, for the purpose of locomotive noise measurements, a reasonable grouping of these factors would be the following:

- Temperature, pressure, humidity, and precipitation.

- Barriers, vegetation, site geometry, reflections, ground effect
- Wind and temperature gradients, turbulence.

The first grouping of the factors gives meteorological effects that vary from hour to hour but are considered constant during a particular test; the second grouping gives site-specific effects that are constant for each site but vary between sites; and the last grouping is meteorological effects that can vary during a test.

Each of these factors is now considered in turn and is either classified as negligible for the present study or is included in the prediction scheme.

3.1.1 Slowly Varying Meteorological Effects

Precipitation

The effects of snow and rain on acoustic propagation have been studied [2]; but no precipitation was present during the measurements (as required by the EPA Railroad Noise Emission Standard) and, consequently, these effects were ignored.

Temperature and Humidity

The effects of temperature and humidity on atmospheric absorption have been understood for some time and are well documented. Heat conduction and viscosity in the air (classical absorption) account for the low frequency attenuation, while molecular absorption by oxygen molecules can give significant high frequency attenuation. Standard values for these effects are given in Ref. 3 and are used in the present scheme. Over a measurement distance of 100 ft and frequencies up to 8 kHz, the maximum possible attenuation is of the order 1-2 dB.

Recent work by Piercy *et al.*[4] has shown that nitrogen relaxation (similar to oxygen relaxation) is also a factor that was not previously considered. A new draft SAE standard, including the effects of nitrogen, has recently been proposed.* However the effects of nitrogen relaxation are generally low frequency ones (typically 50-300 Hz) and are also of very small magnitude – of the order of fractions of dB over 100 ft. Therefore, the SAE Standard ARP866 [3] was considered adequate for the present calculations. The charts for each 1/3 octave band level are given in Fig. 24, and with a known temperature (°F) and relative percentage humidity, the attenuation in dB/1000 ft can be found.

Since temperature and humidity varied from site-to-site during this test program it is conceivable that some measurement error could have been induced by changes in atmospheric absorption. Table 7 lists the test sites, the average meterological conditions during the dedicated locomotive tests, and the resulting atmospheric absorption in dB/1000 ft calculated from Fig. 24. It is readily apparent that site-to-site differences are negligible for all frequencies up through the 2000 Hz octave band. Differences begin to appear only starting in the 4000 Hz octave band. The major contribution to locomotive noise comes from frequencies below 4000 Hz. As a result, site-to-site variations in locomotive noise due to atmospheric absorption are negligible.

Attenuation due to atmospheric absorptions in the sound received through reflections off large surfaces may, however, be of some importance. At many of the "typical" test sites large reflecting objects were present. As we shall show in Sec. 3.1.2, sound from the locomotive can reflect off these objects and interfere with the sound directly radiated to the microphone.

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*Although it was not available at the writing of this report.

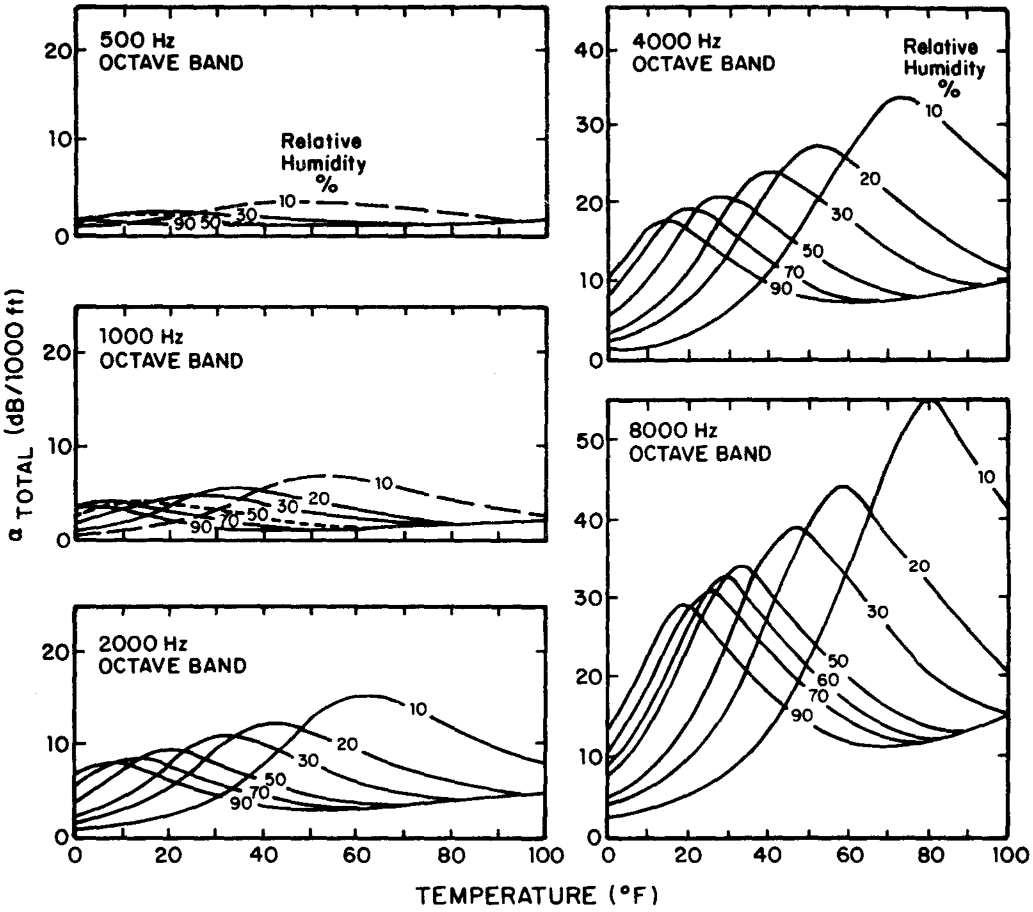


FIG. 24. ATMOSPHERIC ABSORPTION COEFFICIENTS FOR OCTAVE BANDS OF NOISE FOR DIFFERENT TEMPERATURES AND HUMIDITIES

Since the path lengths for the reflected paths can be considerably longer than for the direct path, the attenuation in the reflected sound produced by atmospheric absorption can have some effect on this interference. We will discuss this further in Sec. 3.1.4.

Pressure

Attenuation due to changes in barometric pressure are only significant for large changes in altitude, i.e., typically in

TABLE 7. ATMOSPHERIC ABSORPTION AT THE TEST SITES

Test Site	Pressure mbar	Temperature °F	Relative Humidity %	Absorption				
				500 dB/1000 Ft	1k dB/1000 Ft	2k dB/1000 Ft	4k dB/1000 Ft	8k dB/1000 Ft
1	904	70	(70)	1	1.5	3	6	11
2	1007	70	(70)	1	1.5	3	6	11
3	903	74	(70)	1	1.5	3	7	10
4	1000	75	(70)	1	1.5	3	7	10
5	993	77	(70)	1	1.5	3	7	10
6	1011	61	50	1	1.5	3	10	18
7	1007	67	40	1	1.5	3	12	20
8	983	50	90	1	1.5	3	7	12
2 Revisited	991	55	85	1	1.5	3	6	12
Typical 1	991	55	(70)	1	1.5	3	7	13
Conform 1	993	86	58	1	1.5	3	7	11

aircraft noise measurement studies. Barometric pressure readings were taken at each test site but the corrections in dB are negligible for the present study.

3.1.2 Site-Specific Effects

Barriers

The general theories of barriers are well defined [*2,5,6*]; and predictions within ±3 dB are possible for certain barrier configurations. However, from the detail plan maps of the test sites, clear line of site existed between the microphone and locomotive and no significant barrier effects on the direct path needed to be considered. However, in some instances barriers (usually in the form of the test locomotive itself) interferred not with direct path but with paths involving reflection off large flat surfaces. For those calculations, we used the following formula [*2*] for the attenuation ΔB due to the barrier:

$$\Delta B = \begin{cases} 20 \log \left[\dfrac{\sqrt{2\pi N}}{\tanh\sqrt{2\pi N}} \right] + 5 \; ; & N \geq -0.2 \\ 0 \; ; & \text{otherwise} \end{cases} \qquad (1)$$

where $N = \pm 2/\lambda\ (A+B-d)$ where λ is the wavelength of sound in air; and A, B and d are defined in Fig. 25.

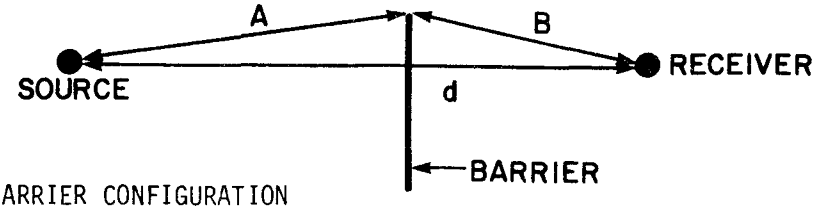
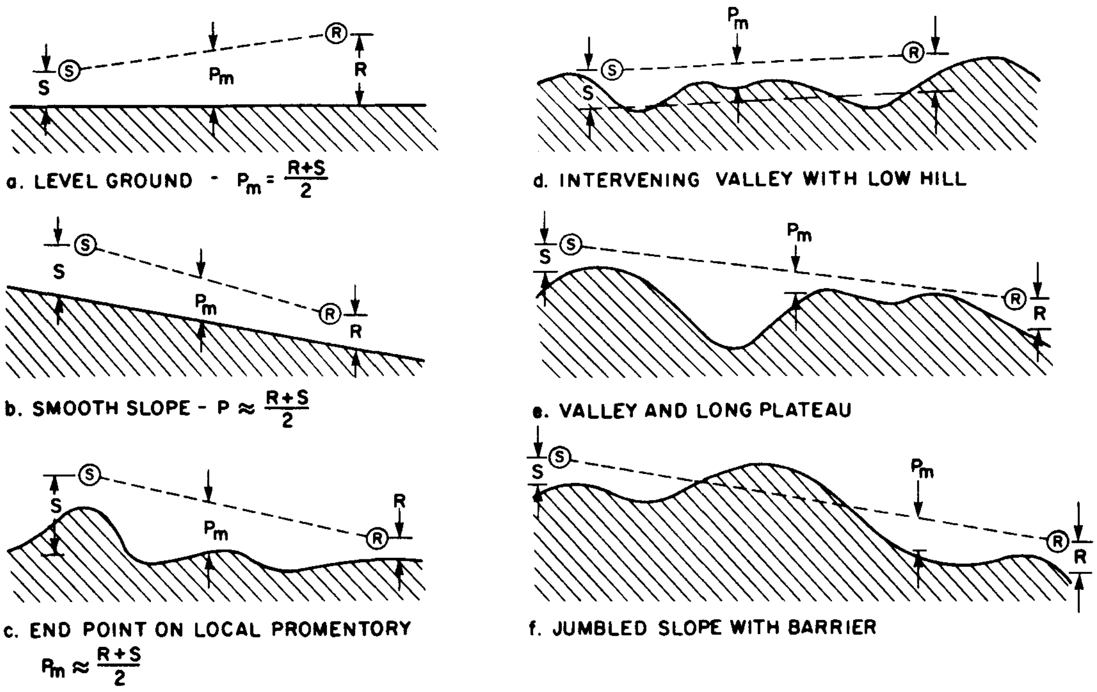


FIG. 25. BARRIER CONFIGURATION

Site Geometry and Terrain

Large dips and humps in the ground terrain can affect the amount of excess attenuation since they act as simple barriers. Keast [7] has used the charts given in Fig. 26 to estimate the



a. LEVEL GROUND - $P_m = \frac{R+S}{2}$

b. SMOOTH SLOPE - $P \approx \frac{R+S}{2}$

c. END POINT ON LOCAL PROMENTORY $P_m \approx \frac{R+S}{2}$

d. INTERVENING VALLEY WITH LOW HILL

e. VALLEY AND LONG PLATEAU

f. JUMBLED SLOPE WITH BARRIER

FIG. 26. EXAMPLES OF DETERMINATION OF EFFECTIVE SOURCE, RECEIVER, AND MEAN PATH HEIGHTS

"average" height, P_m, between source and receivers for a number of terrain conditions. For extreme cases, these charts can be used but the test sites used here do not exhibit very large dips and humps and these effects are assumed to be negligible.

Reflecting Surfaces

For the present procedure, one of the more significant effects is likely to be the reflection of acoustic waves off buildings and other large reflecting surfaces that are in proximity to either the source or microphone. Image source techniques have been used successfully for reflections for both indoor and outdoor measurements. The techniques rely on adding a further (equal strength) acoustic source into the pressure field that is at a distance from the microphone equal to the reflected path distance. The assumptions inherent in this approach are

- Specular reflection
- Infinitely hard reflecting surfaces.

The second assumption is that all the buildings, etc., have relatively hard surfaces, i.e., brick, steel, and concrete. The image source could be attenuated by a $(1-\alpha)$ factor where α is the coefficient of absorption of the building surface (but it is felt that this refinement is unnecessary quite apart from the fact that it would be extremely difficult to obtain the relevant information).

A method for obtaining the corrections required for the SPL off a reflective plate is given in SAE Standard AIR1327 [*8*]. The theory of the interference effects one gets between a direct and a reflected wave is well known. When the difference between the two path lengths is an even number of half wavelengths, the two waves add, and a gain in SPL is apparent — for an odd number of half wavelengths, cancellation occurs. This effect is frequency-dependent and of great significance when a spectrum composed primarily of discrete tones is analzyed. For spectra with significant broad band components as in locomotive noise, the effects will not be as significant:

If we assume the following:

- The locomotive is a point source producing random, stationary, ergodic noise
- The microphone is in the far field
- Surface irregularities on the reflecting surface are small compared to the wavelengths of frequencies of interest

then the ratio of mean square pressure (direct plus reflected) to mean square pressure (direct) is given by [8]:

$$R = 1 + \frac{1}{Z^2} + \frac{2}{Z} C_R \tag{2}$$

where Z = r'/r (Fig. 27), and

$$C_R = \frac{\int_{f_a}^{f_b} w(f)\cos(2\pi\tau f)df}{\int_{f_a}^{f_b} w(f)df} . \tag{3}$$

C_R is the autocorrelation coefficient between the sound arriving by the direct path and the sound arriving by the reflected path in frequency band (f_a, f_b); w(f) is the spectral density of the sound arriving by the direct path; $\tau = \Delta r/c_0$, $\Delta r = r'-r$, and c_0 is the speed of sound.

Now using the notation in Fig. 27, we can write

$$\Delta r = \sqrt{d^2+(h_s+h_r)^2} - \sqrt{d^2+(h_s-h_r)^2} . \tag{4}$$

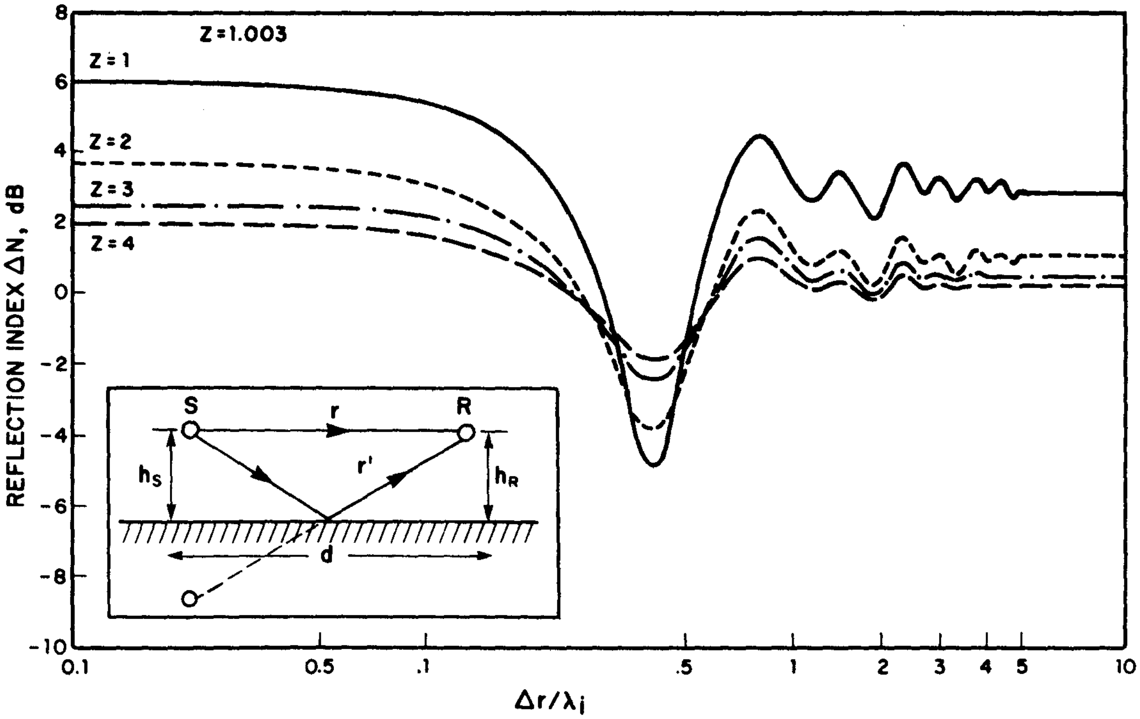


FIG. 27. THEORETICAL REFLECTION INDICES (OCTAVE BANDS) (POINT SOURCE OVER A REFLECTING SURFACE)

If $w(f) = w_0$ (approximately a constant in the frequency band f_a to f_b), we can show

$$C_R = \frac{\sin \pi\tau(f_b - f_a)}{\pi\tau(f_b - f_a)} \cos \pi\tau(f_b + f_a) \quad . \tag{5}$$

Now, defining ΔN as

$$\Delta N = 10 \log_{10} R$$

one can show [8] for octave or 1/3 octave bands that

$$N = 10 \log_{10}\left\{1 + \frac{1}{Z^2} + \frac{2}{Z}\,\frac{\sin\left(\alpha \frac{\Delta r}{\lambda_i}\right)}{\left(\alpha \frac{\Delta r}{\lambda_i}\right)} \cos\left(\beta \frac{\Delta r}{\lambda_i}\right)\right\} \tag{6}$$

where

$$\alpha = 2\pi\left(\frac{\Delta f}{2f_i}\right)$$

$$\beta = 2\pi\sqrt{1 + \left(\frac{\Delta f}{2f_i}\right)^2}$$

where $f_i = \sqrt{f_a f_b} \qquad \lambda_i = c/f_i$

and

$$\frac{\Delta f}{f_i} = \begin{cases} 0.231 \text{ for 1/3 octave band} \\ 0.707 \text{ for 1/1 octave band} \end{cases} .$$

The interference pattern in octave bands obtained from Eq. 6 is shown in Fig. 27. It is apparent from the figure that for $\Delta r/\lambda > 3$, the fluctuations in the pattern become quite small. The fluctuations are caused by the last term in Eq. 6. A reasonable approximation to Eq. 6 for Δr large would then be

$$\Delta N \cong 10 \log\left[1 + \frac{1}{Z^2}\right];\ \frac{\Delta r}{\lambda} > 3 \quad . \tag{7}$$

For reflections off buildings and other large objects in which the microphone is not too close to the reflecting surface, Δr is generally sufficiently large for Eq. 7 to be valid. For example, at 100 Hz, if the path length difference is 33 ft, Eq. 7 will be a reasonable approximation.

To include the effects of atmospheric absorption, we need simply note that the amplitude of the direct path is reduced by $e^{-\gamma r}$ and that that of the reflected path is reduced by $e^{-\gamma r'}$ where

$\gamma = \alpha/8690$ and α is the atmospheric attenuation in dB/1000 ft described in Sec. 3.1.1. Equation 6 then becomes

$$\Delta N = 10 \log\left[1 + \frac{e^{-2\gamma\Delta r}}{Z^2} + \frac{2e^{-\gamma\Delta r}}{Z}\,\frac{\sin\left(\alpha\frac{\Delta r}{\lambda_i}\right)}{\alpha\left(\frac{\Delta r}{\lambda_i}\right)}\cos\left(\beta\frac{\Delta r}{\lambda_i}\right)\right] , \tag{8}$$

and the simplified form, Eq. 7, becomes

$$\Delta N = 10 \log\left[1 + \frac{e^{-2\gamma\Delta r}}{Z^2}\right] . \tag{9}$$

If Δr is so small that Eq. 8 or 6 must be used, then the absorption correction is generally negligible for the frequencies of interest here. In Eq. 9, the absorption correction becomes significant (on the order of a dB) only at high frequency and for large Δr.

For the sites examined here, Eq. 9 is a reasonable approximation to the increase in sound level at a microphone due to the presence of a large reflecting object. It assumes that the direct and reflected waves add incoherently at the microphone and spherical spreading and atmospheric absorption are taken into account. Equation 9 is, however, not in quite the proper form for our use. We wish to know, given the locomotive noise spectrum at the conforming site (where there are no large reflecting objects), what the spectrum will be at a typical test site. The spectrum at the conforming site contains within it the effects of reflections off the ground on the direct path. At typical sites the spectrum contains both direct and reflected path contributions and the effects of ground reflections on each. Because the path lengths for the direct and reflected paths are different, the effect of the ground reflections on each can be different. This very complex problem of ground effects is discussed below.

Ground Effects

The presence of the ground at a locomotive test site has an effect on the sound at the microphone conceptually similar to the effects of the large reflecting surfaces just discussed. The problem is, however, considerably more complex because the ground plane cannot generally be considered to have an infinite impedance, as was assumed for the reflecting surfaces. An accurate assessment of the ground effects requires a detailed knowledge of the actual ground impedance. Since the changes in this impedance from site-to-site were not known in this program, we have made no attempt to assess the site-to-site variations in measured locomotive noise due to changes in ground interaction effects. Since the sites generally had similar ground conditions (dirt and gravel with sparse low vegetation) we believe this omission to be the source of only minor errors. The other issue, alluded to above, that ground interaction effects for the reflected paths at typical sites can be different from the ground interaction effects for the direct path because of path length differences is examined in Appendix B. The results in that appendix show that the ground interaction effects can be quite different for different path lengths. The ultimate effect on the sum of the contribution received from both the direct and reflected paths, however, is quite small. For this reason and because ground effects depend greatly on the ground impedance, about which we have no information for the sites considered, we will not include any ground effect corrections in the contribution from reflections off large flat surfaces.

3.1.3 Rapidly Varying Meteorological Effects

Wind and Temperature Gradients

Wind and temperature gradients close to the surface of the ground can cause refraction of acoustic waves. Under some circumstances, it is possible for shadow zones to form (Fig. 28) into which no direct sound can propagate.

Low frequency sound (f < 200 Hz) is less affected by refraction than high frequency sound. This is due to the fact that the wavelengths are much longer than the scale of the wind or temperature gradients. At high frequencies, f > 500 Hz, the attenuation

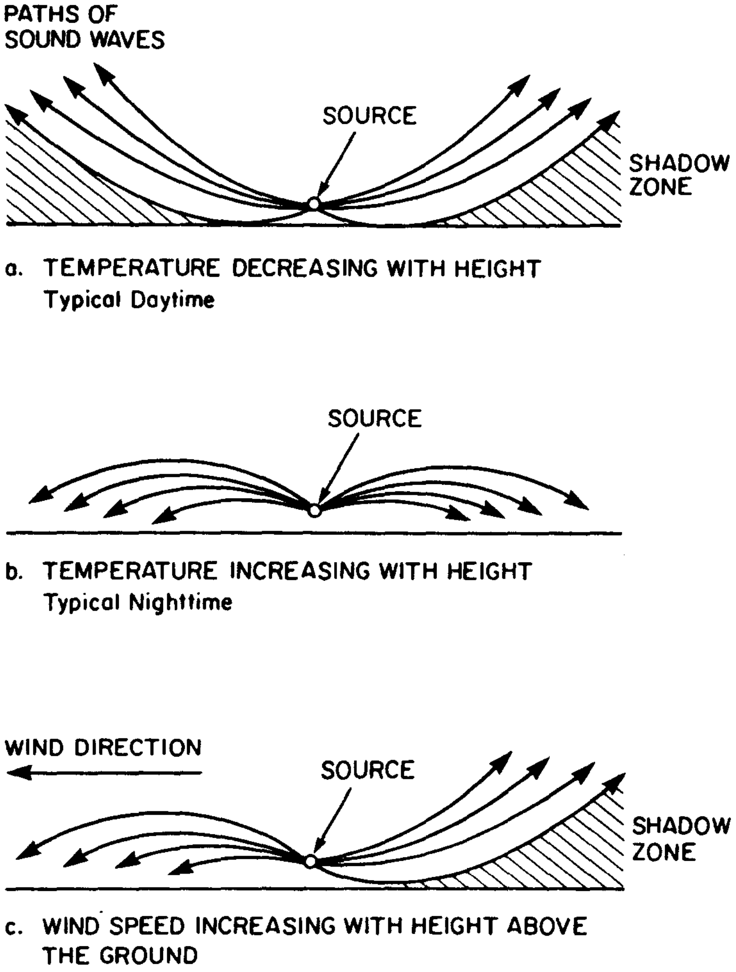


FIG. 28. SKETCHES ILLUSTRATING THE EFFECTS OF VERTICAL TEMPERATURE AND WIND GRADIENTS IN FORMING ACOUSTIC SHADOW ZONES

can be 0 dB for the receiver downwind from the source, and up to 20 dB for the receiver upwind from the source and in the shadow zone. The distance from the source to the shadow zone (Fig. 29) can be calculated by procedures outlined in Ref. 7. For

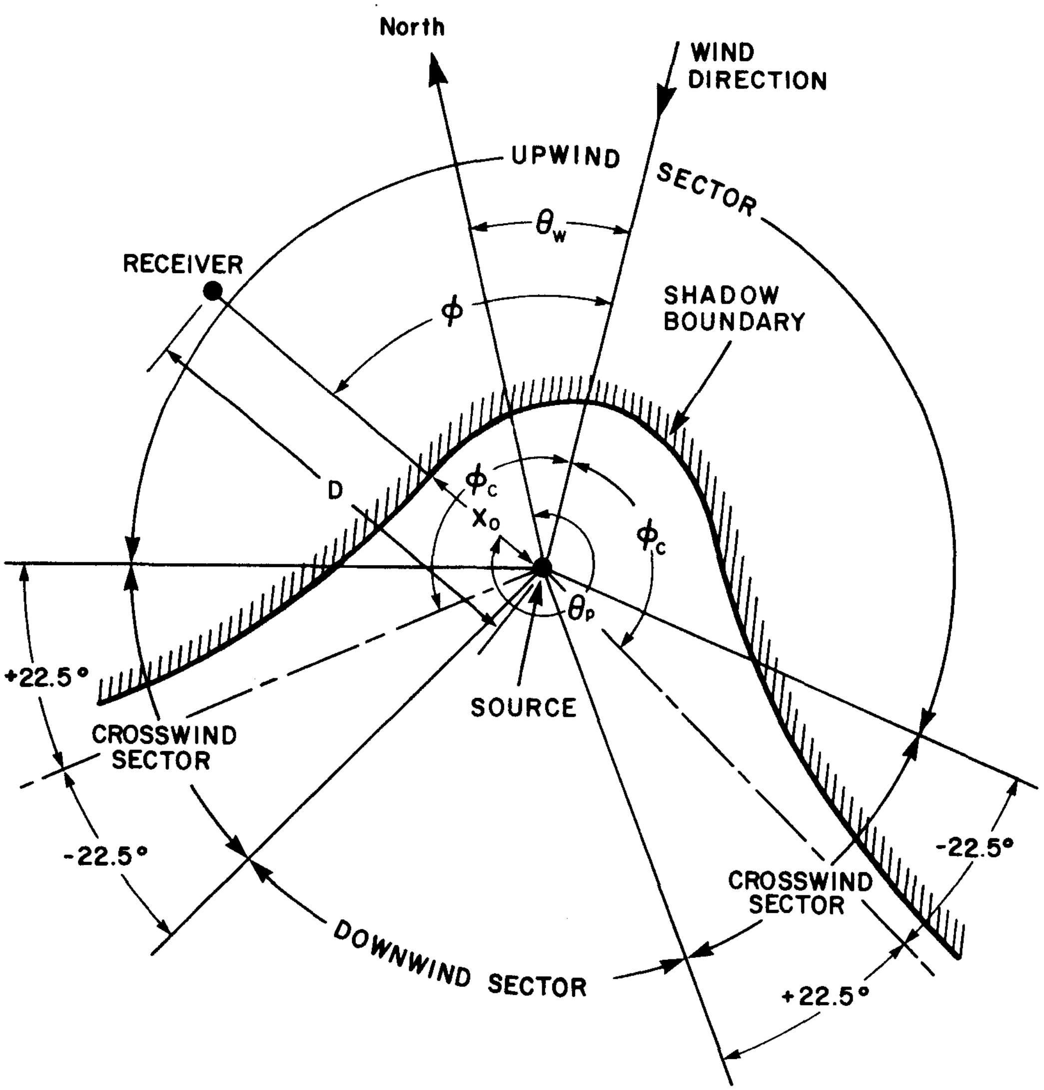


FIG. 29. PLAN VIEW OF SOUND PROPAGATION SECTORS, WITH PARAMETERS USED TO DESCRIBE THEM (See Text)

a source height of 15 ft (typical locomotive exhaust stack) and a receiver height of 4 ft (typical microphone height), we have calculated the radius of the shadow zone for the receiver upwind from the source. Figure 30 illustrates the results of those calculations assuming that temperature decreases with height above the ground (a typical daytime condition). The wind speeds in the figure are the speeds at 6 ft above the ground* assuming zero wind speed at 3 in. above the ground, and the temperatures in the figure are the decreases in temperature from ground level to 6 ft above the ground. When the receiver is located at distances less than the shadow zone radius from the source, there is nominally no attenuation [4]. Once the microphone is in the shadow zone, the attenuation due to diffraction increases with distance to nominally 20 dB at a source-receiver distance of two shadow zone radii. Thereafter, further increases in the source-receiver separation have little effect on the attenuation due to diffraction.

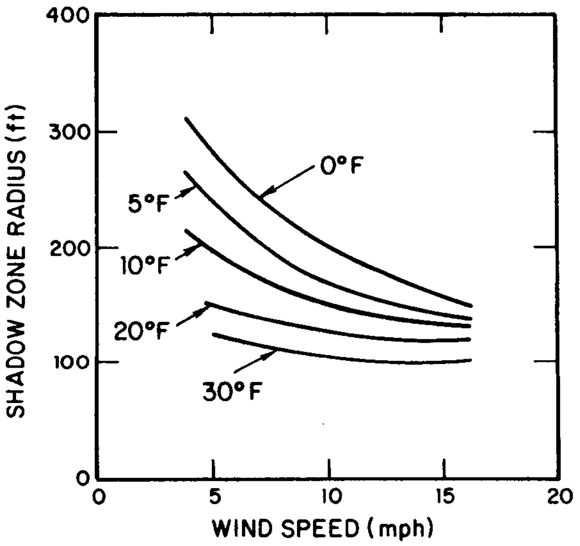


FIG. 30. RADIUS OF THE SHADOW ZONE IN THE UPWIND DIRECTION [7]. (The Source is Assumed to be 15 Ft High and the Receiver 4 Ft High. The Temperatures Shown are the Decreases in Temperature Going from Ground Level to 6 Ft. The Wind Speed is the Value at 6 Ft and the Calculation Assumes Zero Wind Speed 3 In. Above the Ground.)

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*The wind speed was measured 6 ft above the ground during the test program.

Figure 30 indicates that only for severe negative temperature gradients and significant wind speeds is the 100 ft microphone near the boundary of the shadow zone. For the testing performed during this program, a strong wind blowing from the microphone to the locomotive, as assumed in Fig. 30, was a rare occurrence. (See Appendix A.) In addition, although we have no measurements of the temperature gradient, temperature changes of 20 to 30°F within 6 ft of the ground (such as indicated in the figure) would require a bright hot sun, low wind, and probably a dark surface on the ground such as asphalt. Because all of our measurements were performed in the fall (when the sun is weaker) and over dirt and gravel with sparse vegetation, it is unlikely that such severe temperature gradients occurred.

For the reasons described above, we have neglected the effects of wind and temperature gradients on the propagation of sound to the 100 ft microphone. It must be emphasized, though, that these diffraction effects could be very significant at the 200 ft microphone since that microphone might indeed be in the shadow zone. In addition, under certain meteorological conditions, it is possible for the 100 ft microphone to be in the shadow zone or near the boundary of the zone. In such a case, the signal at the 100 ft microphone could be attenuated by a few decibels. We do not believe that this situation occurred during the measurement reported here.

Turbulence

Atmospheric turbulence is caused by instabilities in the atmosphere that form eddies which are successively broken down in size and form statistical distributions of small eddies. Time series analysis techniques are used to describe the turbulence, whose intensity is dependent on the meteorological conditions and height above the ground. At distances up to 10 meters above the ground, one is in a shear layer region, and turbulence is strongly influenced by surface friction, i.e., ground cover.

Ingard and Maling [*9*] were among the first to investigate theoretically the effects of turbulence on the interference between the direct sound and that reflected from a hard surface. They found that even when in the free field, turbulence is very small but is still sufficient to affect the sound field above a boundary. This is especially true in regions of interference where the sound level is critically dependent on phase relationships.

Consequently, turbulence produces fluctuations in the amplitude and phase during propagation which increase with increasing distance from the source [*4*]. The increasing fluctuations reach a maximum of approximately 6 dB variation in the standard deviation at a distance of 700λ, i.e., 7875 ft at 100 Hz to 78.75 ft at 10 kHz for a summer day. Recently, Daigle *et al.* [*10*], assuming a normal gaussian distribution for turbulence, have compared theoretical and experimental work for distances up to 45 meters (source-receiver distance). They found experimentally that the correlation length of atmospheric turbulence is on the order of 1.1 meters for wind and temperature fluctuations within a few meters from the ground. Using a relatively involved theory involving parameters of fluctuating phase, amplitude and index of refraction (all dependent on wind and temperature), they were able to show relatively close agreement between theory and experiment and concluded that for conditions typical of our locomotive site geometry, the standard deviation of the fluctuating measured sound levels is a maximum of 3 dB at 1.6 kHz.

Although the magnitude of variation appears significant, the correlation length of 1.1 meters implies that the period of these variations would be less than 1 sec if the turbulence propagated at a velocity comparable to the prevailing wind. Since all of our stationary measurements were conducted with the locomotives operating between 16 and 32 sec in any throttle setting, variations with a period of less than a second would have been averaged out. Even during the passby tests, the duration of the maximum level was on the order of a second, implying that the rapid variations due to atmospheric turbulence would tend to average out.

For the above reasons, as well as the lack of adequate meteorological data, we have not included any turbulence effects in our propagation model.

3.1.4 Summary

Because of a lack of adequate ground impedance data, we could not take into account changes in ground interaction from site to site. Other sources of variations in measured sound levels from site to site such as

- Precipitation
- Pressure changes
- Atmospheric turbulence
- Terrain effects
- Wind and temperature gradients, and
- Atmospheric absorption

were found to be negligible. Consequently, we were left with

- Reflections from buildings and other large surfaces

corrected for atmospheric absorption and barrier effects.

The final expression (based on Eq. 9) for the increase in the sound pressure spectrum in decibels due to a single reflecting surface at a typical site, $L_p^{(T)}(\omega)$, over that measured at the conforming site, $L_p^{(C)}(\omega)$, is given by

$$\Delta L_p^{(T)}(\omega) = L_p^{(T)}(\omega) - L_p^{(C)}(\omega) = 10 \log \left[1 + 10^{\frac{\Delta(\omega)}{10}} \right] ,$$

$$\Delta(\omega) = -20 \log(r'/r) - \frac{\alpha(\omega)\Delta r}{1000} - \Delta B \qquad (10)$$

where r' and r are the reflected and direct path lengths respectively; $\Delta r = (r'-r)$; $\alpha(\omega)$, the atmospheric absorption, is found in Table 7; and ΔB can be calculated by using Eq. 1. To apply Eq. 10, one must identify all reflected paths and determine path lengths and intervening barrier geometry (if any). A correction factor $\Delta_i(\omega)$ is obtained for each path (i), and the resulting total correction is given by

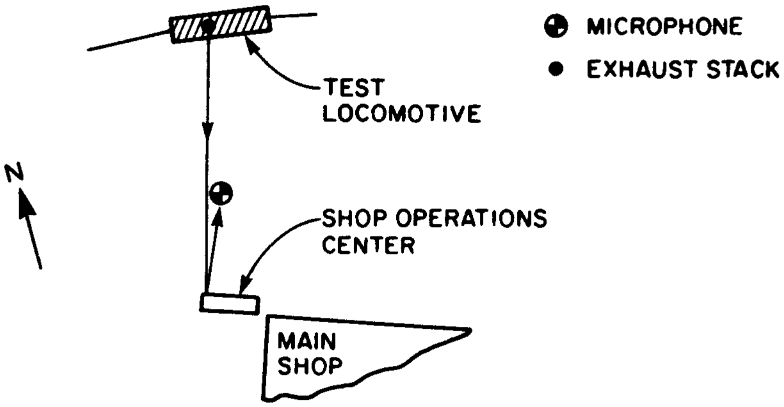
$$\Delta L_p^{(T)}(\omega) = 10 \log \left\{ 1 + \sum_i 10^{\frac{\Delta_i(\omega)}{10}} \right\}. \qquad (11)$$

The resulting analytical model in Eq. 11 is extremely simple, but we shall see in the next section that it appears to explain the changes in locomotive noise measured at most of the typical sites.

3.2 CALCULATIONS

In order to apply Eqs. 10 and 11, the primary reflecting surfaces must be identified and the reflected path lengths determined. Figure 31 shows those paths for each test site. That figure is based on careful examination of maps provided by the Chessie system, on photographs taken during the tests, and on measurements made at the test sites. Test Sites No. 2 and 8 are not included in the figure since there were no significant reflecting objects at those sites. The reflected paths shown are the only ones by which sound can reach the microphone by specular reflections. They were determined graphically from the maps using image source techniques. Table 8 summarizes the results of

(a) LOAD CELL TEST SITE NO. 1



(b) LOAD CELL TEST SITE NO. 2

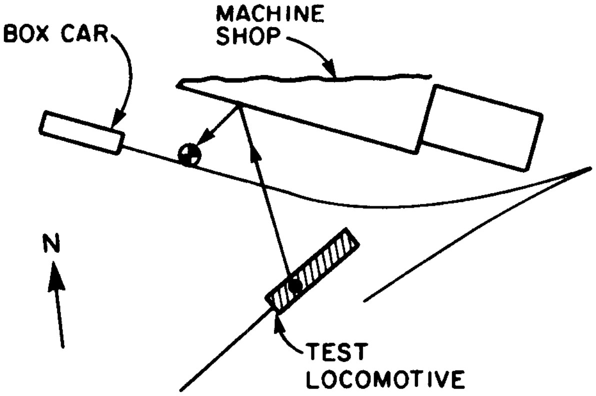
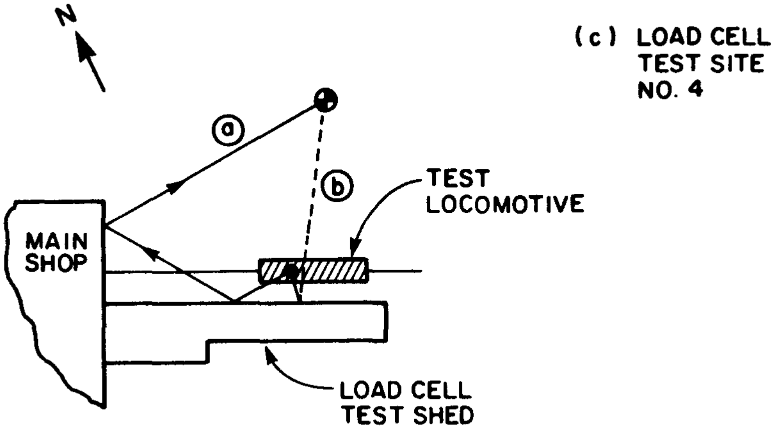


FIG. 31. PRINCIPAL REFLECTING PATHS AT EACH LOAD CELL TEST SITE



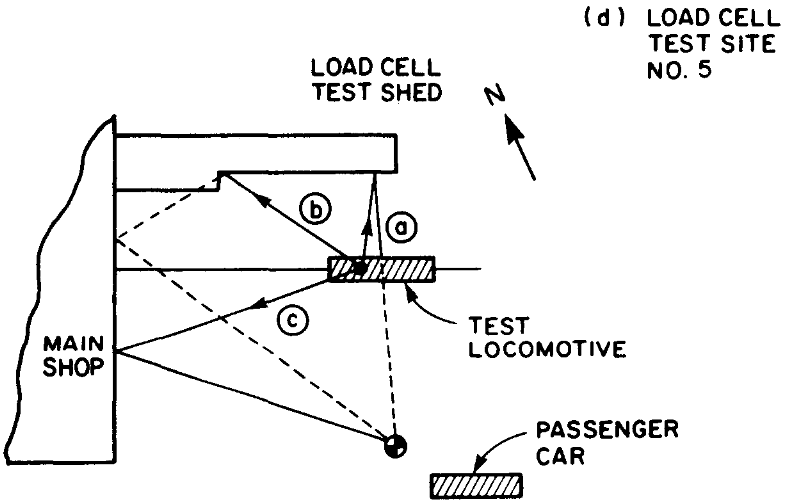
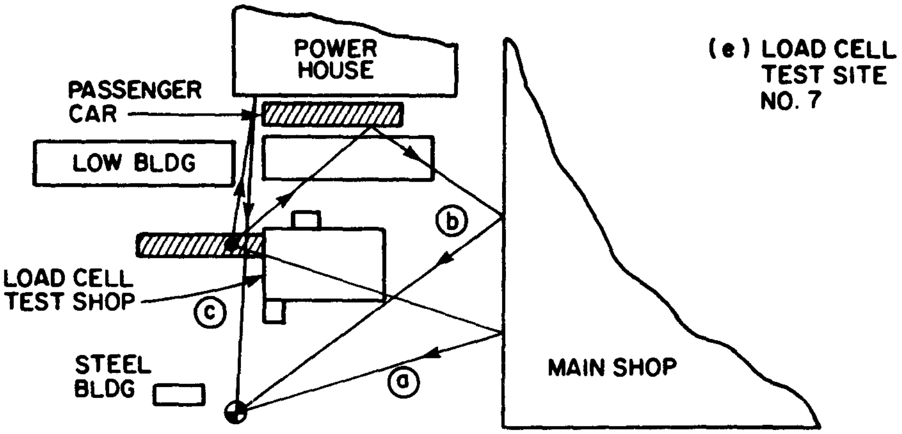


FIG. 31. (Continued)



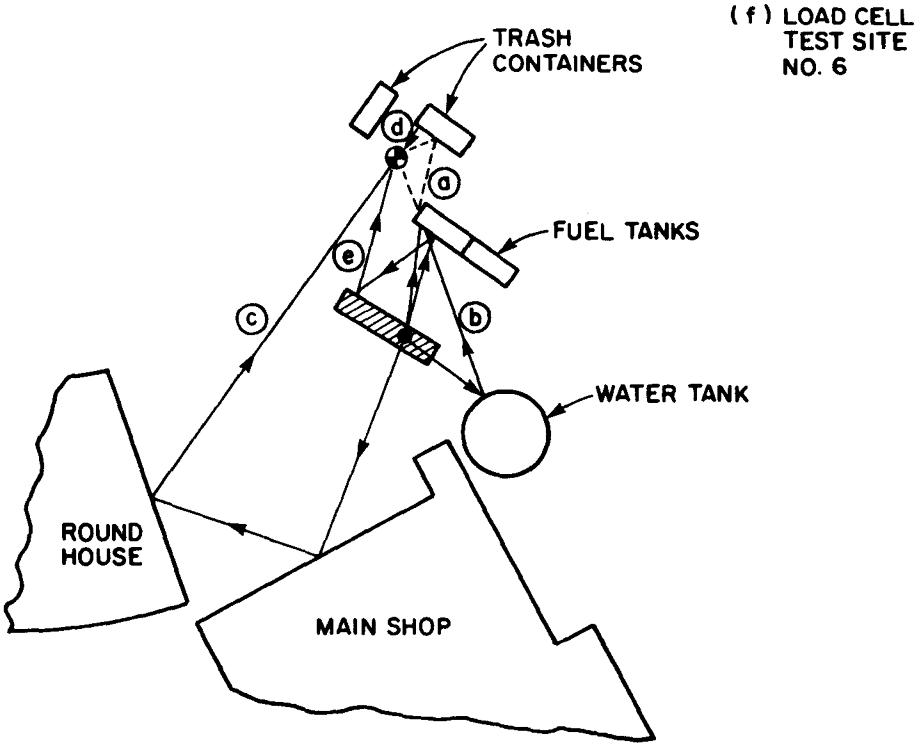


FIG. 31. (Continued)

TABLE 8. SUMMARY OF SOURCES OF MEASUREMENT ERROR AT EACH TEST SITE RELATIVE TO THE CONFORMING SITE

Site No.	Propagation Correction	Background Correction	Load Cell Correction	Total* Correction	Measured Correction
1	0.9	0.4	0.2	1.5	1.0
3	1.6	-	-	1.6	0
4	1	0.2	-	+1.2	+.5
5	0.5	-	0.1	+0.6	-.5
6	1.2 - 3.8	-	0.5	1.7 - 4.3	+2.0
7	0.8	-	-	0.8	+1.0
8	-	-	0.1	0.1	0

*The incremental increase for each source of error is calculated assuming that it acts alone. As a result, the incremental increases do not always add up to the total.

using Eq. 11 to estimate the contribution from reflections. To carry out the calculations leading to the results in Table 8, we used the spectrum of the noise at 100 ft with the locomotive operating fully loaded at throttle 8. That spectrum is presented in Fig. 32. Path characteristics are summarized in Table 9. Paths considered but not included in the calculations are shown dashed in Fig. 31. In general, we have limited our considerations to, at most, two reflections. Path ⓓ Site No. 6 is an exception and is included only because its strength is essentially equal to Path ⓒ Site No. 6.

Table 8 also shows the contribution of background noise to load cell noise and the sum of these three sources of measurement error. The measured differences between each site and the conforming site are also shown.

In general, there is reasonable agreement between measured and predicted site-to-site measurement errors. Site No. 3 is a

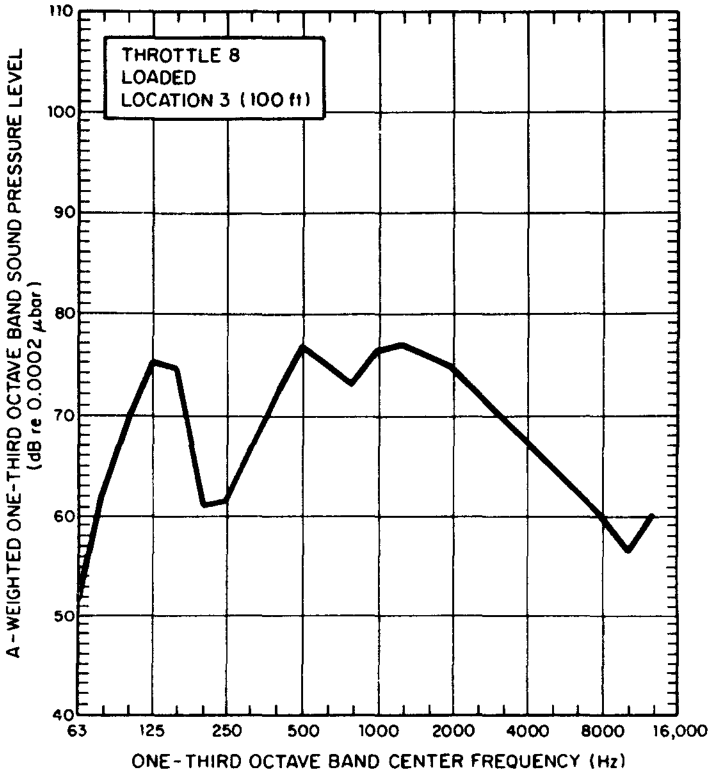


FIG. 32. THE A-WEIGHTED SOUND LEVEL SPECTRUM AT 100 FT WITH THE LOCOMOTIVE OPERATING FULLY LOADED AT THROTTLE 8

notable exception. The single reflection off the machine shop should produce ~1.6 dBA higher noise level than the conforming site. In fact, we measure no increase over conforming site levels. At present, we have no explanation for this discrepancy.

The 0.7 dBA difference between predicted and measured measurement error for Site No. 4 is probably within the limits of measurement and prediction accuracy.

The estimate for the measurement error at Site No. 5 may be high by about 0.4 dBA. This is because path ⓒ reflects off the main shop exactly where there is a huge garage door for admitting locomotives. If that door were open it would have significantly

TABLE 9. SUMMARY OF REFLECTING PATHS FOR EACH TEST SITE

Test Site No. and Path	Path Length	Comment
1	210 Ft	
3	150 Ft	
4a	280 Ft	
4b	145 Ft	
5a	210 Ft	
5b	385 Ft	Neglected due to barrier effect of projection from load cell test shed
5c	330 Ft	
7a	335 Ft	
7b	400 Ft	
7c	270 Ft	
6a	140 Ft	Paths a and b may be attenuated by the barrier effect of the fuel tanks. Paths b and c involve reflections off cylinders
6b	225 Ft	
6c	500 Ft	
6d	540 Ft	
6e	210 Ft	

affected the contribution from path ⓒ. Unfortunately, we do not know whether the door was open or not.

Site No. 6, because of its complexity, requires some further explanation. Over five reflected paths have been identified. Paths a and b appear to be partially blocked by the last fuel tank. (See Fig. 31.) Those tanks are cylinders approximately 10 ft in diameter, so the blockage they provide could be significant – especially at the higher frequencies. Unfortunately, analytical estimates of the blockage are extremely complex. Consequently, we have simply provided in Table 8 two estimates of the site measurement error, a high estimate including paths a and b, and a low one not including those two paths. The low estimate of +1.7 dBA is very near the measured value of +2 dBA.

Two of the paths at Site No. 6 involve reflection off cylinders. In both instances, we have assumed a reflection coefficient of 1. This is a valid estimate for cylinders whose circumference is large compared to a wavelength and for reflections back at small angles relative to the path of the incident wave. Both of these conditions are satisfied for both reflected paths at both cylinders.

Table 8 indicates that the major site-induced measurement errors are due to reflections off nearby buildings and other large surfaces. For measurement of locomotive noise at throttle 8, background and load cell noise do not contribute significantly to measurement errors.

3.3 GUIDELINES FOR LOCOMOTIVE NOISE MEASUREMENT

If a conforming site is available, locomotive noise should be measured in conformance with the Environmental Protection Agency's Railroad Noise Emission Standards (Title 40, Chapter I, Part 201). If a site conforming with the provisions in that standard is not available, then it may still be possible to obtain acceptably accurate measurements of locomotive noise at existing load cell test sites. In any event, measurements should conform as closely as possible to the requirements of the EPA Standard. However, based on the results of this study, the requirements of the Standard can be relaxed, as described below; and one should still be able to obtain measurements of locomotive noise within +1 dBA to -0.5 dBA of measurements at a conforming site.

3.3.1 Load Cell Requirements

- The locomotive should be located between the test microphone and load cell with no part of the load cell visible from the test microphone.

- The outlet for cooling air from the load cell should be as low as possible. High chimneys should be avoided.

3.3.2 Site Geometry

- The locomotive should be fully visible from the test microphone, especially the exhaust outlet and radiator cooling fan inlets and outlets.
- A single large reflecting surface (greater than 6 ft x 6 ft) directly behind the microphone, e.g., such that the microphone is between the locomotive and the reflecting surface, can be as close as 50 ft away from the microphone. This restriction can be relaxed if it can be shown that because of the limited size and orientation of the reflecting surface no paths exist for sound to propagate from the locomotive, reflect off the surface and strike the microphone.
- A single large reflecting surface (greater than 6 ft x 6 ft) to the side of and approximately parallel to a line joining the center of the locomotive and microphone should be 100 ft from that line, as the EPA standard requires. This restriction can be relaxed if it can be shown that no paths (rays) exist for sound to propagate from the locomotive, reflect off the surface of interest, and strike the microphone.
- A single large reflecting surface behind the locomotive, e.g., such that the locomotive is between the microphone and the surface, does not present as severe a problem because of the substantial barrier that the locomotive presents to reflected sound. If sound reflecting off that surface must pass through the locomotive (i.e., the locomotive acts as a barrier to the sound) in order to reach the microphone, the surface may be as

close as 10 ft from the side of the locomotive. Otherwise the spacing requirements of a reflecting surface behind the microphone apply.

3.3.3 Weather Conditions

- Requirements on weather conditions specified in the EPA standard should be adhered to. In addition, it is desirable to locate the microphone downwind from the locomotive and to test on days with steady wind rather than on days in which the wind speed fluctuates between calm and the 20 mph wind gust limits specified in the standard.

4. CONCLUSIONS

The major conclusion of this study is that it is possible to obtain acceptably accurate measurements of locomotive noise for throttle 8 full load operation at many typical load cell test sites. The major effect on differences between measurements at typical sites and sites that conform with EPA railroad noise emission standards appears to be reflections from nearby buildings or other large reflecting surfaces. Load cell noise and background noise are of considerably less importance.

The accurate measurement of locomotive noise at idle is difficult at most typical load cell test sites due to the high background noise levels. However, since idle noise measurements do not require a load cell, they can be performed in remote areas where sites conforming with EPA standards and low background noise can more easily be found.

Finally, an alternate locomotive noise test procedure for throttle 8 full load operation was examined. The passby procedure obtained full load operation by accelerating the locomotive from rest at throttle 8 with a full service brake application. Sound levels at the 100 ft microphone were on the average less than 1 dBA above the noise measure at the 100 ft microphone at the conforming site, with the locomotive operating at throttle 8 full load.

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APPENDIX A

DETAILED DATA SHEETS

A.1 DEDICATED LOCOMOTIVE

The following sheets present a detailed compilation of data from tests on the dedicated locomotive at each of the eight load cell test sites. Site numbers refer to the designation in Table 1 in the text. The throttle settings are designated T1 for throttle 1, T2 for throttle 2, etc.; and the letter in parentheses following the throttle designations indicates whether the locomotive was loaded by the load cell (L) or unloaded (U). All tests were performed with all fans on unless otherwise indicated. For example, T8(L)2 fans indicates that the test was performed at throttle 8, loaded, with 2 radiator cooling fans running. Throttle wipe tests are indicated by the throttle setting at the beginning of the wipe and the throttle setting at the end of the wipe. Again, (L) or (U) indicates whether the locomotive was loaded by the load cell or not. The sound level for the throttle wipes is the maximum achieved at the particular microphone during the wipe.

All sound levels are overall A-weighted sound levels and were read from strip chart recordings of tape recorded signals. All in-cab sound levels were taken with cab windows open and cab doors closed.

The arrows in the charts indicate wind direction. Wind directions are all relative to the microphones and locomotive. For example,

- An arrow pointing to the top of the page is for the wind blowing from the microphone to the locomotive;
- An arrow pointing to the bottom of the page is for wind blowing from the locomotive to the microphone, and

- An arrow pointing to the right of the page is for wind blowing from left to right as one faces the locomotive from the wayside microphones and an arrow pointing to the left is for wind blowing in the opposite direction. Where more than one arrow is shown the indication is a fluctuating wind direction in the indicated quadrant.

TEST SITE NO. 1

LOCOMOTIVE MODEL AND SERIAL NO. GP38 #3804

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone - (dBA)
					Speed (mph)	Direction		
Idle	73.	69.5	68.5		2	↙	88	71
T1(L)	73.5	69.5	68.5		2	↙	88	71
T2(L)	77	73.5	74		2	↙	92	75.5
T3(L)	79.5	76.5	75.5	300	2	↙	97	77
T4(L)	83	78.5	77	700	2	↙	102	79.5
T5(L)	87	81	79.5	1100	2	↙	105.5	82
T6(L)	89.5	84	81.5	1450	2	→	108	85
T7(L)	93.5	88.5	85	1500	2	→	110.5	85
T8(L)	95	89.5	87.5	2000	2	↓	113.5	87
T8(L)0 Fan	94.5	89.5	86	2000	5	-	114	86.5
T8(L)1 Fan	94.5	89.5	86	2000	8	-	114	87
T8(L)2 Fans	95	90	87	2000	6	-	114	87.5
T8(L)3 Fans	-	-	-		-	-		
T8(L)4 Fans	-	-	-		-	-		
T1(U)(Idle)	73	71.5	72.5	-	2	↓	88	71.5
T2(U)	76	73	73	-	2	↓	90	75
T3(U)	78.5	74.5	74	-	2	↓	94	75
T4(U)	81	77	76	-	2	↘	96	77
T5(U)	84	79	77	-	2	↘	97.5	80
T6(U)	87.5	81.5	80	-	2	→	101.5	81.5
T7(U)	89.5	82	82.5	-	2	→	103	82.5
T8(U)	92	86.5	85.5	-	2	→	105.5	85
T8(U)0 Fan	87	82.5	80.5	-	4	↖	105.5	85.3
T8(U)1 Fan	87	83	80	-	4	↖	106	85
T8(U)2 Fans	90	86	83.5	-	6	↖	106	85
T8(U)3 Fans	-	-	-	-	-	-		
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	83	79	76	0-650	5	↙	103.5	79
T4→8(L)	96	90.5	87	650→2050	7	↙	114	89
T8→6(L)	90	85.5	82.5	2050→1400	6	↙	109	85.5
T6→8(L)	95.5	90.5	87	1400→2000	7	↓	114	88.5
T8→Idle(L)	74.5	73.5	71	2000→0	8	↙	89	72
Idle→T8(L)	95.5	91	88	0→2000	6	↘	114	88
T1→4(U)	82	78.5	76	-	4	↙	97	78
T4-8(U)	91.5	85.5	84	-	5	↙	106.5	86.5
T8→6(U)	87	81	78.5	-	5	↙	101.5	82
T6→8(U)	92	86	84.5	-	6	↙	106.5	87
T8→I(U)	74	73.5	70.5	-	7	↙	88	71.5
I→T8(U)	92	86.5	84	-	4	↙	106.5	82

Ambient:

50 Ft Mic: 75-78 dBA
100 Ft Mic: 74-78 dBA
200 Ft Mic: 73-77 dBA

Weather:

Barometric Pressure: 904 mbar
Temperature: 45-70°F
Humidity: -

TEST SITE NO. 2

LOCOMOTIVE MODEL AND SERIAL NO. GP38 #3804

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	70.5	66.5	62	-	7	↓	88.5	71.5
T1(L)	71	67	62.5	-	9	↓	89	71.5
T2(L)	74	69	64	100	9	↓	92.5	75
T3(L)	78	73	67	325	7	↓	98	76
T4(L)	81.5	76.5	70.5	775	8	↓	103.5	78.5
T5(L)	85	80	75	925	9	↓	106.5	81
T6(L)	87.5	82	78	1400	9	↙	109	82.5
T7(L)	91	85.5	79.5	1750	10	←	111.5	84.5
T8(L)	93.5	88.5	82	2000	5	↙↓	114.5	86.5
T8(L)0 Fan	92	85	81.5	-	10	↘	114	86.5
T8(L)1 Fan	92.5	88.5	82	-	15	↘	114	86.5
T8(L)2 Fans	93.5	88.5	82.5	-	11	↘	114	86.5
T8(L)3 Fans	-	-	-	-	-	-	-	-
T8(L)4 Fans	-	-	-	-	-	-	-	-
T1(U)(Idle)	70	65	60	-	12	↓	88	71.5
T2(U)	74	68	62.5	-	13	↓	90.5	75
T3(U)	76.5	72	65	-	11	↓	94	75
T4(U)	79.5	74	67.5	-	10.5	↓	95.5	76.5
T5(U)	83.5	77	72	-	11	↓	99	80
T6(U)	85	79.5	74	-	11	↓	101.5	80.5
T7(U)	88	83.5	76.5	-	15	↓	103	83
T8(U)	91	85	78.5	-	13-14	↓	106	85
T8(U)0 Fan	-	-	-	-	-	-	-	-
T8(u)1 Fan	-	-	-	-	-	-	-	-
T8(U)2 Fans	-	-	-	-	-	-	-	-
T8(U)3 Fans	-	-	-	-	-	-	-	-
T8(U)4 Fans	-	-	-	-	-	-	-	-
T1→4(L)	81.5	75	72	500	12	↓	103	78
T4→8(L)	94	87.5	82	2000	12	↓	114	86
T8→6(L)	88	80	76	1350	11	↓	108.5	83
T6→8(L)	94	88	84	2000	10	↓	114	86
T8→Idle(L)	71.5	67	68	0	8	↓	88	71.5
Idle→T8(L)	94	88	82.5	1950	6-8	↓	114	86
T1→4(U)	80	73	67.5	-	8.5	↘	96	77
T4-8(U)	90.5	85	79	-	7	↘	106	85
T8→6(U)	85.5	76.5	73	-	9	↘	101.5	80.5
T6→8(U)	91	86	78.5	-	10	↘	106	85
T8→I(U)	70.5	64	62	-	12	↘	88	70
I→T8(U)	91	86	79	-	11	↘	106	85

Ambient:

50 Ft Mic:	63.5-68 dBA
100 Ft Mic:	61.5-66 dBA
200 Ft Mic:	60.5-67 dBA
Nearfield Mic:	64-71 dBA
In-Cab Mic:	60.5-67 dBA

Weather:

Barometric Pressure:	1007 mbar
Temperature:	70°F
Humidity:	-

TEST SITE NO. 3

LOCOMOTIVE MODEL AND SERIAL NO. GP38 #3804

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind Speed (mph)	Wind Direction	Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
Idle	72	69.5	67.5		6	↑	89	70
T1(L)	72	69.5	67.5		4	→	89	70
T2(L)	74.5	70.5	69	75	6	↑	93	75
T3(L)	77.5	74	72.5	300	6	↑	97.5	76
T4(L)	82	77	77	700	6	↑	103	78.5
T5(L)	85	80.5	80	1100	8	↗	107	81
T6(L)	88.5	83.5	82.5	1400	10	↗	109.5	82
T7(L)	91	86.5	84.5	1700	9	↑	112	84.5
T8(L)	93	88	87	1950	7-9	↗	115	86.5
T8(L)0 Fan	91.5	87	85	2000	9	↖	114.5	86.5
T8(L)1 Fan	92	87.5	86	2000	7-9	↖	114.5	86.5
T8(L)2 Fans	93.5	88.5	87	1950	7	↑	114.5	86.5
T8(L)3 Fans	-	-	-	-	-	-		
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	71	67.5	66.5	-	6-8	↑	88.5	70.5
T2(U)	74	70	63.5	-	7	↗	91	75
T3(U)	76.5	72.5	71	-	5	→	94	74
T4(U)	79.5	74.5	72.5	-	4	↗	96.5	76
T5(U)	82.5	77	76.5	-	6	↑	98.5	79
T6(U)	84.5	80	79	-	5	↗	102	80
T7(U)	87	82.5	81.5	-	8	↗	104	82
T8(U)	89.5	84.5	83.5	-	7-8	↑↗	106	84.5
T8(U)0 Fan	85.5	81.5	80	-	9	↖	105.5	85.5
T8(U)1 Fan	87	82.5	82	-	5	↖	106	85.5
T8(U)2 Fans	90	84.5	84	-	9	↖	106	85.5
T8(U)3 Fans	-	-	-	-	-	-		
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	82	77.5	77	750	6	↑	103.5	78
T4→8(L)	93.5	88	87	1950	7-8	↖↑	115	86
T8→6(L)	88.5	83.5	82.5	1400	6	↑	109	82
T6→8(L)	93	88	87	2025	6	↑	115	86
T8→Idle(L)	71	67.5	67	0	5	↑	89	71
Idle→T8(L)	93.5	88.5	87.5	2000	5-6	↖↑	115	86.5
T1→4(U)	79.5	75.5	74	-	8-9	↑	96.5	75.5
T4-8(U)	90	84	84	-	8	↖	106	84.5
T8→6(U)	85	79.5	79	-	9	↖	101.5	80
T6→8(U)	90	84.5	84	-	8	↖	106	84
T8→I(U)	71	68	67.5	-	7-9	↖	89	70.5
I→T8(U)	90	84	83.5	-	5-7	↖	106.5	84.5

Ambient:

50 Ft Mic:	66.5 dBA
100 Ft Mic:	64 dBA
200 Ft Mic:	65 dBA
Nearfield Mic:	71 dBA
In-cab Mic:	59 dBA

Weather:

Barometric Pressure:	903 mbar
Temperature:	70°F

TEST SITE NO. 4

LOCOMOTIVE MODEL AND SERIAL NO. GP38 #3804

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	74.5	72.5	73		6	→	89	70
T1(L)	74.5	72.5	73	50	6	→	89.5	70
T2(L)	76.5	73.5	73	125	6	→	93	75
T3(L)	79	75	74	350	6	↖	99	76
T4(L)	82.5	78	75.5	750	5	↖	104.5	80
T5(L)	85.5	81	77	1050	5	↖	108	82
T6(L)	89	84	79	1350	5	←	110.5	84.5
T7(L)	91	86.5	81.5	1725	5	↖	113	85
T8(L)	93	89	83.5	1950	5	↑	115.5	88
T8(L)0 Fan	91	87.5	-	2000	5- 9	→	115	88
T8(L)1 Fan	92	88.5	-	2000	7- 9	↘	115	88
T8(L)2 Fans	93	89	-	2000	7	↘	115	88.5
T8(L)3 Fans	-	-	-	-	-	-		
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	74	72	72.5	-	7	→	90	71
T2(U)	75.5	73	72.5	-	6	→	92	75
T3(U)	78	74	73	-	5	→	96	74.5
T4(U)	81	76.5	75	-	5	→	97.5	77
T5(U)	83	78.5	75.5	-	4	→	100	80
T6(U)	85.5	81	76.5	-	7	→	102.5	80.5
T7(U)	87.5	84.5	79.5	-	8	→	105	82.5
T8(U)	90	86	82	-	6- 7	→	107	85.5
T8(U)0 Fan	86	82		-	5- 6	→	107	85.5
T8(U)1 Fan	87.5	84.5		-	5- 8	→	107	85.5
T8(U)2 Fans	90	86		-	8	→	107	85.5
T8(U)3 Fans	-	-	-	-	-	-		
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	83	78.5	76	750	9	→	104	79.5
T4→8(L)	93.5	89	84.5	2000	7	→	115.5	88.5
T8→6(L)	89	84	79.5	1375	7	→	110.5	83.5
T6→8(L)	93.5	89.5	83	2000	6	→	116	88.5
T8→Idle(L)	76	73.5	76	0	5	→	90	72.5
Idle→T8(L)	93	89.5	83.5	1950	5- 6	↘	115.5	88.5
T1→4(U)	81	77	74.5		6- 9	→	97.5	78
T4-8(U)	90.5	86	81		9-11	→	117.5	85.5
T8→6(U)	86	80.5	77		9	→	102.5	80
T6→8(U)	90.5	86	82		10	→	107.5	85.5
T8→I(U)	75.5	73	73		8- 9	→	90	71.5
I→T8(U)	90	86	83.5		9-10	→	107	85.5

Ambient:

50 Ft Mic: 74 dBA
100 Ft Mic: 74.5 dBA
200 Ft Mic: 78.5 dBA
Nearfield Mic: 71 dBA
In-Cab Mic: 60 dBA

Weather:

Barometric Pressure: 1000 mbar
Temperature: 73-78°F
Humidity: -

TEST SITE NO. 5

LOCOMOTIVE MODEL AND SERIAL NO. GP38 #3804

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	72.5	68.5	65.5		7	↗	89.5	72
T1(L)	72.5	68.5	65.5		7	↗	90	72
T2(L)	75	70.5	66	75	7	→	93	75.5
T3(L)	77.5	73	69.5	300	7- 8	↗	98	75.5
T4(L)	81.5	77	73	700	8- 9	↗	101	78
T5(L)	84.5	79.5	76	1050	11	↗	107.5	79.5
T6(L)	87	82	78.5	1400	8-11	↗	110	82
T7(L)	90	85	81	1700	7- 8	↗	112.5	83
T8(L)	92.5	88	83.5	2000	10-11	↗	115.5	87.5
T8(L)0 Fan	92	86.5	82.5		7- 8	→		
T8(L)1 Fan	92	87	82.5		6-12	→		
T8(L)2 Fans	93	88.5	83		12-13	→		
T8(L)3 Fans	-	-	-	-	-	-		
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	72.5	68.5	65	-	9-10	↗	89.5	73
T2(U)	74	69.5	65	-	9-10	↗	91.5	76
T3(U)	76.5	72	66.5	-	8	→	95.	75
T4(U)	78	74	68.5	-	7	↗	96.5	76
T5(U)	81.5	77.5	72	-	7	↗	99.5	77.5
T6(U)	83.5	78.5	73	-	8	↗	102	79
T7(U)	88.5	81	77	-	7	↗	104	81
T8(U)	89.5	84.5	78.5	-	9	↗	106.5	85.5
T8(U)0 Fan	86	80.5	76	-	11-13	→	106.5	86.5
T8(U)1 Fan	87.5	82.5	77.5	-	13-16	→	106.5	86.5
T8(U)2 Fans	89.5	84.5	78	-	10-16	→	107	86
T8(U)3 Fans	-	-	-	-	-	-		
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	80.5	76.5	71.5	750	8- 9	→	103.5	78
T4→8(L)	92.5	87.5	82.5	2000	9-10	→	115	87
T8→6(L)	86.5	81.5	77	1400	6- 8	→	109.5	81.5
T6→8(L)	92.5	88	83	1950	7- 9	↗	115	87
T8→Idle(L)	72.5	68.5	64	0	8- 9	→	89	72
Idle→T8(L)	92.5	88	82	1950	9-12	→	115	87
T1→4(U)	79.5	75	70	-	11-14	→	97	75.5
T4-8(U)	89.5	85	80	-	12-13	→	107	85
T8→6(U)	84	79	74	-	12-13	→	102	80
T6→8(U)	89.5	85	80	-	13-15	→	97	85
T8→I(U)	72.5	69	64.5	-	12-13	→	89.5	71
1→T8(U)	89.5	85	80	-	13-14	→	97	85

Ambient:

50 Ft Mic:	65.5 dBA
100 Ft Mic:	64 dBA
200 Ft Mic:	64 dBA
Nearfield Mic:	73.5 dBA
In-Cab Mic:	55 dBA

Weather:

Barometric Pressure:	993 mbar
Temperature:	76-78°F
Humidity:	-

TEST SITE NO. 6

LOCOMOTIVE MODEL AND SERIAL NO. GP38 #3804

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind Speed (mph)	Wind Direction	Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
Idle	76	70.5	63		4- 5	↘	88	70
T1(L)	76	70.5	63		4- 5	↘	88	70
T2(L)	78	72.5	64.5	100	5- 6	↘	92	75
T3(L)	81	76	67.5	300	6- 7	↘	97	81
T4(L)	84	80	70.5	800	5- 7	↘	102	85
T5(L)	87.5	84	74	1050	5- 7	↘	106	92
T6(L)	90	86.5	76.5	1150	5- 6	→	108	88
T7(L)	93	89.5	80	1750	4- 6	↘	110.5	91.5
T8(L)	95.5	91.5	82.5	2000	7- 9	↘	113	94
T8(L)0 Fan	94.5	90.5	82.5	2050	8	↓	114	93
T8(L)1 Fan	95	91	82.5	2050	6- 7	↙	114	93.5
T8(L)2 Fans	95.5	91.5	83	2000	7	↙	114	94
T8(L)3 Fans	-	-	-	-	-	-		
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	76	70	62.5	-	7-10	↘	88	70
T2(U)	77	72	63.5	-	6- 7	↓	90.5	74
T3(U)	79.5	75	65.5	-	9	↓	93.5	75
T4(U)	82	77.5	67	-	8	↓	95.5	76.5
T5(U)	85	80.5	70	-	8- 9	↓	98.5	78.5
T6(U)	88	83	72	-	8- 9	↓	101	81
T7(U)	90	86.5-87	75	-	6- 7	→	103	82
T8(U)	92.5	88	77.5	-	8- 9	↘	105.5	85.5
T8(U)0 Fan	89.5	84	76.5	-	9	↓	105.5	85
T8(U)1 Fan	90	86.5	77	-	6- 8	↓	105	85.5
T8(U)2 Fans	92.5	88	78	-	5- 7	↓	106	85.5
T8(U)3 Fans	-	-	-	-	-	-		
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	84.5	80	71.5	400	5- 7	→	102	87
T4→8(L)	95.5	91.5	82.5	1950	5- 7	→	113	91
T8→6(L)	90	87	76.5	1400	6- 8	→	108	88.5
T6→8(L)	96	91.5	82.5	1900	6- 8	→	113	92.5
T8→Idle(L)	71	70	62.5	0	7- 8	→	88	70
Idle→T8(L)	96	91.5	83	1950	7- 9	→	113	92.5
T1→4(U)	82	77	68.5	-	9-10	↘	95.5	78.5
T4-8(U)	92.5	88.5	76.5	-	8- 9	↓	105.5	85
T8→6(U)	88	83	71.5	-	8	↘	101	81.5
T6→8(U)	93	88	77	-	8-10	↘	105.5	85
T8→I(U)	76	70	62.5	-	7-10	↓	88	70
I→T8(U)	92.5	88.5	77	-	7-10	↓	105.5	85.5

Ambient:

50 Ft Mic: 65-66 dBA
100 Ft Mic: 61-63 dBA
200 Ft Mic: 58-59.5 dBA
Nearfield Mic: 65.5 dBA
In-Cab Mic: 51-60 dBA

Weather:

Barometric Pressure: 1011 mbar
Temperature: 60-62°F
Humidity: 50%

TEST SITE NO. 7

LOCOMOTIVE MODEL AND SERIAL NO. GP38 #3804

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	72.5	66.5	-		-	-	88.5	70
T1(L)	72.5	66.5	-		-	-	88.5	70
T2(L)	76	70	-	50	-	-	92.5	75
T3(L)	79.5	74	-	325	-	-	97	75.5
T4(L)	84	78.5	-	750	-	-	102.5	78
T5(L)	87	81	-	1100	-	-	106	81.5
T6(L)	90.5	84.5	-	1400	-	-	109	83
T7(L)	93	87	-	1700	-	-	111	84
T8(L)	96	90	-	1950	-	-	114	87
T8(L)0 Fan	-	-	-	1950	-	-	114	86
T8(L)1 Fan	-	-	-	1950	-	-	114	86.5
T8(L)2 Fans	-	-	-	1950	-	-	114	86.5
T8(L)3 Fans	-	-	-	-	-	-		
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	72	66.5	-	-	-	-	89	71.5
T2(U)	76	70	-	-	-	-	91.5	75
T3(U)	78	72.5	-	-	-	-	94.5	75
T4(U)	81.5	75	-	-	-	-	96	77.5
T5(U)	84	78	-	-	-	-	99	80.5
T6(U)	87	81	-	-	-	-	102	80.5
T7(U)	90	84	-	-	-	-	104	82
T8(U)	92.5	86	-	-	-	-	106	85.5
T8(U)0 Fan	87.5	82	-	-	-	-		
T8(U)1 Fan	90.5	84.5	-	-	-	-		
T8(U)2 Fans	92	85.5	-	-	-	-		
T8(U)3 Fans	-	-	-	-	-	-		
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	83.5	78	-	750	-	-	102.5	78.5
T4→8(L)	95.5	89	-	1950	-	-	114.5	87
T8→5(L)	90.5	84	-	1400	-	-	108.5	82.5
T6→8(L)	95.5	89	-	1950	-	-	114.5	87
T8→Idle(L)	72	66	-	0	-	-	88.5	71
Idle→T8(L)	95.5	89	-	1900	-	-	114	87
T1→4(U)	82	74	-	-	7-8	→	96	77
T4-8(U)	92.5	85.5	-	-	6	→	106	85
T8→6(U)	87.5	80	-	-	7-9	→	102	81
T6→8(U)	92	85.5	-	-	8-9	→	106	85.5
T8→1(U)	72.5	66.5	-	-	6-7	→	89	70.5
1→T8(U)	92.5	85.5	-	-	7-8	→	106	85.5

Ambient:

50 Ft Mic:	51.5-56 dBA
100 Ft Mic:	53-61 dBA
200 Ft Mic:	-
Nearfield Mic:	46-50 dBA
In-Cab Mic:	54-57 dBA

Weather:

Barometric Pressure:	1007 mbar
Temperature:	65-70°F
Humidity:	40%

TEST SITE NO. 8

LOCOMOTIVE MODEL AND SERIAL NO. GP38 #3804

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	72	69	68		10	→	89	70.5
T1(L)	72	69.5	68		10-11	→	89.5	70.5
T2(L)	75.5	71	69	50	10	→	93	74
T3(L)	79	74.5	71	300	10	→	98	77
T4(L)	83	78	74.5	800	10	→	104	83
T5(L)	86	80	75.5	1100	10	→	106.5	82.5
T6(L)	88	82	78.5	1400	10	→	109	84.5
T7(L)	92.5	85.5	81.5	1700	10	→	111	86
T8(L)	93.5	88	85	1950	10	→	113.5	87.5
T8(L)0 Fan	93	87	83.5	1975	5	→	114	87
T8(L)1 Fan	93	87	83.5	1975	6	→	114	87
T8(L)2 Fans	93.5-94	87.5	85.5	1950	5	→	114	87
T8(L)3 Fans	-	-	-	-	-	-		
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	72	69	68	-	11	→	89.5	70.5
T2(U)	74	70.5	69	-	11	→	91	73.5
T3(U)	77.5	72.5	70	-	10	→	94	77
T4(U)	81	74.5	71.5	-	10	→	96	78.5
T5(U)	85	78.5	74.5	-	9	→	99.5	79.5
T6(U)	86	79.5	75.5	-	10	→	102.5	83
T7(U)	90	83	79	-	9	→	104	82.5
T8(U)	90.5	84	79.5	-	9	→	106	85
T8(U)0 Fan	89	89.5	78.5	-	9	→	106	84
T8(U)1 Fan	89	82.5	78.5	-	7- 9	→	106	84
T8(U)2 Fans	90	84.5	80	-	7	→	106	84
T8(U)3 Fans	-	-	-	-	-	-		
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	83	77.5	74	800	9	→	104	81
T4→8(L)	94.5	88	85	1950	8	→	114	87.5
T8→6(L)	89	82	79	1425	9	→	109	84
T6→8(L)	94	88	84.5	1950	9	→	114	87.5
T8→Idle(L)	72	70	68.5	-	9	→	89	70
Idle→T8(L)	94	88.5	84.5	1950	8	→	114	87.5
T1→4(U)	82	75	72	-	9-10	→	91.5	78
T4-8(U)	91	85.5	81.5	-	9-10	→	106.5	84
T8→6(U)	85	79	75.5	-	10	→	102	81
T6→8(U)	91	85	81.5	-	9	→	106.5	84
T8→1(U)	72	69	69	-	9	→	89.5	70
I→T8(U)	91	85.5	81.5	-	8- 9	→	106	84

Ambient:

50 Ft Mic: 65-73 dBA

100 Ft Mic: 65-74.5 dBA

200 Ft Mic: 57-62 dBA

Weather:

Barometric Pressure: 983 mbar

Temperature: 45-52°F

Humidity: 90%

TEST SITE NO. 2 (Revisited)

LOCOMOTIVE MODEL AND SERIAL NO. GP38 #3804

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind Speed (mph)	Wind Direction	Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
Idle	71	67	61.5-63.5	0	-	→	89.5	72
T1(L)	71.5	67	61.5-63.5	-	-	→	90	72
T2(L)	75	69	64.5	75	-	→	93	75
T3(L)	77.5	72	67	300	-	→	97.5	75
T4(L)	81	76	71	750	-	→	103	79
T5(L)	84.5	79.5	74	1050	-	→	106	81
T6(L)	88.5	82	77	1475	4- 5	→	110	83
T7(L)	90.5	85	79.5	1750	5	→	112	84.5
T8(L)	93.5	88	82	2000	5- 6	→	115	86.5
T8(L)0 Fan	92.5	86	80.5		7	←		
T8(1)1 Fan	93	87	81		5- 6	←		
T8(L)2 Fans	93.5	88	82.5		5- 6	←		
T8(L)3 Fans	-	-	-	-	-	-		
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	71	67	62	-	4-5-9	↓	90	70
T2(U)	75	69.5	64.5	-	6	↓	92	72.5
T3(U)	77.5	72	67	-	6	→	95	75
T4(U)	80	74	69	-	5- 6	→	96.5	76.5
T5(U)	82	77	71.5	-	4	→	99.5	79.5
T6(U)	85	79.5	73.5	-	3	→	102	81
T7(U)	88	82	75.5	-	3	→	104	83
T8(U)	90	84	78.5	-	3	→	107	85
T8(U)0 Fan	87	80	75	-	7	→		
T8(U)1 Fan	88	83.5	78	-	6	→		
T8(U)2 Fans	90.5	86	79.5	-	5	→		
T8(U)3 Fans	-	-	-	-	-	-		
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	81	76.5	70.5	750	5	↓	103	78.5
T4→8(L)	94	88	82	2000	5	↓	115	86
T8→6(L)	88	82.5	77	1400	5	↓	109.5	83
T6→8(L)	94	88	82.5	2000	5	↓	115	86.5
T8→Idle(L)	71	67	61.5	0	2- 5	↓	89	70
Idle→T8(L)	94	88	82.5	2000	5	↓	115	87
T1→4(U)	80	74.5	69.5	-	5	↓	96.5	78
T4-8(U)	90.5	85	79	-	6- 7	↓	106.5	85.5
T8→6(U)	85	79.5	73	-	7	↓	102	81
T6→8(U)	90.5	85.5	79.5	-	7	↓	106.5	85.5
T8→I(U)	70.5	66.5	61	-	4- 5	↓	90	71
I→T8(U)	90.5	85.5	89.5	-	5- 7	→	106.5	85.5

Weather:

Barometric Pressure: 991 mbar

Temperature: 55°F

Humidity: 85-100%

A.2 OPPORTUNITY LOCOMOTIVES

The data for the opportunity locomotive at Site No. 1 and the conforming site are arranged in the same format as the dedicated locomotive data.

TEST SITE NO. 1

LOCOMOTIVE MODEL AND SERIAL NO. GP40-2 #4147

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft* Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle							89.5	73.5
T1(L)	77	74.5	74	60	5	↘	90	73.5
T2(L)	81	76	75	360	3	↘	94.5	75.5
T3(L)	82.5	76	76	540	4	↘	96	78
T4(L)	86	79.5	78.5	840	4	↘	99	82.5
T5(L)	88	82	82	1200	3	↘	103.5	86
T6(L)	91	84	84	1680	4	↘	106	86.5
T7(L)	93	85.5	85.5	2220	3	↘	107.5	87
T8(L)	94	88	88	2730	3	→	109	88.5
T8(L)0 Fan	91.5	84.5	86	2880	-	-	109	88
T8(L)1 Fan	92	85	86.5	2880	-	-	109	87.5
T8(L)2 Fans	92.5	86	88	2820	-	-	109	88
T8(L)3 Fans	93.5	88	88.5	2820	-	-	109	88.5
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	78	75	74.5	-	3	↑	90	73
T2(U)	79	75.5	74.5	-	4	↑	91	73
T3(U)	81	76	75	-	4	↑	95	76
T4(U)	83.5	78	77.5	-	5	↑	98	79
T5(U)	86	80	79	-	5	↖	98.5	83
T6(U)	88	82	81	-	5	↖	100.5	80
T7(U)	90	85	83	-	4	↖	103.5	84
T8(U)	91.5	86.5	86	-	3	↖	106	84.5
T8(U)0 Fan	88	82.5	81.5	-	5	→	105	84.5
T8(U)1 Fan	88	82.5	82	-	4	→	105	84.5
T8(U)2 Fans	90	84	83	-	5	→	106	84.5
T8(U)3 Fans	91	86	86	-	4	→	106	84.5
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	85	79.5	78	840	4	←	99	81.5
T4→8(L)	93.5	88	87	2760	5	←	108.5	87.5
T8→6(L)	91	86	86.5	1680	7	←	107.5	85
T6→8(L)	94	88	88	2820	7	←	99	88.5
T8→Idle(L)	78	76	75.5	0	6	←	92	74
Idle→T8(L)	93.5	87.5	88	2820	6	←	109	88
T1→4(U)	84	80	77	-	2	↖	97.5	74
T4-8(U)	91.5	86	86	-	2	↖	106	84
T8→6(U)	87.5	80.5	80	-	3	↖	100.5	80
T6→8(U)	91.5	86	86	-	4	←	106	85
T8→I(U)	76	74	73	-	5	↘	90	72
I→T8(U)	92	85.5	85	-	7	→	106	85

Ambient:

50 Ft Mic:	73 dBA
100 Ft Mic:	74 dBA
*200 Ft Mic:	73 dBA
Nearfield Mic:	73.5 dBA
In-Cab Mic:	63 dBA

*Actual distance is 144 Ft

Weather:

Barometric Pressure:	993 mbar
Temperature:	57°F
Humidity:	-

TEST SITE NO. 2 (Revisited)

LOCOMOTIVE MODEL AND SERIAL NO. GP40-2 #4147

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	71.5	68.5	62-4	-	-	-	-	-
T1(L)	72.5	68.5	63	90	-	-	89	71
T2(L)	77	72.5	67	300	-	-	94	71
T3(L)	80	74.5	68.5	600	-	-	96	75
T4(L)	83	78	73.5	990	-	-	99	82
T5(L)	86.5	83	77	1200	-	-	103.5	81
T6(L)	89	86	77	1620	-	-	106	79.5
T7(L)	90	87.5	81	2220	-	-	108	82.5
T8(L)	93	89	81.5	2400	-	-	109	85
T8(L)0 Fan	90	86.5	81.5	-	7- 8	↓	109	87.5
T8(L)1 Fan	91	87.5	82	-	9	↓	109.5	87
T8(L)2 Fans	91.5	88	82	2700	9-10	↘	109.5	87.5
T8(L)3 Fans	92.5	89	82	2700	7-10	↓	109.5	88
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	71.5	68.5	62-4	-	-	-	89.5	71
T2(U)	76.5	70	64	-	-	-	90	71
T3(U)	78	73	65	-	-	-	93.5	75
T4(U)	81	76.5	68	-	-	-	97	82
T5(U)	84.5	78	72.5	-	-	-	98	81
T6(U)	86	82.5	74	-	-	-	100	79.5
T7(U)	88	84.5	77	-	-	-	103	82.5
T8(U)	91.5	86	78.5	-	-	-	105.5	85
T8(U)0 Fan	85	81	75	-	4- 5	↘	105	84.5
T8(U)1 Fan	88.5	83.5	76	-	5- 6	↓	105	84.5
T8(U)2 Fans	90	85.5	78.5	-	5- 9	↓	105.5	84.5
T8(U)3 Fans	91.5	87	79	-	8-10	↘	105.5	84.5
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	82.5	78	73	900	5	↓	99	80
T4→8(L)	93	88	82	2640	7- 8	↓	108.5	88
T8→6(L)	90	86	80	1620	8- 9	↓	102	86
T6→8(L)	93	89	82	2700	8- 9	↓	109	87
T8→Idle(L)	73.5	68.5	63	-	7- 8	↓	89	71
Idle→T8(L)	92.5	88.5	81	2580	7- 9	↓	109	87
T1→4(U)	81	76	69	-	6- 7	↙	96.5	81
T4-8(U)	91	87	78.5	-	7- 8	↙	105.5	85
T8→6(U)	86	82	73.5	-	6- 7	↙	99	81
T6→8(U)	91	87	78.5	-	5- 7	↙	105	86
T8→I(U)	73.5	68	63	-	7	↓	89	70.5
I→T8(U)	91	87	88	-	7- 9	↘	105	86

Ambient:

50 Ft Mic:	57.5 dBA
100 Ft Mic:	56 dBA
200 Ft Mic:	56 dBA
Nearfield Mic:	61 dBA
In-Cab Mic:	51.5 dBA

Weather:

Barometric Pressure:	984 mbar
Temperature:	85°F
Humidity:	-

TEST SITE NO. 1 (Typical)

LOCOMOTIVE MODEL AND SERIAL NO. GP40 #3784

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle								
T1(L)	77	73	-	300	5	↙	90	72
T2(L)	81	75	-	500	6	↙	95	75
T3(L)	83	78	-	700	6	↓	97	77
T4(L)	85	80	-	1050	6	↙	101	82
T5(L)	91	84	-	1400	7	↓	106	83
T6(L)	91	85	-	1500	7	↙	106	84
T7(L)	91	86	-	1800	7	↓	107	85
T8(L)	94	88	-	2300	8	↓	109	90
T8(L)0 Fan	-	-	-	-	-	-		
T8(L)1 Fan	90	85	84	2400	9	↙	108	90
T8(L)2 Fans	92	86	85	2300	8	↙	109	90
T8(L)3 Fans	94	87	86	2350	9	↙	109	90
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	-	-	-	-	-	-		
T2(U)	-	-	-	-	-	-		
T3(U)	-	-	-	-	-	-		
T4(U)	-	-	-	-	-	-		
T5(U)	-	-	-	-	-	-		
T6(U)	-	-	-	-	-	-		
T7(U)	-	-	-	-	-	-		
T8(U)	-	-	-	-	-	-		
T8(U)0 Fan	-	-	-	-	-	-		
T8(U)1 Fan	-	-	-	-	-	-		
T8(U)2 Fans	-	-	-	-	-	-		
T8(U)3 Fans	-	-	-	-	-	-		
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	85	80	79	-	7	↙	100	79
T4→8(L)	94	87	86	2300	8	↓	108	90
T8→6(L)	91	85	85	1500	9	↙	106	84
T6→8(L)	94	88	87	2350	9	↙	109	90
T8→Idle(L)	78	75	75	0	7	↙	89	70
Idle→T8(L)	94	88	86	2350	6	↓	109	90
T1→4(U)	82	78	76	-	5	↓	-	-
T4-8(U)	92	86	85	-	7	↓	106	87
T8→6(U)	88	81	80	-	6	↓	101	80
T6→8(U)	93	86	84	-	6	↓	106	87
T8→1(U)	76	72	70	-	6	↓	89	71
I→T8(U)	93	87	84	-	7	↓	106	88

Ambient:

50 Ft Mic:	71-72 dBA
100 Ft Mic:	70.5 dBA
200 Ft Mic:	69.5 dBA
Nearfield Mic:	69-71 dBA
In-Cab Mic:	58-69 dBA

Weather:

Barometric Pressure:	986 mbar
Temperature:	95°F
Humidity:	42%

TEST SITE NO. 2 (Conforming)

LOCOMOTIVE MODEL AND SERIAL NO. GP40 #3784

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind Speed (mph)	Wind Direction	Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
Idle								
T1(L)	74	69	66		3-5	↙	91	
T2(L)	78	72	68		3-5	↙	94	75
T3(L)	82	76	73		3-5	↘	98	78
T4(L)	84	78	73		3-6	↘	101	79
T5(L)	88	83	80		3-6	↓	105	84
T6(L)	89	84	80		3-6	↘	107	85
T7(L)	90	85	80		3-6	↓	107	86
T8(L)	93	87	81	2100	3-6	↓	110	91
T8(L)0 Fan	-	-	-	-	-	-		
T8(L)1 Fan	89	84	79		3	←	109	90
T8(L)2 Fans	91	85	80		4	↙	109	90
T8(L)3 Fans	92	87	81		3	↓	109	90
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	-	-	-	-	-	-		
T2(U)	-	-	-	-	-	-		
T3(U)	-	-	-	-	-	-		
T4(U)	-	-	-	-	-	-		
T5(U)	-	-	-	-	-	-		
T6(U)	-	-	-	-	-	-		
T7(U)	-	-	-	-	-	-		
T8(U)	-	-	-	-	-	-		
T8(U)0 Fan	-	-	-	-	-	-		
T8(U)1 Fan	-	-	-	-	-	-		
T8(U)2 Fans	-	-	-	-	-	-		
T8(U)3 Fans	-	-	-	-	-	-		
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	84	77	75		7	↘	100	80
T4→8(L)	93	87	82	2000	8	↘	109	91
T8→6(L)	89	85	79	1500	7	↘	107	83
T6→8(L)	92	87	81	2500	6	→	109	91
T8→Idle(L)	74	70	66	0	4	↓	90	71
Idle→T8(L)	93	87	81	2400	5	↓	109	91
T1→4(U)	83	78	71		5	↖	94	78
T4-8(U)	92	86	79		4	←	107	88
T8→6(U)	86	80	74		4	↑	102	80
T6→8(U)	92	86	78		6	↑	107	88
T8→I(U)	74	69	65		6	↑	89	70
I→T8(U)	92	86	79		7	↑	107	89

Ambient:

50 Ft Mic:	66.5 dBA
100 Ft Mic:	65.5 dBA
200 Ft Mic:	63 dBA
Nearfield Mic:	68 dBA
In-Cab Mic:	69-76 dBA*

*Note radio in cab is on.

Weather:

Barometric Pressure:	993 mbar
Temperature:	86°F
Humidity:	42%

TEST SITE NO. 1 (Typical)

LOCOMOTIVE MODEL AND SERIAL NO. GP40 #3797

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	144 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	80	76	74		5	↗	-	-
T1(L)	80	76	74	-	6	↗	-	-
T2(L)	82	78	76	-	8	→	98	79
T3(L)	83	79	77	-	9	↓	101	81
T4(L)	87	83	79	-	7	↓	104	84
T5(L)	90	85	83	-	7	↓	108	87
T6(L)	92	90	86	-	6	→	101*	88
T7(L)	92	89	87	-	6	→	101*	89
T8(L)	93	90	89	-	10	→	102*	90
T8(L)0 Fan	-	-	-	-	-	-		
T8(L)1 Fan	-	-	-	-	-	-		
T8(L)2 Fans	-	-	-	-	-	-		
T8(L)3 Fans	-	-	-	-	-	-		
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	-	-	-	-	-	-		
T2(U)	-	-	-	-	-	-		
T3(U)	-	-	-	-	-	-		
T4(U)	-	-	-	-	-	-		
T5(U)	-	-	-	-	-	-		
T6(U)	-	-	-	-	-	-		
T7(U)	-	-	-	-	-	-		
T8(U)	-	-	-	-	-	-		
T8(U)0 Fan	-	-	-	-	-	-		
T8(U)1 Fan	-	-	-	-	-	-		
T8(U)2 Fans	-	-	-	-	-	-		
T8(U)3 Fans	-	-	-	-	-	-		
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	87	83	80	-	4	↙	104	79
T4→8(L)	93	90	88	-	9	↓	112	89
T8→6(L)	90	80	85	-	7	↓	100	86
T6→8(L)	93	90	88	-	10	→	112	89
T8→Idle(L)	78	76	74	-	9	→	92	73
Idle→T8(L)	94	90	89	-	8	→	112	89
T1→4(U)	85	80	79	-	6	→	95	76
T4-8(U)	93	88	86	-	7	→	108	87
T8→6(U)	87	83	81	-	10	→	104	83
T6→8(U)	93	87	86	-	6	→	108	87
T8→I(U)	78	76	74	-	5	→	93	72
I→T8(U)	93	88	86	-	4	↑	108	88

Ambient:

50 Ft Mic: 75 dBA
100 Ft Mic: 75 dBA
200 Ft Mic: 73 dBA
Nearfield Mic: -
In-Cab Mic: -

Weather:

Barometric Pressure: 989 mbar
Temperature: 88°F
Humidity: -

*We suspect a 10 dB error in gain setting, these levels should be 10 dB higher.

TEST SITE NO. 2 (Conforming)

LOCOMOTIVE MODEL AND SERIAL NO. GP40 #3797

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	76	73	70	-	7	←	-	-
T1(L)	76	73	70	-	6	←	-	-
T2(L)	80	76	72	-	6	←	96	-
T3(L)	82	76	72	-	5	←	100	-
T4(L)	85	81	75	-	4	←	105	82
T5(L)	89	86	82	-	4	←	109	82
T6(L)	90	87	81	-	6	←	111	85
T7(L)	91	88	85	-	5	←	111	89
T8(L)	92	89	83	-	6	←	112	89
T8(L)0 Fan	-	-	-	-	-	-		
T8(L)1 Fan	-	-	-	-	-	-		
T8(L)2 Fans	-	-	-	-	-	-		
T8(L)3 Fans	-	-	-	-	-	-		
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	-	-	-	-	-	-		
T2(U)	-	-	-	-	-	-		
T3(U)	-	-	-	-	-	-		
T4(U)	-	-	-	-	-	-		
T5(U)	-	-	-	-	-	-		
T6(U)	-	-	-	-	-	-		
T7(U)	-	-	-	-	-	-		
T8(U)	-	-	-	-	-	-		
T8(U)0 Fan	-	-	-	-	-	-		
T8(U)1 Fan	-	-	-	-	-	-		
T8(U)2 Fans	-	-	-	-	-	-		
T8(U)3 Fans	-	-	-	-	-	-		
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	85	81	76	-	8	←	103	80
T4→8(L)	92	89	82	-	9	←	112	88
T8→6(L)	89	86	79	-	6	←	110	85
T6→8(L)	92	89	82	-	6	←	112	88
T8→Idle(L)	75	70	66	-	4	←	93	73
Idle→T8(L)	92	89	82	-	6	←	112	88
T1→4(U)	83	79	73	-	10	←	101	80
T4-8(U)	93	88	81	-	8	←	108	87
T8→6(U)	87	83	77	-	8	←	105	84
T6→8(U)	92	88	81	-	7	←	108	87
T8→I(U)	75	70	66	-	7	←	92	72
I→T8(U)	92	88	81	-	7	←	108	88

Ambient:

50 Ft Mic: 66 dBA
100 Ft Mic: 63.5 dBA
200 Ft Mic: 61.5 dBA
Nearfield Mic: 65 dBA
In-Cab Mic: 63.5 dBA

TEST SITE NO. 1 (Typical)

LOCOMOTIVE MODEL AND SERIAL NO. GP40 #4143

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	144 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	76	75	74	-	-	-	91	73
T1(L)	77	75	74	-	-	-	92	74
T2(L)	79	76	75	-	-	-	95	77
T3(L)	82	78	76	-	-	-	99	79
T4(L)	85	81	79	-	-	-	102	81
T5(L)	90	86	82	-	-	-	106	86
T6(L)	90	87	86	-	-	-	108	88
T7(L)	92	87	86	-	-	-	109	89
T8(L)	91	88	87	-	-	-	109	89
T8(L)0 Fan	89	85	85	-	6	↖	108	91
T8(L)1 Fan	90	86	86	-	7	↖	109	92
T8(L)2 Fans	90	86	86	-	8	↖	109	92
T8(L)3 Fans	92	87	87	-	9	↖	110	92
T8(L)4 Fans	-	-	-	-	-	-		
T1(U)(Idle)	-	-	-	-	-	-		
T2(U)	77	75	74	-	-	-	91	75
T3(U)	80	76	75	-	6	↖	94	77
T4(U)	83	80	76	-	7	↖	98	79
T5(U)	84	80	77	-	9	↖	99	83
T6(U)	86	81	80	-	7	↖	101	83
T7(U)	90	84	82	-	8	↖	104	87
T8(U)	91	86	84	-	7	↖	106	86
T8(U)0 Fan	87	84	81	-	5	↙	106	84
T8(U)1 Fan	89	85	82	-	6	↙	106	84
T8(U)2 Fans	89	85	83	-	7	↙	106	85
T8(U)3 Fans	91	87	85	-	6	↙	106	85
T8(U)4 Fans	-	-	-	-	-	-		
T1→4(L)	82	78	76	-	9	←	100	80
T4→8(L)	91	87	85	-	6	←	109	89
T8→6(L)	89	84	83	-	6	←	108	87
T6→8(L)	91	88	86	-	7	←	109	90
T8→Idle(L)	77	75	75	-	6	←	91	74
Idle→T8(L)	90	87	85	-	6	←	109	87
T1→4(U)	82	79	76	-	6	↖	99	80
T4-8(U)	91	87	84	-	7	↖	106	86
T8→6(U)	85	82	80	-	7	↖	102	82
T6→8(U)	90	87	84	-	8	↖	106	86
T8→1(U)	75	74	72	-	9	↖	91	72
I→T8(U)	90	87	84	-	6	↖	96	85

Ambient:

50 Ft Mic: 72-74 dBA
100 Ft Mic: 69-72 dBA
200 Ft Mic: 73-75 dBA
Nearfield Mic: 75 dBA
In-Cab Mic: 63-66 dBA

Weather:

Barometric Pressure: -
Temperature: -
Humidity: 80-100%

TEST SITE NO. 2 (Conforming)

LOCOMOTIVE MODEL AND SERIAL NO. GP40-2 #4143

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone* (dBA)	In-Cab Microphone† (dBA)
					Speed (mph)	Direction		
Idle	70	68	62	-	9	↑	-	-
T1(L)	71	68	65	-	5	↑	-	71
T2(L)	75	72	70	-	3	↗	-	75
T3(L)	78	75	71	-	6	↗	-	78
T4(L)	80	77	74	-	7	↗	-	80
T5(L)	85	85	83	-	8	↑	-	83
T6(L)	87	85	80	-	5	↗	-	84
T7(L)	87	86	80	-	6	→	-	86
T8(L)	90	87	81	-	5	→	-	87
T8(L)0 Fan	85	84	79	-	6	↗	-	-
T8(L)1 Fan	87	86	79	-	7	↗	-	-
T8(L)2 Fans	87	86	80	-	6	↗	-	-
T8(L)3 Fans	89	87	80	-	7	↗	-	-
T8(L)4 Fans	-	-	-	-	-	-	-	-
T1(U)(Idle)	72	69	64	-	6	↗	-	71
T2(U)	74	70	65	-	5	↗	-	75
T3(U)	76	73	67	-	7	↑	-	77
T4(U)	80	77	70	-	6	↗	-	78
T5(U)	81	78	73	-	6	→	-	80
T6(U)	83	81	74	-	5	→	-	80
T7(U)	87	84	77	-	5	↗	-	84
T8(U)	88	86	78	-	5	↗	-	84
T8(U)0 Fan	83	82	75	-	7	↗	-	-
T8(U)1 Fan	85	84	76	-	6	↗	-	-
T8(U)2 Fans	85	84	77	-	7	↗	-	-
T8(U)3 Fans	87	86	78	-	4	↗	-	-
T8(U)4 Fans	-	-	-	-	-	-	-	-
T1→4(L)	80	77	71	-	6	→	-	-
T4→8(L)	89	87	80	-	6	→	-	-
T8→6(L)	86	86	82	-	5	↗	-	-
T6→8(L)	89	87	80	-	6	→	-	-
T8→Idle(L)	74	69	65	-	7	→	-	-
Idle→T8(L)	89	87	80	-	9	→	-	-
T1→4(U)	78	77	71	-	5	→	-	-
T4-8(U)	87	86	78	-	6	→	-	-
T8→6(U)	82	81	74	-	5	↗	-	-
T6→8(U)	87	86	78	-	7	↗	-	-
T8→1(U)	71	69	66	-	5	→	-	-
I→T8(U)	88	86	78	-	5	↗	-	-

Ambient:

50 Ft Mic:	72-76 dBA
100 Ft Mic:	59 dBA
200 Ft Mic:	58 dBA
Nearfield Mic:	-
In-Cab Mic:	-

Weather:

Barometric Pressure:	999 mbar
Temperature:	66°F
Humidity:	66%

*Microphone operating improperly during the test.
†Microphone operating improperly during part of this test. The data show is believed to be good.

TEST SITE NO. 1 (Typical)

LOCOMOTIVE MODEL AND SERIAL NO. SD35 #7419

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	144 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	75	73	70	-	-	-	89	71.5
T1(L)	75	72	-	5	-	-	90	72
T2(L)	80	75	-	650	-	-	93	78
T3(L)	84	76	-	1000	-	-	98	81
T4(L)	86	80	-	1250	-	-	102	84
T5(L)	89	84	-	1350	-	-	103	84
T6(L)	87	82	83	1750	-	-	104	85
T7(L)	88	85	84	2000	-	-	105	88
T8(L)	91	86	85	2150	-	-	107	88
T8(L)0 Fan	86	81	80	-	-	-	106	88
T8(L)1 Fan	87	84	82	-	-	-	107	88
T8(L)2 Fans	89	84	83	-	-	-	107	88
T8(L)3 Fans	91	85	84	-	-	-	108	88
T8(L)4 Fans	-	-	-	-	-	-	-	-
T1(U)(Idle)	-	-	-	-	-	-	-	-
T2(U)	-	-	-	-	-	-	-	-
T3(U)	-	-	-	-	-	-	-	-
T4(U)	-	-	-	-	-	-	-	-
T5(U)	-	-	-	-	-	-	-	-
T6(U)	-	-	-	-	-	-	-	-
T7(U)	-	-	-	-	-	-	-	-
T8(U)	-	-	-	-	-	-	-	-
T8(U)0 Fan	-	-	-	-	-	-	-	-
T8(U)1 Fan	-	-	-	-	-	-	-	-
T8(U)2 Fans	-	-	-	-	-	-	-	-
T8(U)3 Fans	-	-	-	-	-	-	-	-
T8(U)4 Fans	-	-	-	-	-	-	-	-
T1→4(L)	87	79	81	700	10	↑	103	81
T4→8(L)	91	85	84	2050	9	↑	108	89
T8→6(L)	88	83	83	1400	10	↑	105	84
T6→8(L)	91	86	85	2100	-	-	108	89
T8→Idle(L)	76	73	72	0	-	-	90	71
Idle→T8(L)	91	86	85	2100	-	-	108	89
T1→4(U)	82	78	77	-	6	↑	98	78
T4-8(U)	90	84	83	-	8	↑	106	86
T8→6(U)	84	79	79	-	7	↑	100	82
T6→8(U)	90	84	84	-	6	↑	106	86
T8→I(U)	75	72	70	-	5	↑	87	71
I→T8(U)	90	85	84	-	8	↑	-	-

Ambient:

50 Ft Mic: 70-75 dBA
100 Ft Mic: 72-76 dBA
200 Ft Mic: 69-75 dBA
Nearfield Mic: -
In-Cab Mic: -

Weather:

Barometric Pressure: -
Temperature: 59°F
Humidity: 44%

TEST SITE NO. 2 (Conforming)

LOCOMOTIVE MODEL AND SERIAL NO. SD35 #7419

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	70	70	65	-	2	↑	89	70.5
T1(L)	71	71	67	-	2	↑	-	-
T2(L)	75	73	69	-	3	↑	-	-
T3(L)	79	76	69	-	2	↑	-	-
T4(L)	80	78	75	-	2	↑	-	-
T5(L)	83	82	77	-	2	↑	-	-
T6(L)	84	84	78	-	2	↑	-	-
T7(L)	85	85	79	-	2	↑	-	-
T8(L)	87	86	80	-	2	↑	-	-
T8(L)0 Fan	-	-	-	-	-	-	-	-
T8(L)1 Fan	80	78	72	-	-	-	105	86
T8(L)2 Fans	84	82	78	-	-	-	106	87
T8(L)3 Fans	85	83	78	-	-	-	106	87
T8(L)4 Fans	-	-	-	-	-	-	-	-
T1(U)(Idle)	-	-	-	-	-	-	-	-
T2(U)	-	-	-	-	-	-	-	-
T3(U)	-	-	-	-	-	-	-	-
T4(U)	-	-	-	-	-	-	-	-
T5(U)	-	-	-	-	-	-	-	-
T6(U)	-	-	-	-	-	-	-	-
T7(U)	-	-	-	-	-	-	-	-
T8(U)	-	-	-	-	-	-	-	-
T8(U)0 Fan	-	-	-	-	-	-	-	-
T8(U)1 Fan	-	-	-	-	-	-	-	-
T8(U)2 Fans	-	-	-	-	-	-	-	-
T8(U)3 Fans	-	-	-	-	-	-	-	-
T8(U)4 Fans	-	-	-	-	-	-	-	-
T1→4(L)	80	78	74	-	-	-	101	80
T4→8(L)	87	86	79	2000	-	-	106	86
T8→6(L)	84	84	78	1300	-	-	103	83
T6→8(L)	87	86	80	2100	-	-	106	87
T8→Idle(L)	70	70	65	0	-	-	89	70
Idle→T8(L)	87	86	80	2100	-	-	106	86
T1→4(U)	77	75	70	-	-	-	97	-
T4-8(U)	87	85	80	-	-	-	105	86
T8→6(U)	82	80	74	-	-	-	100	81
T6→8(U)	87	85	79	-	-	-	105	86
T8→I(U)	70	70	64	-	-	-	90	70
I→T8(U)	87	85	79	-	-	-	105	86

Ambient:

50 Ft Mic: 62-63.5 dBA
100 Ft Mic: 58-61 dBA
200 Ft Mic: 59-64 dBA
Nearfield Mic: 60-62 dBA
In-Cab Mic: 45-70 dBA

Weather:

Barometric Pressure: 988 mbar
Temperature: 75°F
Humidity: 50%

TEST SITE NO. 1 (Typical)

LOCOMOTIVE MODEL AND SERIAL NO. GP35 #3515

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	144 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	76.5	71.5	71	-	8	←	-	-
T1(L)	79	73	72	-	8	←	90	71
T2(L)	80.5	75	72.5	-	8	←	92	76
T3(L)	85	76	74	400	11	↖	96	77
T4(L)	86.5	80.5	78	700	12	↖	102	80
T5(L)	86	83	82.5	1050	10	←	104	81
T6(L)	90	81.5	83.5	1350	11	↖	104	82
T7(L)	91.5	83.5	86	1800	9	←	106	85
T8(L)	95	-	86.5	2300	12	↖	109	87
T8(L)0 Fan	90.5	83	83.5		8	←	107	86
T8(L)1 Fan	94	85	86	-	11	↖	109	87
T8(L)2 Fans	94.5	86	86.5	-	8	←	110	87
T8(L)3 Fans	96	87.5	87.5	-	11	←	110	87
T8(L)4 Fans	-	-	-	-	-	-	-	-
T1(U)(Idle)	76.5	72	73	-	13	↖	88	70
T2(U)	80.5	73.5	74	-	10	↖	91	75
T3(U)	84	75	74	-	9	←	95	75
T4(U)	84.5	77	76	-	9	↙	96	78
T5(U)	87	78.5	78	-	10	←	97	79
T6(U)	90	81	80	-	10	←	100	81
T7(U)	93	83	82	-	11	↖	103	83
T8(U)	95	85	85	-	10	←	105	84
T8(U)0 Fan	87.5	80	78	-	10	↖	104	84
T8(U)1 Fan	89	80	79	-	9	←	104	84
T8(U)2 Fans	93.5	83	83.5	-	9	←	105	85
T8(U)3 Fans	96	84.5	85	-	6	↙	105	85
T8(U)4 Fans	-	-	-	-	-	-	-	-
T1→4(L)	89	82.5	79	800	10	↖	102	81
T4→8(L)	96	86	87	2300	12	↖	108	87
T8→6(L)	92	83	82	1350	10	←	104	83
T6→8(L)	95	86	86	2250	7	←	108	86
T8→Idle(L)	76	83	72.5	0	9	↖	88	70
Idle→T8(L)	96	86	87	2250	10	←	108	87
T1→4(U)	85	76	76	-	10	←	96	78
T4-8(U)	96	86	85	-	20	↙	105	84
T8→6(U)	90	80	80	-	8	↘	100	80
T6→8(U)	95	85	85	-	15	↗	105	84
T8→I(U)	77	73	72	-	9	←	89	70
I→T8(U)	96	87	86	-	9	↘	105	84

Ambient:

50 Ft Mic:	72.5 dBA
100 Ft Mic:	73 dBA
200 Ft Mic:	73-74 dBA
Nearfield Mic:	71 dBA
In-Cab Mic:	62.5 dBA

Weather:

Barometric Pressure:	991 mbar
Temperature:	55°F
Humidity:	-

TEST SITE NO. 2 (Conforming)

LOCOMOTIVE MODEL AND SERIAL NO. GP35 #3515

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft* Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	74	69.5	–	0	12	←	90	70
T1(L)	74	70.5	–	–	12-13	←	90	70
T2(L)	79	73	–	50	11	←	92	76.5
T3(L)	82.5	74	–	350	12	←	96.5	77
T4(L)	84	74	–	600	12-13	←	100.5	81
T5(L)	88	83	–	950	14-16	←	104	82.5
T6(L)	88	82	–	1300	12-13	←	103.5	82
T7(L)	90	83	–	1750	12-14	←	106	85
T8(L)	93	86.5	–	2200	11-15	←	108.5	85.5
T8(L)0 Fan	83	81	–	–	14-16	←	103	86
T8(L)1 Fan	90.5	84.5	–	–	15-16	←	103.5	86
T8(L)2 Fans	90.5	84.5	–	–	15-16	←	103.5	86
T8(L)3 Fans	93	86.5	–	–	16-18	←	104	86
T8(L)4 Fans	–	–	–	–	–	–	–	–
T1(U)(Idle)	74.5	69.5	–	–	12	←	90	69.5
T2(U)	78	72	–	–	12	←	91.5	76
T3(U)	81	75	–	–	11-13	←	95	76
T4(U)	82	76	–	–	13-14	←	97	76.5
T5(U)	85	77.5	–	–	16-19	←	97.5	78.5
T6(U)	87.5	80	–	–	14-17	←	100.5	80.5
T7(U)	91	82	–	–	15	←	103	82
T8(U)	93	86	–	–	12-14	←	105	83
T8(U)0 Fan	84.5	78	–	–	–	←	104	82.5
T8(U)1 Fan	89	83.5	–	–	–	←	104.5	82.5
T8(U)2 Fans	90	83.5	–	–	–	←	105	83
T8(U)3 Fans	93	86	–	–	–	←	105	83
T8(U)4 Fans	–	–	–	–	–	–	–	–
T1→4(L)	84.5	80	–	750	12-13	←	101.5	81
T4→8(L)	93	86.5	–	2250	11-12	←	108.5	86
T8→6(L)	88.5	81	–	1350	11-12	←	104	83.5
T6→8(L)	93	86	–	2200	13-14	←	108.5	86
T8→Idle(L)	73.5	69	–	0	14	←	90	69
Idle→T8(L)	93.5	86	–	2200	9-11	←	108.5	86
T1→4(U)	82	76	–	–	12-15	←	97	76
T4-8(U)	92.5	85	–	–	11	←	105	82.5
T8→6(U)	87.5	80	–	–	11-12	←	101	80.5
T6→8(U)	93	86	–	–	14-18	←	105	83
T8→I(U)	74	69	–	–	12-14	←	90.5	70
I→T8(U)	93	86	–	–	16-17	←	105	83

Ambient:

50 Ft Mic: 65 dBA
100 Ft Mic: 64.5 dBA
*200 Ft Mic: –
Nearfield Mic: 65 dBA
In-Cab Mic: 59 dBA

Weather:

Barometric Pressure: 900 mbar
Temperature: 55-61°F
Humidity: 92%

*This microphone operating improperly during this test.

TEST SITE NO. 1 (Typical)

LOCOMOTIVE MODEL AND SERIAL NO. GP30 #6915

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	144 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	74	72	74	-	4	↖	88	68
T1(L)	75	74	74	-	4	↖	88	68
T2(L)	76	73	74	100	3	↖	90	70
T3(L)	81	75	75	300	3	↖	96	76
T4(L)	83	76	76.5	450	2	↖	99	80
T5(L)	87	81	82.5	1250	2	↖	104	80
T6(L)	87	82	81	1400	5	↖	105	80
T7(L)	90.5	84	83	1900	5	↖	107	83
T8(L)	92	91	84	2100	7	↖	108	84
T8(L)0 Fan	87.5	81	80.5	2150	4	↖	107	84
T8(L)1 Fan	89	82	80.5	2100	3	←	107	84
T8(L)2 Fans	90.5	85	82	-	3	←	107	84
T8(L)3 Fans	91	85	83	2150	3	←	108	84
T8(L)4 Fans	-	-	-	-	-	-	-	-
T1(U)(Idle)	74	73	74	-	6	↖	87	68
T2(U)	76	74	74	-	5	↖	92	69
T3(U)	82	74	75	-	5	↖	96	75
T4(U)	82	76	76	-	5	↖	97	77
T5(U)	85	79	78	-	4	↖	100	76
T6(U)	86	79	80	-	5	↖	100	77
T7(U)	90	84	83	-	4	↖	104	80
T8(U)	92	85	83	-	3	↖	105	81
T8(U)0 Fan	88	78	78	-	4	↖	105	82
T8(U)1 Fan	89	79	78	-	4	↖	105	82
T8(U)2 Fans	91	84	81	-	3	←	105	82
T8(U)3 Fans	90	84	81	-	3	↖	105	82
T8(U)4 Fans	-	-	-	-	-	-	-	-
T1→4(L)	82	77	76	350	4	↘	99	77
T4→8(L)	92	85	84	2050	3	↙	108	84
T8→6(L)	87	81	81	1350	4	↖	104	81
T6→8(L)	92	85.5	84	2050	4	↖	108	85
T8→Idle(L)	73	70	71	-	4	↖	89	68
Idle→T8(L)	92	85.5	84	2100	3	←	108	84
T1→4(U)	82	76	76	-	3	↖	97	77
T4-8(U)	91	84	81	-	4	↖	105	82
T8→6(U)	84.5	79	78.5	-	3	↖	101	76
T6→8(U)	91	83	81	-	4	↖	105	82
T8→I(U)	73	70.5	71	-	6	←	89	68
I→T8(U)	91	83.5	81	-	6	↖	105	83

Ambient:

50 Ft Mic: 71-76 dBA
100 Ft Mic: 70-74 dBA
200 Ft Mic: 71-74 dBA
Nearfield Mic: 71-74 dBA
In-Cab Mic: 61-63 dBA

Weather:

Barometric Pressure: 993 mbar
Temperature: 57°F
Humidity: -

TEST SITE NO. 2 (Conforming)

LOCOMOTIVE MODEL AND SERIAL NO. GP30 #6915

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind Speed (mph)	Wind Direction	Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
Idle	71.5	64	60.5	-	13-14	↙	88	67.5
T1(L)	71	65	60.5	-	13	↙	88.5	67.5
T2(L)	73	66.5	62	50	12	↙	89	69
T3(L)	80.5	74	67	50	11	↓	96	76.5
T4(L)	81	75	69	300	9-10	↙↓	98.5	78
T5(L)	85	80	74.5	1150	5-8	←	103.5	78.5
T6(L)	85	80.5	74	1250	10	←	104	79
T7(L)	88.5	83.5	78	1775	10-11	←	106.5	82.5
T8(L)	89	84	78.5	2000	7-10	←	108	83.5
T8(L)0 Fan	86	81	75	2000	10	←	107	83.5
T8(L)1 Fan	88	83	77	2000	10-12	←	107.5	83.5
T8(L)2 Fans	89	84	78	2000	11-12	←	107.5	83.5
T8(L)3 Fans	89.5	85	78.5	2000	10-16	←	108	83.5
T8(L)4 Fans	-	-	-	-	-	-	-	-
T1(U)(Idle)	71.5	64.5	62.5	-	4-5	↙	88.5	68
T2(U)	73	67	63.5	-	4-8	⤵	90.5	69
T3(U)	78.5	73.5	66	-	8	↷	95.5	74
T4(U)	80	74.5	67	-	8	↙	97	76
T5(U)	84	78.5	71.5	-	8	↙	99	77
T6(U)	85	80	73	-	6-8	←	100	77
T7(U)	89	83.5	76	-	7-8	←	104.5	80
T8(U)	89.5	84	78	-	4-7	←	105	81.5
T8(U)0 Fan	84.5	79.5	71.5	-	7	←	104	80
T8(U)1 Fan	87	81.5	75	-	8	↙	104	81
T8(U)2 Fans	88	82.5	77	-	10	↙	104.5	81
T8(U)3 Fans	89	83	77.5	-	10	↙	105	81.5
T8(U)4 Fans	-	-	-	-	-	-	-	-
T1→4(L)	81.5	74.5	69	350	6-8	↙	98.5	78
T4→8(L)	89	83.5	78	2000	5-8	↙	107.5	84.5
T8→6(L)	85.5	80	73.5	1300	4-6	↙	105	80
T6→8(L)	89.5	83.5	78.5	2000	4-8	↙	108	84
T8→Idle(L)	70	65	60	0	8	↙	88	68
Idle→T8(L)	89.5	84	78.5	2000	6-8	↙	107.5	84
T1→4(U)	80	74	67.5	-	5-6	↙	96.5	77
T4-8(U)	89	83	77	-	4-5	↓	105	81.5
T8→6(U)	85	79.5	72	-	5-6	↓	100.5	77
T6→8(U)	89.5	83	77	-	4-5	↓	105	81.5
T8→I(U)	70	63	60	-	5-6	↓	86.5	67
I→T8(U)	89	83.5	77	-	3-5	↓	105	82.5

Ambient:

50 Ft Mic:	55-56 dBA
100 Ft Mic:	55-57 dBA
200 Ft Mic:	55-56 dBA
Nearfield Mic:	60 dBA
In-Cab Mic:	52-55 dBA

Weather:

Barometric Pressure:	993 mbar
Temperature:	73°F
Humidity:	-

TEST SITE NO. 1 (Typical)

LOCOMOTIVE MODEL AND SERIAL NO. GP9 #6482

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	144 Ft Mic (dBA)	Power (hp)	Wind Speed (mph)	Wind Direction	Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
Idle	75	72	71.5	-	13-15	↘←	86	71
T1(L)	75	72	71.5	-	13	←	86.5	72
T2(L)	76.5	73	71.5	175	10-12	←↙	87	73.5
T3(L)	84.5	77	76	500	9-10	←	97.5	80
T4(L)	85.5	78	76	550	9	←	100	80.5
T5(L)	89	82	81	1000	10	←	104	85
T6(L)	90	82	81.5	1025	8	↙	106	85
T7(L)	93	86.5	85.5	1400	10-13	↙	110.5	89
T8(L)	96	89	88	1450	10-12	↙	112	90
T8(L)0 Fan	-	-	-	-	-	-	-	-
T8(L)1 Fan	-	-	-	-	-	-	-	-
T8(L)2 Fans	-	-	-	-	-	-	-	-
T8(L)3 Fans	-	-	-	-	-	-	-	-
T8(L)4 Fans	-	-	-	-	-	-	-	-
T1(U)(Idle)	-	-	-	-	-	-	-	-
T2(U)	-	-	-	-	-	-	-	-
T3(U)	-	-	-	-	-	-	-	-
T4(U)	-	-	-	-	-	-	-	-
T5(U)	-	-	-	-	-	-	-	-
T6(U)	-	-	-	-	-	-	-	-
T7(U)	-	-	-	-	-	-	-	-
T8(U)	-	-	-	-	-	-	-	-
T8(U)0 Fan	-	-	-	-	-	-	-	-
T8(U)1 Fan	-	-	-	-	-	-	-	-
T8(U)2 Fans	-	-	-	-	-	-	-	-
T8(U)3 Fans	-	-	-	-	-	-	-	-
T8(U)4 Fans	-	-	-	-	-	-	-	-
T1→4(L)	85.5	76.5	74.5	250	5	↙	96.5	80
T4→8(L)	96	87	86	1450	7-8	↙	111	90
T8→6(L)	89	81.5	80.5	900	8-9	↙	105.5	85
T6→8(L)	96	86.5	85.5	1400	9-10	←	111.5	89
T8→Idle(L)	75	72.5	70.5	0	10-12	←	85.5	72
Idle→T8(L)	96	88	87.5	1500	10-12	←	112	90
T1→4(U)	85	76.5	75	-	7	←	91	80.5
T4-8(U)	94	85	85.5	-	6-8	←	106.5	87
T8→6(U)	88	82	80.5	-	7-8	←	99.5	83
T6→8(U)	93.5	86.5	86	-	9-10	←	106	88
T8→I(U)	75.5	78	71.5	-	10-11	←	80	71
I→T8(U)	93	85	84	-	10	←	106	88

Ambient

50 Ft Mic: 75 dBA

100 Ft Mic: 73-80 dBA

200 Ft Mic: 71-74 dBA

Nearfield Mic: 75 dBA

In-Cab Mic: 63 dBA

Weather:

Barometric Pressure: 999 mbar

Temperature: 93°F

Humidity: 76%

TEST SITE NO. 2 (Conforming)

LOCOMOTIVE MODEL AND SERIAL NO. GP9 #6482

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	73	67	65	-	13	←	86	71
T1(L)	73	69	65	-	10	←	86	72
T2(L)	75	69	66	200	12	←	87	73
T3(L)	83	76	70	500	14	←	97	79
T4(L)	86	77	71	550	12	←	100	81
T5(L)	88	84	76	1000	16	←	104	85
T6(L)	89.5	84	76	1000	17	←	106	85
T7(L)	93	84	82	1400	16	←	110	89
T8(L)	94	88	82	1450	18	←	112	90
T8(L)0 Fan	92	88.5	83	-	14	←	-	-
T8(L)1 Fan	93	89	83	-	17	←	-	-
T8(L)2 Fans	93	89	83	-	17	←	-	-
T8(L)3 Fans	94	89	84	-	20	←	-	-
T8(L)4 Fans	94	89	83	-	15	←	-	-
T1(U)(Idle)	-	-	-	-	-	-	-	-
T2(U)	-	-	-	-	-	-	-	-
T3(U)	-	-	-	-	-	-	-	-
T4(U)	-	-	-	-	-	-	-	-
T5(U)	-	-	-	-	-	-	-	-
T6(U)	-	-	-	-	-	-	-	-
T7(U)	-	-	-	-	-	-	-	-
T8(U)	-	-	-	-	-	-	-	-
T8(U)0 Fan	-	-	-	-	-	-	-	-
T8(U)1 Fan	-	-	-	-	-	-	-	-
T8(U)2 Fans	-	-	-	-	-	-	-	-
T8(U)3 Fans	-	-	-	-	-	-	-	-
T8(U)4 Fans	-	-	-	-	-	-	-	-
T1→4(L)	84	76	69	-	11	←	96	80
T4→8(L)	93	88	81	1450	17	←	111	90
T8→6(L)	87	81	75	900	13	←	105	85
T6→8(L)	94	88	81	1400	11	←	112	89
T8→Idle(L)	72.5	68	65.5	0	10	←	86	72
Idle→T8(L)	94	88	81	1500	10	←	112	90
T1→4(U)	82.5	75	69.5	-	16	←	96	80
T4-8(U)	90.5	86	78	-	15	←	106	87
T8→6(U)	86	81	72.5	-	14	←	99	83
T6→8(U)	90	81.5	80	-	14	←	106	87
T8→I(U)	72.5	67.5	64.5	-	17	←	85	71
I→T8(U)	91	85	78	-	12	←	106	88

Ambient:

50 Ft Mic: 75 dBA
100 Ft Mic: 73 dBA
200 Ft Mic: 72 dBA
Nearfield Mic: 73 dBA
In-Cab Mic: 66-70 dBA

Weather:

Barometric Pressure: 993 mbar
Temperature: 86°F
Humidity: 58%

TEST SITE NO. 1 (Typical)

LOCOMOTIVE MODEL AND SERIAL NO. GP38 #3827

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	144 Ft Mic (dBA)	Power (hp)	Wind Speed (mph)	Wind Direction	Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
Idle	72	67	-	-	5	↘	-	-
T1(L)	73	68	-	-	6	↘	86	-
T2(L)	76	71	-	-	6	↘	92	-
T3(L)	79	72	-	-	6-7	↘	96	-
T4(L)	82	76	76	-	8	↘	101	-
T5(L)	85	80	80	950	7	↘	105	-
T6(L)	88	83	82	1400	5	→	108	83
T7(L)	89	84	83	1400	6	→	110	85
T8(L)	91	87	87	-	6	→	-	-
T8(L)0 Fan	-	-	-	-	-	-	-	-
T8(L)1 Fan	91	85	85	-	5	↘	112	86
T8(L)2 Fans	(91)	86	86	-	4	↙	112	86
T8(L)3 Fans	-	-	-	-	-	-	-	-
T8(L)4 Fans	-	-	-	-	-	-	-	-
T1(U)(Idle)	-	-	-	-	-	-	-	-
T2(U)	-	-	-	-	-	-	-	-
T3(U)	-	-	-	-	-	-	-	-
T4(U)	-	-	-	-	-	-	-	-
T5(U)	-	-	-	-	-	-	-	-
T6(U)	-	-	-	-	-	-	-	-
T7(U)	-	-	-	-	-	-	-	-
T8(U)	-	-	-	-	-	-	-	-
T8(U)0 Fan	-	-	-	-	-	-	-	-
T8(U)1 Fan	-	-	-	-	-	-	-	-
T8(U)2 Fans	-	-	-	-	-	-	-	-
T8(U)3 Fans	-	-	-	-	-	-	-	-
T8(U)4 Fans	-	-	-	-	-	-	-	-
T1→4(L)	81	75	77	-	5	↖	100	80
T4→8(L)	91	86	86	1850	6	↖	112	87
T8→6(L)	88	82	83	-	5	↖	108	84
T6→8(L)	92	86	85	-	7	↖	113	86
T8→Idle(L)	78	75	74	0	7	↖	86	-
Idle→T8(L)	91	86	86	1750	4	↖	112	87
T1→4(U)	81	75	77	-	5	↖	96	80
T4-8(U)	91	86	86	-	5	↖	105	85
T8→6(U)	88	82	83	-	6	↖	102	81
T6→8(U)	92	86	86	-	5	↖	105	85
T8→I(U)	72	67	69	-	3	↖	86	-
I→T8(U)	87	83	82	-	3	↖	105	84

Ambient:

50 Ft Mic: 68-79 dBA*
100 Ft Mic: 68-77 dBA*
200 Ft Mic: 68-80.5 dBA*
Nearfield Mic: 68-77 dBA
In-Cab Mic: 60-67 dBA

Weather:

Barometric Pressure: 993 mbar
Temperature: 82°F
Humidity: -

*Note: Locomotive going back and forth in background.

TEST SITE NO. 2 (Conforming)

LOCOMOTIVE MODEL AND SERIAL NO. GP38 #3827

Test Condition	50 Ft Mic (dBA)	100 Ft Mic (dBA)	200 Ft Mic (dBA)	Power (hp)	Wind		Nearfield Microphone (dBA)	In-Cab Microphone (dBA)
					Speed (mph)	Direction		
Idle	70	64	60	-	7	↘	-	-
T1(L)	70	64	61	-	6	↘	86	-
T2(L)	75	68	63	-	6	→	91	-
T3(L)	76	70	66	-	5	↘	95	-
T4(L)	80	75	71	650	6	↘	101	79
T5(L)	85	79	75	900	5	↘	105	81
T6(L)	82	82	76	1150	6	↘	107	83
T7(L)	89	83	77	1300	6	↘	110	84
T8(L)	92	85	81	1700	6	↘	112	85
T8(L)0 Fan	91	83	80	-	6	→	112	85
T8(L)1 Fan	92	84	80	-	6	→	112	86
T8(L)2 Fans	83	85	81	-	6	→	112	86
T8(L)3 Fans	-	-	-	-	-	-	-	-
T8(L)4 Fans	-	-	-	-	-	-	-	-
T1(U)(Idle)	-	-	-	-	-	-	-	-
T2(U)	-	-	-	-	-	-	-	-
T3(U)	-	-	-	-	-	-	-	-
T4(U)	-	-	-	-	-	-	-	-
T5(U)	-	-	-	-	-	-	-	-
T6(U)	-	-	-	-	-	-	-	-
T7(U)	-	-	-	-	-	-	-	-
T8(U)	-	-	-	-	-	-	-	-
T8(U)0 Fan	-	-	-	-	-	-	-	-
T8(U)1 Fan	-	-	-	-	-	-	-	-
T8(U)2 Fans	-	-	-	-	-	-	-	-
T8(U)3 Fans	-	-	-	-	-	-	-	-
T8(U)4 Fans	-	-	-	-	-	-	-	-
T1→4(L)	80	75	71	-	6	→	100	79
T4→8(L)	92	86	81	1850	5	→	112	86
T8→6(L)	87	82	77	700	7	→	107	83
T6→8(L)	93	85	80	-	8	→	110	86
T8→Idle(L)	70	64	60	0	6	→	96	-
Idle→T8(L)	93	85	81	1850	4	→	112	86
T1→4(U)	79	72	68	-	6	↘	96	77
T4-8(U)	89	82	78	-	6	↘	104	84
T8→6(U)	85	79	73	-	5	→	101	81
T6→8(U)	89	82	78	-	5	→	104	84
T8→I(U)	70	63	60	-	4	→	85	-
I→T8(U)	89	82	79	-	5	→	104	84

Ambient:

50 Ft Mic: 60 dBA
100 Ft Mic: 58.5 dBA
200 Ft Mic: 58 dBA
Nearfield Mic: 64-70 dBA
In-Cab Mic: 57-88 dBA*

Weather:

Barometric Pressure: 997 mbar
Temperature: 72°F
Humidity: 56%

*Cab radio came on briefly during background measurement.

A.3 LOAD CELL NOISE DATA

Upper bound and best estimates of load cell noise contribution at the 100 ft microphone are presented in the following table. "Site number" refers to the designations in Table 1 of the text.

TYPICAL SITES — LOAD CELL NOISE

	Best Estimate of Noise							
	Site Number							
Throttle	1	2	3	4	5	6	7	8
1	-	-	-	-	-	-	-	-
2	70	-	-	-	-	-	-	-
3	71	-	60	-	-	68	-	-
4	71	-	64	-	-	70	-	-
5	73.5	-	64	-	-	73	63	-
6	75.5	-	65	67.5	-	75.5	65.5	67.5
7	74	-	67	68	-	78	67.5	71.5
8	74	<66	69	78	<71.5	80	69	71.5

	Upper Bound							
	Site Number							
Throttle	1	2	3	4	5	6	7	8
1	-	-	-	-	-	-	-	-
2	74	-	-	-	-	69.5	-	-
3	75	-	70	72	67.5	72	67.5	67.5
4	76	64.5	71	73	68.5	74.5	69	70
5	77	-	71	73.5	69	76	69.5	71.5
6	78	64.5	71	74.5	69	78	70.5	73
7	78	66	72	65	70.5	80	71.5	75
8	78	66	73	75	71.5	81	73	75

A.4 OPPORTUNITY LOCOMOTIVE SUMMARY SHEET

A summary of data at the 100 ft microphone is presented in the table for the opportunity locomotives at the two load cell test sites and the passby site. The sound levels were obtained in the same manner as for the previous tables.

OPPORTUNITY LOCOMOTIVE: SUMMARY DATA SHEETS (Noise Emissions at 100 Ft in dBA).

Locomotive Model and Serial No.	Throttle Setting	Site #2 (Conforming)	Site #1 (Typical)	Site #9 (Passby)
GP40-2 #4143	T8(L)	88	88.5	88.25
	T8(U)	86.5	87	-
	Idle	67.5	75	-
	TW(L)*	87.75	88.5	-
	TW(U)	87	87	-
GP40 #3797	T8(L)	89.25	90.5	90.25
	T8(U)	-	-	-
	Idle	72.5	76.5	-
	TW(L)	89.5	90.0	-
	TW(U)	88.5	88	-
GP40-2 #4147	T8(L)	89	87.75	88.5
	T8(U)	86	86	-
	Idle	68.5	74.5	68.5
	TW(L)	88.5	87.75	-
	TW(U)	87	85.75	-
GP40 #3784	T8(L)	87.5	88	87.5
	T8(U)	-	-	-
	Idle	69.5	73.5	66
	TW(L)	87.5	88	-
	TW(U)	86.5	87	-
GP35 #3515	T8(L)	87	87	88.5
	T8(U)	86.5	84.5	-
	Idle	69.5	73	68
	TW(L)	86.5	86	-
	TW(U)	86	86	-

*Maximum sound level achieved during throttle wipe (TW) tests.

OPPORTUNITY LOCOMOTIVE: SUMMARY DATA SHEETS (Noise Emissions at 100 Ft in dBA).

Locomotive Model and Serial No.	Throttle Setting	Site #2 (Conforming)	Site #1 (Typical)	Site #9 (Passby)
SD35 #7419	T8(L)	86	86	88
	T8(U)	84	-	-
	Idle	69.5	73.5	71.5
	TW(L)	86	86	-
	TW(U)	85	85	-
GP30 #6915	T8(L)	85	86	86
	T8(U)	83.5	84	-
	Idle	65	72.5	67.5
	TW(L)	84	85.5	-
	TW(U)	83	83	-
GP9 #6482	T8(L)	88.5	89	89.5
	T8(U)	-	-	-
	Idle	67.5	72	-
	TW(L)	88	88	-
	TW(U)	86.5	86.5	-
GP38 #3827	T8(L)	85.5	87	87.5
	T8(U)	-	-	-
	Idle	63.5	67	67
	TW(L)	86	86.5	-
	TW(U)	82.5	83	-

A.5 DEDICATED LOCOMOTIVE SUMMARY SHEET

The following table provides a summary sheet for the dedicated locomotive at the nine test sites. All sound data are in overall A-weighted sound levels (dBA).

DEDICATED LOCOMOTIVE: SUMMARY DATA SHEET (NOISE EMISSIONS AT 100 FT IN dBA)

Throttle Setting	Site #1 (Typical)	Site #2 (Conforming)	Site #3 (Typical)	Site #4 (Typical)	Site #5 (Typical)	Site #6 (Typical)	Site #7 (Typical)	Site #8 (Typical)	Site #9 (Passby)	Site #2 Revisited
T8(L)	89.5	88.5	88.5	89	88	91.5	89.5	88	88.5	88
T8(U)	86.5	86	85	86	84.5	88	86	84.5	-	85
Idle	71.5	66.5	69	72	68.5	70	66.5	69	69.5	67
TW(L)*	91	88	87	89.5	87.5	91.5	89	88.5	-	88
TW(U)*	87	85.5	84	86	85	88	86	85	-	85

*Maximum level achieved during the throttle wipe (TW) test.

A.6 PASSBY TEST SUMMARY SHEETS

This table summarizes the significant data obtained during the passby tests, including the horsepower achieved. All ten locomotives are listed. When very high brake-by noise levels occur in the table, it generally indicates that brake squeal occurred during the test.

PASSBY TESTS

Locomotive Model and Serial No.	Speed (MPH) / Direction	Power Achieved	Powered Noise Level (dBA)		Brake-By Noise Level (dBA)		Ambient Noise Level (dBA)	
			50 Ft Mic	100 Ft Mic	50 Ft Mic	100 Ft Mic	50 Ft Mic	100 Ft Mic
GP40-2 #4143	25/E	-	-	96	-	-	-	-
	25/W	-	-	95.5	-	-	-	-
	31/E	-	-	-	-	88	-	-
	22/W	-	-	-	87.5	83	-	-
	26/W	-	103	98	-	-	-	-
	25/E	-	102.5	97.5	-	-	-	-
	24/E	-	-	-	95	90	-	-
	23/E	-	-	-	104	97.5	-	-
GP40 #3797	-	-	-	-	-	-	68.5	69
	25-30/E	-	93.5	90	-	-	-	-
	27/W	-	93	89	-	-	-	-
	27/E	-	-	-	87.5	78.5	-	-
	21/W	-	-	-	79.5	76	-	-
GP9 #6482	18/W	1550 hp	93	89	-	-	-	-
	17/W	1475 hp	93.5	89.5	-	-	-	-
	17/E	1500 hp	93.5	88	-	-	-	-
	19/W	-	-	-	83	77.5	-	-
	22/E	-	-	-	86	84.5	-	-
	-	-	-	-	-	-	65	63
GP38 #3827	16/E	1600 hp	93.5	87.5	-	-	-	-
	16/W	1600 hp	93.5	87	-	-	-	-
	18/E	1550 hp	102	93.5	-	-	-	-
	16/W	1650 hp	92	86	-	-	-	-
	18/E	1650 hp	95.5	89.5	-	-	-	-
	18/W	1600 hp	92	86	-	-	-	-
	18/W	-	-	-	80	77.5	-	-
GP40 #3784	20/E	2350 hp	92	87.5	-	-	-	-
	20/W	2350 hp	91	86.5	-	-	-	-
	-	-	-	-	80	-	-	-
	/E	-	-	-	82	75	-	-
	-	-	-	-	-	-	70	66

PASSBY TESTS

Locomotive Model and Serial No.	Speed (MPH) Direction	Power Achieved	Powered Noise Level (dBA)		Brake-By Noise Level (dBA)		Ambient Noise Level (dBA)	
			50 Ft Mic	100 Ft Mic	50 Ft Mic	100 Ft Mic	50 Ft Mic	100 Ft Mic
GP38 #3804	17/E	1850 hp	97.5	90	-	-	-	-
	17/W	1800 hp	97.5	90	-	-	-	-
	17/E	1800 hp	95	88.5	-	-	-	-
	16/W	1800 hp	95	89	-	-	-	-
	17/W	-	-	94	-	-	-	-
	17/E	-	-	89	-	-	-	-
	20/W	-	-	88.5	-	-	-	-
	20/E	-	-	89	-	-	-	-
	-	-	-	-	-	-	68	62
	17/W	-	-	-	92	85.5	-	-
	21/E	-	-	-	82	78	-	-
GP40-2 #4147	20/W	2750 hp	90.5	87	-	-	-	-
	19/W	2700 hp	91	87.5	-	-	-	-
	20/E	2825 hp	93	88.5	-	-	-	-
	19/W	2850 hp	92	88.5	-	-	-	-
	18/E	2850 hp	92.5	88.5	-	-	-	-
	19/W	2750 hp	92	88.5	-	-	-	-
	20/E	2850 hp	93	88.5	-	-	-	-
	20/W	-	-	-	86	81	-	-
	20/E	-	-	-	82.5	80.5	-	-
	20/W	-	-	-	84	80	-	-
	20/E	-	-	-	87	81.5	-	-
	-	-	-	-	-	-	58-62	58-65
GP30 #6915	17/W	1900 hp	90	85	-	-	-	-
	18/E	1900 hp	90.5	85	-	-	-	-
	28/W	1900 hp	90	85	-	-	-	-
	18/W	1900 hp	90.5	85.5	-	-	-	-
	21/E	1900 hp	91	85.5	-	-	-	-
	-	-	-	-	-	-	65	66
	/W	-	-	-	79	73	-	-
GP35 #3515	19/W	2100 hp	94.5	88.5	-	-	-	-
	/E	2000 hp	93.5	86.5	-	-	-	-
	19/W	2000 hp	94	87	-	-	-	-
	18/E	2000 hp	93	87	-	-	-	-
	20/E	-	-	-	79.5	71	-	-
	10/W	-	-	-	75	69	-	-
	27/E	-	-	-	80	75	-	-
	-	-	-	-	-	-	70	65
SD35 #7419	15/W	1600 hp	92	82	-	-	-	-
	14/E	1600 hp	88	87	-	-	-	-
	25/W	1500 hp	89	85	-	-	-	-
	22/E	1500 hp	93	87.5	-	-	-	-
	24/E	1400 hp	90	85.5	-	-	-	-
	21/W	-	87.5	82	-	-	-	-
	/W	-	-	-	76.5	74	-	-
	/E	-	-	-	82	77.5	-	-
	-	-	-	-	-	-	67	66.5

APPENDIX B

GROUND INTERACTION

The theory of the reflection of acoustic waves off a finite impedance boundary dates back at least to 1944 [*B1*]. For the last 15 years, papers by Ingard [*B2*], Lawhead and Rudnick [*B3*], have been regarded as standard works. Recently, however, a number of important contributions to the theory have largely superseded the earlier work. These include the work by Piercy *et al.* [*B4*], Wenzel [*B5*], Thomassen [*B6*], and Pao [*B7*]. All of these theories generally assume an infinite flat plate with a normal impedance boundary. Since "real media" (ground surfaces) are porous with high internal flow resistance and poor wave propagation characteristics, we can treat the surface as a locally reacting surface. This is the model used by Piercy [*B4*] and has been justified by others.

Basically, one has three effects:

- Direct and reflected waves (as illustrated in Fig. B1)
- Ground waves
- Surface waves.

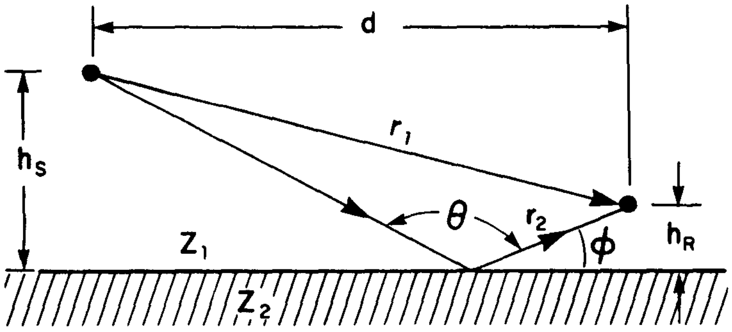

FIG. B1. GROUND INTERACTION

Ground Waves and Surface Waves

The exact nature or physical interpretation of ground waves is still unclear, but they are one of the principal mechanisms by which sound penetrates a shadow zone caused by the finite impedance of the ground. The common analogy is to radio (AM) wave propagation, and Piercy's [*B4*] solutions are based on Weyl-Vander Pol equations for such radio waves. These ground waves are essentially a low frequency phenomenon (200 - 600 Hz) in outdoor noise propagation.

For propagation near the surface of the ground, a second surface phenomenon has been shown theoretically to provide additional low frequency attenuation. The existence of surface waves is hard to show experimentally. It is confined to a region near the ground and has a decrease in amplitude with distance (similar to cylindrical spreading at 3 dB per doubling of distance) and an additional attenuation with height away from the boundary.

To illustrate the three effects, Fig. B2 is taken from Piercy [*B4*]; and the individual components, direct and reflected (D&R), ground wave (G), and surface wave (S) are shown.

Although the geometry of the problem is slightly different, we see that at 31.2 meters the surface wave is negligible and the effect of the ground wave is to increase the excess attenuation at 500 Hz. For broad frequency bands and the range of distances considered in this study, it appears reasonable to neglect ground and surface waves. This is fortunate, for at present no single numerical solution exists to readily calculate the ground effects for a particular geometry. Not least is the problem of attempting to find reasonable estimates of the ground impedance. Piercy *et al.* [*B4*] gives a relatively large collection of data on different ground impedances but the scatter in these is appreciable. Embleton [*B8*] and Pao [*B7*] give data for asphalt and grass but

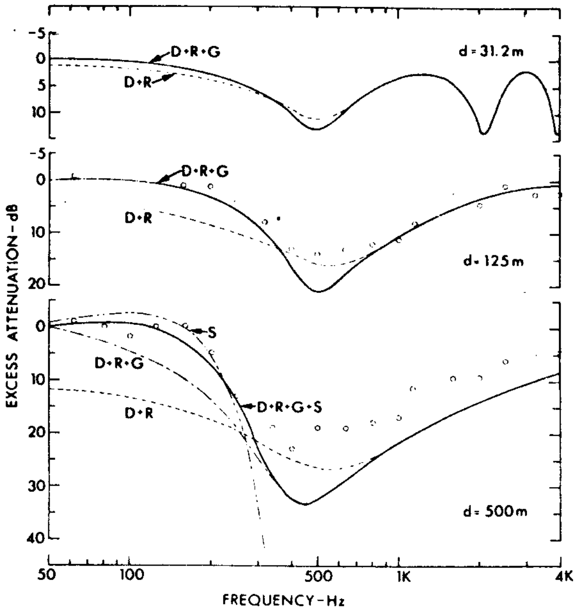

FIG. B2. EXCESS ATTENUATION FOR PROPAGATION FROM A POINT SOURCE OVER MOWN GRASS. (h_s = 1.8 m, h_r = 1.5 m. The Calculated Curves Show the Contributions from the Various Waves – Direct D, Reflected R, Ground G, and Surface S. The Points are Measurements of Jet Noise at Comparable Distances. The Excess Attenuation is Relative to that for a Point Source Placed on a Perfectly Hard Surface.)

neither of these is a good model of the surfaces encountered at the Chessie test sites. Experimental data on ground and surface waves are consequently limited, and at present, it is only possible to make inferences as to the likely effects and regimes of dependence for the ground effects.

Direct and Reflected Waves

As with an infinitely hard reflective surface, one gets interference effects due to the summation of the reflected and direct waves. However, there is the additional possibility of a phase change between the two waves due to diffraction effects caused by ground surfaces that are less than perfect reflectors.

Reference B9 provides a calculation scheme for estimating the ratio of the sum of the direct and reflected waves at the receiver to the direct wave alone.

$$\Delta N_G = 10 \log_{10}\left\{1 + \left(\frac{|Q_i|}{Z}\right)^2 + 2\,\frac{|Q_i|}{Z}\,\frac{\left[\sin \alpha\left(\frac{\Delta r}{\lambda_i}\right)\right]}{\alpha\,\frac{\Delta r}{\lambda_i}}\cos\left[\beta\,\frac{\Delta r}{\lambda_i} - \delta_i\right]\right\} \qquad \text{(B.1)}$$

where $\Delta r = (r_2 - r_1)$; λ_i, α, and β are as defined for Eq. 6 in the text; ρc is the acoustic impedance; and r_1, r_2, and θ are defined in Fig. B1,

$$|Q_i| = \frac{\sqrt{\left(\left|\frac{Z_n}{\rho c}\right|^2 \cos^2\theta - 1\right)^2 + 4\left(\frac{X_a}{\rho c}\right)^2 \cos^2\theta}}{\left(\left|\frac{Z_n}{\rho c}\right|^2 \cos^2\theta + 1 + 2\,\frac{R_a}{\rho c}\cos\theta\right)} ,$$

$$\sin\delta_i = \frac{2\,\frac{X_a}{\rho c}\cos\theta}{\sqrt{\left(\left|\frac{Z_n}{\rho c}\right|^2 \cos^2\theta - 1\right)^2 + 4\left(\frac{X_a}{\rho c}\right)^2 \cos^2\theta}} ,$$

$$\cos\delta_i = \frac{\left|\frac{Z_n}{\rho c}\right|^2 \cos^2\theta - 1}{\left(\left|\frac{Z_n}{\rho c}\right|^2 \cos^2\theta - 1\right)^2 + 4\left(\frac{X_a}{\rho c}\right)^2 \cos^2\theta} .$$

$|Z_n|^2 = X_a^2 + R_a^2$, where X_a and R_a are the imaginary and real parts of the complex ground impedance, respectively.

Except for the impedance terms Q_i and the phase change δ_i, Eq. B.1 is very similar to Eq. 6 in the text. Because of the small path length difference for ground reflections, the last term in Eq. B.1 cannot, in general, be neglected except at high frequency; and there is no need to include atmospheric absorption. Using Eq. B.1, we have calculated the ground interaction correction that must be added to the direct path sound for a typical locomotive test configuration (h_s = 15 ft; h_r = 4 ft; d = 100 ft; as defined in Fig. B.1). The results in 1/3 octave bands for an infinitely hard surface and a grassy surface are presented in Fig. B.4, where the ground impedance data in Fig. B.3 has been used. [*B4*]. The corrections in octave bands for a source receiver distance of both 100 and 200 ft are presented in Table B.1. Table B.1 shows fairly significant differences in the corrections between the 200 and 100 ft distance, due primarily to the shift in frequency of the interference pattern. Consequently, we need examine, at least to first order, the final effect of ground interaction effects when assessing the contribution of reflections from

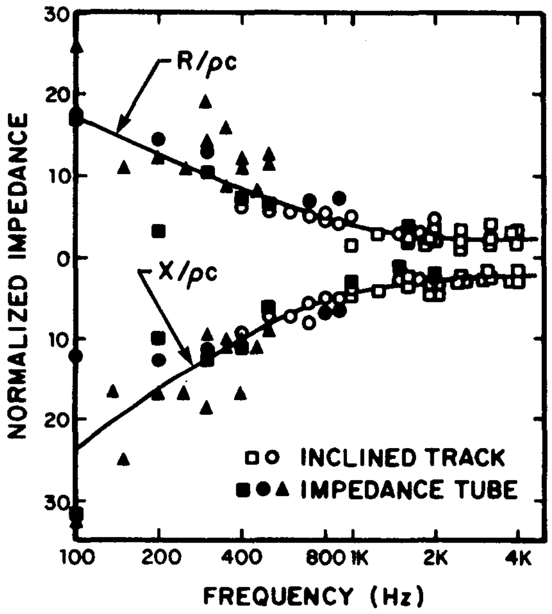

FIG. B3. REAL AND IMAGINARY COMPONENTS OF THE NORMAL SURFACE IMPEDANCE OF GRASS-COVERED FLAT GROUND [*B4*]

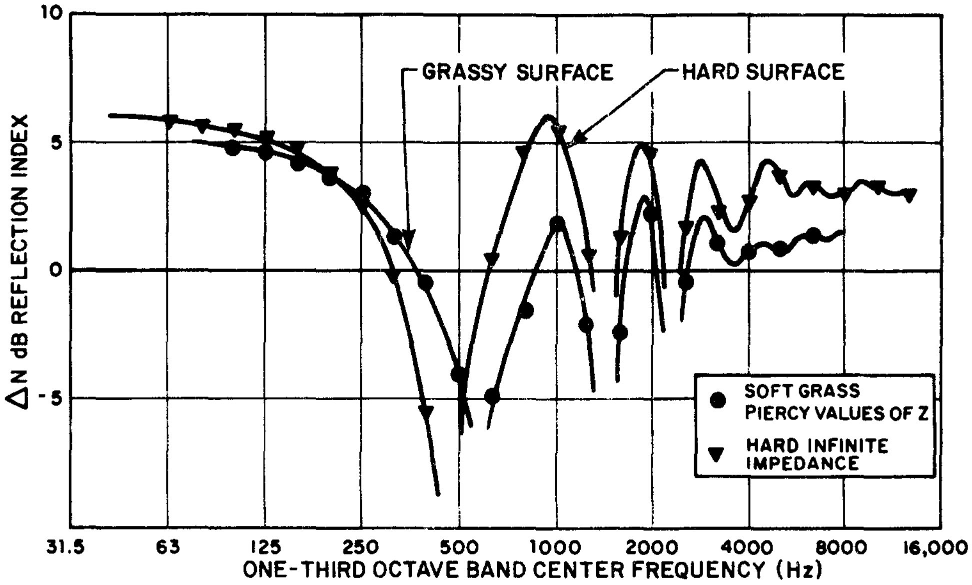

FIG. B4. GROUND REFLECTION INTERFERENCE PATTERNS FOR GRASS AND A HARD SURFACE IN 1/3 OCTAVE BANDS. (Source height 15 ft, receiver height 4 ft, source receiver distance 100 ft.)

TABLE B.1. GROUND INTERACTION FOR h_s = 15 FT AND h_r = 4 FT FOR AN INFINITELY HARD SURFACE AND GRASS FOR TWO SOURCE-RECEIVER DISTANCES IN OCTAVE BANDS

	d = 100 Ft		d = 200 Ft	
Frequency	Hard Surface (dB)	Grass (dB)	Hard Surface (dB)	Grass (dB)
125	5	4.7	5.8	4.1
250	2	2.8	5.1	3.2
500	-2.6	-2.9	2.1	0.1
1000	3.9	1.7	-2.7	-3
2000	3	0	3.8	2
4000	3	0.8	3	1.5

large surfaces to the measured noise. To do so we will use the model of Eq. B.1 and define the correction due to ground interaction to be $\Delta N_G(\omega,r)$ where $\Delta N_G(\omega,r)$ is the result of using Eq. B.1 for a source receiver path length r (Fig. B.1) to calculate the correction. The sound pressure spectrum $S_p^{(R)}(\omega)$ at the microphone due to the sound reflected from a building or other large surface then becomes

$$S_p^{(R)}(\omega) = S_p^{(C)}(\omega)\ \frac{e^{-2\gamma(\omega)\Delta r}}{(r_R/r_D)^2}\ 10^{\left[\frac{\Delta N_G(\omega,r_R)}{10} - \frac{\Delta N_G(\omega,r\ )}{10}\right]}$$

$$\Delta r = r_R - r_\Delta \qquad (B.2)$$

where $S_p^{(C)}(\omega)$ is the sound pressure spectrum at the microphone measured at the conforming site, r_R is the source receiver path length via the reflected path, and r_D is the source receiver path length via the direct path.* Equation B.2 has been obtained from the second term in Eq. 9 in the text. That second term is effectively the contribution of the reflected path to the measured sound in the absence of ground interaction. Equation B.2 allows for the ground interaction effects to be different for the direct and reflected path. Its validity depends on the fact that the direct and reflected path contributions can be added incoherently.

Expressing Eq. B.2 in terms of logarithms

$$L_p^{(R)}(\omega) = L_p^{(c)}(\omega) - 20\ \log(r_R/r_D) - \frac{\alpha(\omega)\Delta r}{1000} + \Delta N_G(\omega,r_R) - \Delta N_G(\omega,r_D) \qquad (B.3)$$

---

*r_D is the same path length for both conforming and typical site.

where r is in feet; $L_p^{(i)}(\omega) = 10 \log S_p^{(i)}(\omega)$, $i = R, C$; and Eq. B.3 is to be evaluated for each octave band. The sound pressure spectrum at the microphone then becomes

$$L_p^{(t)}(\omega) = L_p^{(c)}(\omega) \oplus L_p^{(R)}(\omega)^* . \tag{B.4}$$

Table B.2 shows the results of using Eqs. B.3 and B.4 to calculate the contribution of a reflected path (200 ft long) to the direct path at the 100 ft microphone. The terms $N_G(\omega,r)$ for the 100 ft direct path and the 200 ft reflected path were taken directly from Table B.1. The locomotive spectrum used is from an SD40-2 operating fully loaded at throttle 8 [*B10*]. The sum of the direct and reflected path contributions becomes

- 87.2 dBA – ignoring ground effects
- 87.4 dBA – including hard surface ground effects
- 87.3 dBA – including grassy surface ground effects.

TABLE B.2. CALCULATION OF THE REFLECTED PATH WITH AND WITHOUT THE GROUND EFFECT CORRECTION

Frequency	Locomotive Spectrum A-Weighted @ 100 Ft	Absorption Correction	20 Log r_R/r_D	$\Delta N_G(r_R)-\Delta N_G(r_D)$		$L_p^{(R)}(\omega)$		
				Hard Surface	Grass	No Ground Effect	Hard Surface	Grass
125	78.4	-	6	.8	- .6	72.4	71.6	71.8
250	68.4	-	6	3.1	+ .4	62.4	65.5	62.8
500	79.9	-.2	6	+4.7	+ .3	73.8	78.5	76.8
1000	81.1	-.2	6	-6.6	-4.7	74.9	68.3	70.2
2000	79.8	-.3	6	+ .8	2	73.5	74.3	75.5
4000	73.3	-.4	6	6	1.5	66.9	66.9	68.4
Overall	86.2					80.1	81.0	80.7

$^*A \oplus B = 10 \log\left(10^{\frac{A}{10} + \frac{B}{10}}\right)$.

Clearly, the influence of ground effects on the reflected path contribution is small. There are a number of reasons for this. First, the ground effect correction becomes significant only when the reflected path length is significantly larger than the direct path length. Under that circumstance, the reflected path contribution is small and the magnitude of the ground effect correction has little effect on the *sum* of the direct and reflected path contributions. Second, the ground effect correction is greatest in the mid-frequencies where the locomotive noise spectrum is fairly flat and where the correction in decibels tends to alternate in sign. Consequently, the correction will increase one frequency band but decrease the next. As a result the effect on the overall level when all the bands are added together is small.

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APPENDIX C: REPORT OF NEW TECHNOLOGY

During the course of the program, a technique was developed for assessing the contribution of load cell noise to the total measured locomotive. In addition, it was found that the requirements in the EPA Railroad Noise Emission Standards could be relaxed to some degree without seriously compromising the measurement of locomotive noise. We believe, however, that these discoveries and innovations do *not* represent patentable inventions.

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