WYLE LABORATORIES

WYLE RESEARCH
El Segundo, California

REPORT

WYLE LABORATORIES

DRAFT

WYLE RESEARCH REPORT

WR 80-5

TRUCK NOISE DEGRADATION
- FINAL REPORT -

For

U. S. ENVIRONMENTAL PROTECTION AGENCY
Office of Noise Abatement and Control
Arlington, VA 22202

(Contract No. 68-01-4414)

By

Jerry Thompson

WYLE RESEARCH
El Segundo, California 90245

JANUARY 1980

REPORT

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTORY SUMMARY

This report is the final submittal of data for a test program sponsored by the U. S. Environmental Protection Agency and aimed at evaluating the potential degradation of medium and heavy duty truck noise emission levels over a vehicle's life. This test program was first described in detail in Interim Technical Report I, submitted to EPA by Wyle Research in November 1978 in support of a technology impact analysis for revision of the interstate motor carrier emission regulations. This document presents the results of measurements and analyses performed since the first report. A detailed description of the full test program and a summary of the complete data base is provided in this report, therefore no reference to the original report is necessary.

The results of the test program indicate there is no single discernible trend with respect to degradation of truck noise levels. Within the population of vehicles monitored, there were examples of trucks exhibiting increasing, decreasing and constant noise levels over time.

A complete analysis of the test results is provided in the sections which follow. The most significant results may be summarized as follows:

- For the 26 trucks tested, the fleet average noise level measured using the "Idle-Max-Idle" test procedure remained essentially constant from the beginning to the end of the test sequence (81.2 versus 81.5 dB). However, the average maximum change between the first test and any subsequent test was 1.1 dB, indicating that, on the average, the trucks exhibited an increase followed by a decrease in total vehicle noise over the course of the measurements.

- About 60 percent (or 16) of the trucks tested completed more than 100,000 kilometers by the end of the program; two completed over 500,000 kilometers.

- Of the 26 trucks, six (or 23 percent) exhibited a measured increase in exterior noise level of 1 dB or more. Four of the trucks showed evidence of engine noise degradation, while two showed evidence of exhaust gas noise degradation.

- Of the trucks exhibiting noticeable increases in noise level, those employing 2-cycle diesel engines showed the most significant increases in comparison to 4-cycle diesel engines.
- All of the vehicles studied here met the appropriate noise emission standard for the year in which they were manufactured, both before and after extensive time in service.

The sections which follow provide a detailed summary of the test procedures (Section 2.0), a complete analysis of the resulting data (Section 3.0), a review of existing data on truck noise degradation (Section 4.0), and an assessment of the potential effects of vehicle maintenance and modification procedures which might influence truck noise degradation characteristics. Supporting information, including photographs of most of the test vehicles, is provided in Appendices A through C.

2.0 TEST PROGRAM

The field test program was designed to enable compilation of data on the degradation of truck noise emission levels for a representative sample of medium and heavy duty trucks. It consisted of noise measurements exterior to the vehicle during stationary and passby tests, and interior noise measurements at the driver's location during engine run-up tests. A description of the test vehicles and the associated measurement methodology is provided in this section.

2.1 Test Vehicles

The trucks tested in this study were actual in-service vehicles loaned by rental agencies, motor carriers, private haulers and owner-operators. To qualify for participation in the program, each vehicle was tested prior to placement in fleet service. By July 1978, a total of 30 trucks were participating in the noise degradation measurement program. Eight of these trucks were manufactured in 1978, while the remainder were manufactured in 1977. A description of each truck according to its key design parameters is provided in Table 1. Photographs of most of the test vehicles are provided in Appendix A. As will be discussed in Section 2.2, each vehicle was tested either at the owner's facility or at Wyle Laboratories' Norco, California test facility. The location of each truck noise test site is also listed in Table 1. Note that two of the vehicles which started the program, Numbers 11 and 12, were subsequently involved in accidents. Truck Number 12 was rebuilt and returned to service. A second test was performed with this vehicle. Twenty-six trucks were tested two or more times using the stationary test procedure (see Section 2.4). Final measurements were made in July of 1979.

Figure 1 illustrates the distribution of types of trucks involved in the program according to vehicle weight class, cab type and engine type. The total test sample included engine configurations manufactured by Cummins, Detroit Diesel, Caterpillar, Mack and International Harvester.

All of the trucks utilized in this test program were equipped with fan clutches, with the exception of Truck Numbers 10, 14, 16, 18 and 29. Vehicles having standard and automatic transmissions were included in the test sample.

Table 1

Vehicle Descriptions, Owners, and Test Site Locations

Truck No.	Manufacturer & Model	Engine Make & Model	Rated RPM	Exhaust System	No. of Axles	Type of Fan Clutch	Owner	Test Site Location
1	Peterbilt COE - H.D.	Cummins NTC-350 Turbo I-6, 4-cycle	2100	Single Vertical Right Side	3	Thermal Air Operated	National Car Rental	Norco, CA
2	Freightliner CONV 12062TGT - H.D.	Detroit Diesel DD6V92TT Turbo V-6, 2-cycle	2100	Single Vertical Right Side	3	Viscous	Redwing Carriers	Tampa, FL
3, 40	Freightliner CONV 12062TGT - H.D.	Cummins VT903 Turbo V-8, 4-cycle	2100	Single Vertical Right Side	3	Viscous	Redwing Carriers	Tampa, FL
4, 41	Freightliner CONV 12062TGT - H.D.	Detroit Diesel DD6V92TT Turbo V-6, 2-cycle	2100	Single Vertical Right Side	3	Viscous	Redwing Carriers	Tampa, FL
5	Freightliner CONV 12062TGT - H.D.	Cummins VT903 Turbo V-8, 4-cycle	2100	Single Vertical Right Side	3	Viscous	Redwing Carriers	Tampa, FL
6	Freightliner COE H.D.	Detroit Diesel DD6V92TT Turbo V-6, 2-cycle	2300	Single Vertical Right Side	2	Viscous	Consolidated Freightliners	Santa Fe Springs, CA
7	Ford CONV C-600 - M.D.	Ford Gas V361 Naturally Aspirated	4300	Single Horizontal Right Side	2	Viscous	Post Office	Riverdale, MD
8	Ford CONV C-600 - M.D.	Ford Gas V361 Naturally Aspirated	4300	Single Horizontal Right Side	2	Viscous	Post Office	Riverdale, MD
9	Freightliner COE H.D.	Cummins VT903 Turbo V-8, 4-cycle	2500	Single Vertical Right Side	2	Viscous	Consolidated Freightliners	Santa Fe Springs, CA
10	International Harvester CONV 2050 - H.D.	Caterpillar 3208 Naturally Aspirated V-8, 4-cycle	2900	Single Vertical Right Side	3	None Direct Drive	Caltrans	Cajon, CA
11	General Motors - H.D.	Detroit Diesel DD 6V92TT Turbo V-6, 2-cycle	2200	Single Vertical Right Side	2	Thermal Air Operated	Arrowhead Water	Norco, CA

Table 1 (Continued)

Truck No.	Manufacturer & Model	Engine Make & Model	Rated RPM	Exhaust System	No. of Axles	Type of Fan Clutch	Owner	Test Site Location
12	White CONV Road Boss II - H.D.	Cummins NTC 290 Turbo I-6, 4-cycle	2100	Single Vertical Right Side	3	Thermal Air Operated	Burlington Industries	Burlington, NC
13	White COE Road Commander H.D.	Cummins NTC 290 Turbo I-6, 4-cycle	2100	Single Vertical Right Side	3	Thermal Air Operated	Burlington Industries	Burlington, NC
14	International Harvester CONV Loadstar 1750 - M.D.	International Harvester D-190DT-466 Turbo I-6, 4-cycle	2900	Single Vertical Right Side	2	None Direct Drive	National Car Rental	Norco, CA
15	White CONV Road Boss II - H.D.	Cummins NTC 290 Turbo I-6, 4-cycle	2100	Single Vertical Right Side	3	Thermal Air Operated	Burlington Industries	Burlington, NC
16	General Motors CONV P800 Van - M.D.	General Motors 292, Gas I-6 Naturally Aspirated 4-cycle	3600	Single Horizontal Left Side	2	None Direct Drive	U.P.S.	Orlando, FL
17	Mack CONV Dump - H.D.	Mack Turbo I-6 4-cycle	2300	Single Vertical Right Side	2	Viscous	Caltrans	Groveland, CA
18	International Harvester CONV Paystar 5000 - H.D.	Cummins NTC 250 Turbo I-6, 4-cycle	2100	Single Vertical Right Side	2	None Direct Drive (Had Shutters)	Caltrans	Whitmore, CA
19, 20, 27, 28	General Motors CONV 6000 - M.D.	General Motors 114-366, Gas V-8 Naturally Aspirated	3800	Dual Horizontal	2	Viscous	Arrowhead Water	Norco, CA
21, 22	Mack CONV H.D.	Mack 675 Turbo I-6, 4-cycle	2300	Single Horizontal Right Side	2	Viscous	U.P.S.	Charlotte, NC
23, 24, 25, 26	Mack CONV R686 - H.D.	Mack T676 Turbo I-6, 4-cycle	2350	Single Vertical Right Side	3	Thermal Air Operated	Matlack	Swedesboro, NJ
29	International Harvester CONV Paystar 5000 - H.D.	Cummins NTC 250 Turbo I-6, 4-cycle	2300	Single Vertical Right Side	2	None Has Shutters	Caltrans	Whitmore, CA
30	General Motors COE Astro 95 - H.D.	Cummins NTC 270 Turbo I-6, 4-cycle	2300	Single Horizontal Right Side	2	Thermal Air Actuated	U.P.S.	Earth City, MO

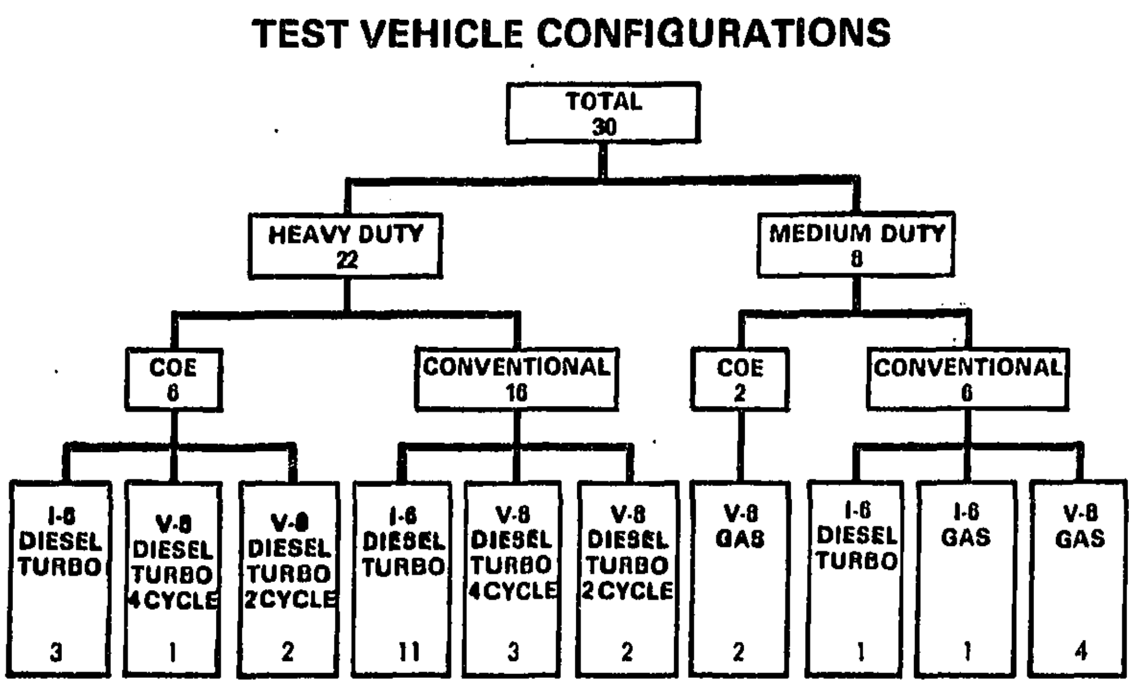

Figure 1. Test Vehicle Configurations

2.2 Test Sites

When possible, truck noise measurements were performed using the test pad located at Wyle Laboratories' test facility in Norco, California. However, to facilitate the utilization of trucks supplied by motor carriers and private haulers, noise measurements were also conducted with the use of a temporary standard test site setup at the vehicle owners' respective terminals.

Figure 2 shows the test pad used for stationary measurements at the Wyle/Norco facility. It consists of a circular asphalt surface 36.5 m (120 ft) in diameter. This site was developed in accordance with the specifications set forth in Section 205.54-1 of the EPA Noise Emission Standards for New Medium and Heavy Duty Trucks.[1] The test surface was constructed according to EPA paving specifications outlined in Appendix B of this report.

An underground ducting system was constructed with the pad to allow for component noise measurements. Intake air was drawn through a 30.5 cm (12 in) diameter steel pipe, with air entering 12 m (40 ft) from the edge of the pad and exiting at the center of the site. A 20 cm (8 in) diameter steel pipe was similarly used to route exhaust gases underground and away from the pad. The duct openings at the edge of the pad were shielded by a 1.2 m (4 ft) berm to assure that each source was 10 dB below the measured truck noise levels. Figure 3 illustrates how the ducting system was attached to a truck.

A majority of the trucks were tested at the vehicle owners' facilities, thereby resulting in the use of test sites located in the west, midwest, and east. Photographs of some of the test sites are provided in Appendix A. In all cases, care was taken to select a test site for stationary testing that met the specifications set forth in Subpart E of the DOT Regulations for Enforcement of Motor Carrier Emission Standards,[2] and a test site for passby measurements that met the specifications set forth in the EPA New Truck Noise Emission Standards.[1] All tests were performed on hard surfaces consisting of either asphalt or concrete. With the exception of one site, sufficient space was available to ensure that there were no obstacles within 30 m (100 ft) of the microphone or test zone. The exception was the CALTRANS facility at Cajon, California (Truck Numbers 18 and 29). Here, only 24.4 m (80 ft) of clear space was available between the microphone and the nearest obstacles. This was considered sufficient to avoid significant

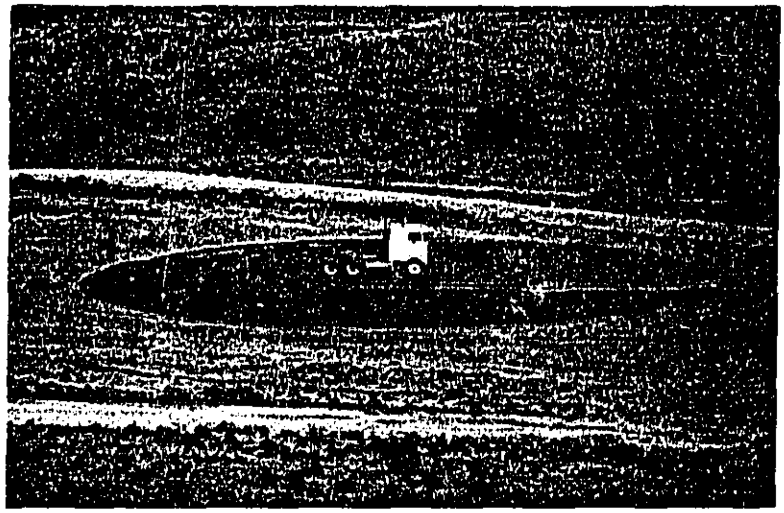

Figure 2. Norco Stationary Test Site

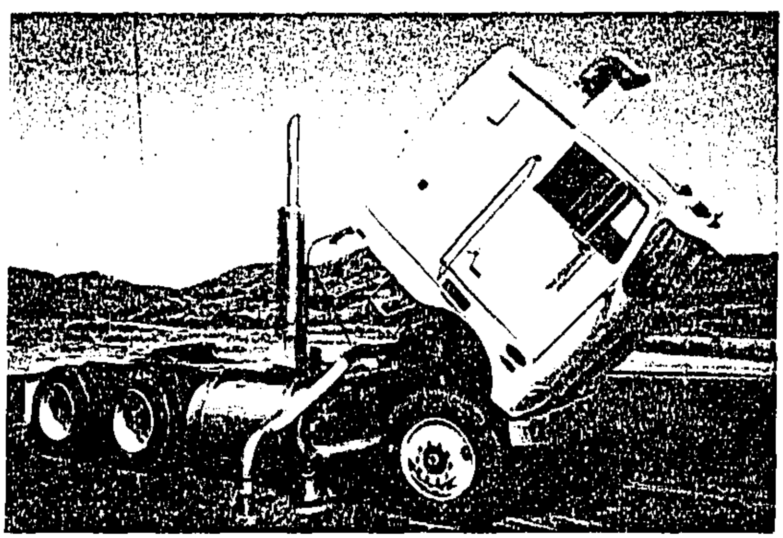

Figure 3. Close-up of Underground Duct Attachment with Truck Number 1 in Place

changes in measured noise levels. At each facility the vehicle and microphone positions were permanently established by painted markers, thus assuring repeatability of site characteristics from test to test.

Seven of the field test sites were large enough to allow performance of passby tests. Local highways were used for passby testing at Norco, California, Groveland, California, and Earth City, Missouri.

2.2.1 Stationary Tests

For stationary run-up noise tests, measurements were made at the four microphone positions shown in Figure 4. Each microphone was positioned 15 m (50 ft) from the center of the front axle, and 1.2 m (4 ft) above the ground plane. A-weighted noise levels, using the fast meter response, were read on a precision (Type 1) sound level meter at either measurement position A or C (illustrated in Figure 4) for each test sequence. Tape recordings of broad-band noise were made simultaneously for all four positions. The number of microphone positions was reduced from four to two (positions A and C) for some vehicles because of time limitations. Measurements were made in succession at each position with a sound level meter and tape recorder. From these sound level meter data, maximum A-weighted noise levels were tabulated for each microphone position for each test run. Note that each truck was always tested at the same site using the identical vehicle/microphone geometry.

2.2.2 Passby Tests

Figure 5 illustrates the site plan used for passby testing. At each site a clean test zone with a diameter of 30 m (100 ft) was established. The center point of the test zone was established as the "microphone point." A truck acceleration point was established on the vehicle path 30 m (100 ft) from the endpoint of the test zone and 15 m (50 ft) from the microphone centerline point. An end or test zone was established as the last 12 m (40 ft) of the vehicle path prior to the end point.

A-weighted noise levels, using the fast meter response, were read on a precision (Type 1) sound level meter for each passby sequence. Tape recordings of broadband noise were also made for each run. Maximum A-weighted noise levels read from the sound level meter were tabulated for each microphone position for each test run. As with the stationary tests, each truck was always tested at the same site using the identical vehicle/microphone geometry.

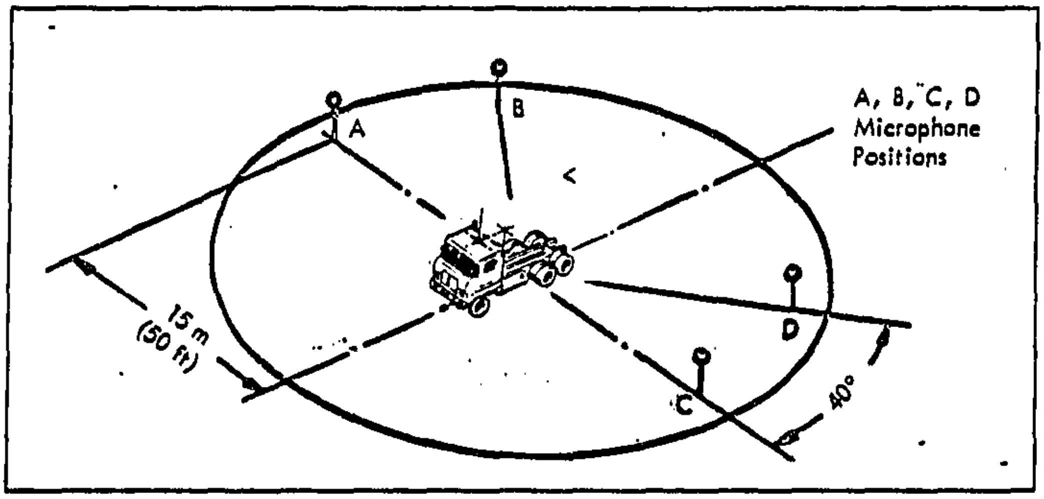

Figure 4. Microphone Positions for Stationary Testing

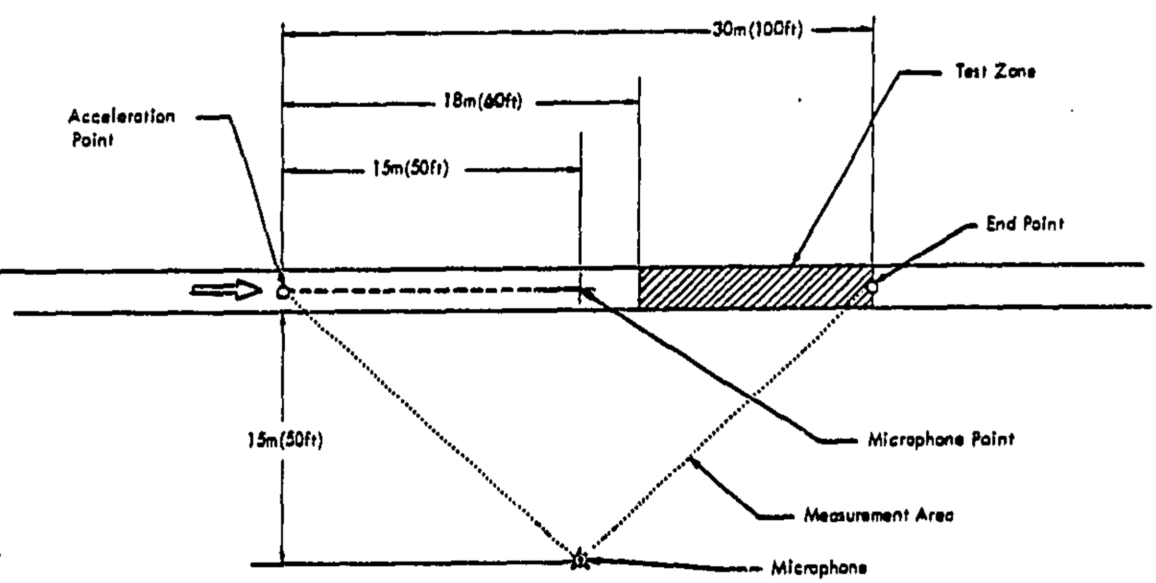

Figure 5. Passby Test Site Configuration and Microphone Position

2.2.3 Interior Tests

During interior noise measurements, the microphone was oriented 15 cm (6 in.) to the right of, and at the same height as, the driver's right ear. A-weighted noise levels, using the fast meter response, were read on a precision (Type I) sound level meter for each run-up sequence. Tape recordings of broadband noise were made for each run. From these data, A-weighted noise levels with the engine in a stabilized speed condition were acquired.

2.3 Test Instrumentation

All instrumentation used in this test program met the specifications defined in Sections 205.54-1 and 205.54-2 of the EPA Noise Emission Standards for New Medium and Heavy Duty Trucks.[1] This includes the instrumentation listed in Table 2. Primary data were obtained using a precision (Type I) sound level meter (specified in ANSI S.14-1971), while simultaneously the data were recorded on a Nagra IV SJ tape recorder. This backup system used a separate ½-inch condenser microphone in a system meeting all requirements of SAE J184, "Qualifying a Sound Data Acquisition System," 1972. Calibration of both the sound level meter (SLM) and tape recorder were obtained using a B&K 4230 acoustic calibrator. The 94 dB SPL, 1 kHz signal provided a means of accurately adjusting the sensitivity of the SLM, and was also recorded on tape. The data recorded on tape were later analyzed in the laboratory to confirm the levels measured in the field. These dual measurements with corresponding calibrations produced data with high validity.

2.4 Test Procedures

The test program was designed to obtain stationary run-up, passby, and interior noise level measurements from each of the test vehicles. In conducting these tests, the following standard test procedures were employed:

- o Stationary run-up tests were performed in accordance with the procedures provided in Subpart E of the DOT Regulations for the Enforcement of Motor Carrier Noise Emission Standards.[2] These regulations specify that the fan clutch be disengaged during the test.

Table 2

Primary Instrumentation Used for
Truck Noise Degradation Tests

1.	Bruel & Kjaer Type I Sound Level Meter (Model 2203) with a 1-inch type 4145 microphone.
2.	Recording System:
	o Nagra IV SJ Recorder
	o Bruel & Kjaer 1/2-inch type 4134 Microphone
	o Kudelski Preamplifier
3.	Bruel & Kjaer Calibrator Model 4230
4.	Engine Speed Tachometer accurate to within ± 2 percent of meter reading.
5.	Meteorological instrumentation to record temperature, humidity, and wind.

- o Passby tests were performed according to the procedures outlined in the EPA Noise Emission Standards for New Medium and Heavy Duty Trucks.[1]
- o Interior measurements were conducted in accordance with the procedures set forth in the DOT Regulations for Vehicle Interior Noise Levels.[3]

Six noise measurements were made for each test sequence.

In conducting all of the above described measurements, the following general test methodology was employed for each test vehicle:

1. At the outset of testing, information was obtained regarding the truck's specifications and the type of service in which it was typically used.
2. A set of stationary run-up, passby, and interior noise measurements were performed on each truck prior to its initial entry into fleet service.
3. Initially, it was established that each vehicle would be subjected to an identical set of noise level measurements at the following approximate accumulated mileage:
   - o 16,000 km (10,000 mi)
   - o 32,000 km (20,000 mi)
   - o 80,000 km (50,000 mi)
   - o 160,000 km (100,000 mi)
   - o 240,000 km (150,000 mi)
   - o 320,000 km (200,000 mi)

   Later, however, it was determined that it would be more convenient for the truck owners if testing was performed on a time interval basis (e.g., monthly). Therefore, a time interval was established that would enable at least three sets of measurements to be performed on each truck prior to completion of the test program. Table 3 summarizes the mileages at which noise measurements were performed on each vehicle.

Table 3

Mileage at Each Test Sequence for All Trucks
(kilometers)

Truck Number	Test Number					
	1	2	3	4	5	6
1	1,970	51,200	201,400	261,400	333,700	
2	40	49,000	108,700	184,000	193,800	268,500
3	43	57,500	109,300	181,700	201,400	281,100
4	91	36,400	92,100	144,100	217,700	270,200
5	37	59,000	118,500	183,100	229,500	317,600
6	1,700	127,200	344,900	501,600		
7	520	28,200	60,000	97,000		
8	600	11,300	56,300	69,100		
9	1,600	214,700	513,400			
10	700	11,900				
12	3,800	278,200				
13	13	82,000	163,600	222,400	249,500	
14	1,200	22,600	23,900	72,800		
15	200	62,000	120,800	215,700	346,400	
16	700	6,900	10,700	21,000		
17	3,900	11,300	16,000			
18	1,040	11,000				
19	20					
20	29					

Table 3 (Continued)

Truck Number	Test Number					
	1	2	3	4	5	6
21	1,100	38,000	140,800	344,100		
22	1,040	36,100	140,800	345,400		
23	1,700	29,200	46,800	115,100		
24	2,400	56,300	136,600			
25	3,090	36,900	68,900	157,200		
26	2,790	36,600	66,200			
27	18	130	32,600			
28	27	230	12,800			
29	340	10,900				
30	50	40,300	89,200	263,800		

4. When test site geometry and truck fleet scheduling permitted, idle-max-idle (IMI) tests were also performed under the following conditions:

   - Truck in "as delivered" condition;
   - Truck exhaust connected to remote ducting system;
   - Engine fan clutch fully engaged.

For eight of the 30 trucks, it was possible to obtain passby and IMI noise data from tests conducted by the truck manufacturers at their respective facilities. The data were measured using essentially the same test procedures employed in this study. These data are presented in this report for comparative purposes.

Maintenance sheets from each vehicle were reviewed at each test interval to determine compliance with manufacturer's recommended maintenance procedures. Particular attention was given to noise generating components such as the exhaust, intake and cooling system, and special equipment installed for noise control purposes.

The degradation of the total vehicle noise as a function of exhaust components and nonexhaust components was evaluated based upon the noise levels measured over an operating period of approximately 240,000 km (150,000 mi). Results of this evaluation are presented in the section which follows.

2.5 Component Noise Degradation Testing

In addition to the measurements described above, a selected number of vehicles were subjected to component noise source measurements designed to better identify the contribution, if any, of engine, fan, intake and exhaust noise degradation to total truck noise degradation. Two series of measurements were undertaken. In the first series, emphasis was placed on evaluation of the effects of exhaust system deterioration on total truck noise levels. Eleven vehicles were tested in a configuration which allowed for removal of exhaust gas noise from the measured environment. Truck Numbers 1, 14, 27 and 28 were tested in this manner using the previously described ducting system at the Wyle/Norco facility (see Figure 3). Truck Numbers 2, 3, 4 and 5 were tested at Redwing Carrier's facility in Tampa, Florida, using a 20-foot length of flexible ducting and a muffler attached to the exhaust stack (see Appendix A). Truck Numbers 7 and 8 were tested at

Riverdale, Maryland, with a 25-foot length of flexible ducting attached to the exhaust pipe. The flexible duct was routed toward the front of the vehicle (see Appendix A). Truck Number 6, tested at Santa Fe Springs, California had a 20-foot flexible duct attached to the exhaust stack. It was routed toward the opposite side of the vehicle from where the microphone was positioned. In this manner, the truck acted as a shield to help mask out exhaust gas noise.

In a second series of measurements, Truck Numbers 1 and 14 were subjected to a detailed set of component noise measurements in which the fan intake, and exhaust noise components were each eliminated in succession, thus providing measurements of the following configurations:

- Total vehicle noise
- Engine noise only
- Engine plus fan noise only
- Engine plus exhaust noise only
- Engine plus intake noise only.

Elimination of the intake and exhaust noise components was accomplished using the ducting systems available at the Wyle/Norco facility, while elimination of fan noise was accomplished by disengaging the fan clutch. Note, however, that elimination of fan noise on Truck Number 14 was not possible because it used a fixed fan.

The test methodologies employed here were identical to those used previously for total vehicle noise. Only stationary tests were performed. For each configuration tested, four sets of measurements were performed. These data are summarized and evaluated in Section 3.0.

3.0 TEST RESULTS

3.1 Total Vehicle Noise Levels

A summary of the truck noise level data acquired in this test program as well as data obtained from the truck manufacturers is presented in Table 4. All values shown represent arithmetic averages of the two highest levels recorded during each test sequence. Close duplication of the site characteristics and calibration procedures between tests eliminated the need to apply data correction factors, with the exception of Truck Numbers 6 and 9, where a 1.5 dB correction was added to the right side measurements in Test Number 4 to compensate for a partial soft site. This correction factor was determined by testing Truck Number 6 at the Santa Fe Springs facility and then repeating the test on the same day at the Wyle/Norco facility. The difference in the measured noise levels was then applied as the correction factor for Test Number 4.

The effects which ambient temperature variations might have had on the repeatability of truck noise measurements were considered using the following relationship:[4]

$$C = +15 \log \frac{T\,(^{\circ}F) + 459}{T_o\,(^{\circ}F) + 459} \quad ,\text{dB}$$

where

C = Ambient temperature correction factor for diesel engine noise (dB)

T = Ambient temperature during second measurement ($^{\circ}$F)

and

T_o = Ambient temperature during first measurement ($^{\circ}$F)

Using the above correction factor, there is an indicated temperature-induced variation of 0.25 dB/20°F. The maximum temperature differences occurring during this program were in the range of 20°F. Therefore, the effects of temperature variations were considered secondary.

Noise degradation curves have been plotted by using the highest average noise level for each test sequence regardless of whether it was measured on the right or left side of the vehicle. In some instances these values did vary by more than 2 dB from one side to the other.

Table 4

Summary of Truck Noise Degradation Test Results*

Truck Number	Factory Test				Test 1						Test 2						Test 3						Test 4					
	Pass-By		IMI		Pass-By		IMI		Exhaust Relocated		Pass-By		IMI		Exhaust Relocated		Pass-By		IMI		Exhaust Relocated		Pass-By		IMI		Exhaust Relocated	
	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	
1					77.6	76.3	78.3	77.0	77.0	75.7			77.1	76.8	76.2	76.2			78.0	78.0					77.5	77.7	76.0	7
2	81.0	81.0	80.0	79.5	79.9	79.6	80.6	78.1	78.7	77.2	84.2	82.8	82.0	80.8	79.0	78.0			82.7	81.6	78.4	78.9			82.8	81.0	79.0	7
3	83.0	82.0	84.0	84.0	84.2	83.0	85.1	84.3	85.9	85.5	84.5	84.7	86.1	87.2	85.2	86.6			85.0	85.7					86.8	84.2	86.0	8
4	82.0	81.5	81.0	80.5	79.4	78.8	80.6	79.0	78.3	77.3	82.7	82.3	82.2	81.1	78.6	77.8			81.2	80.7	78.6	78.6			83.5	82.6	80.8	7
5	83.0	83.0	84.5	85.0	82.5	81.8	84.4	84.8	84.3	84.2	84.2	82.9	85.7	86.8	86.0	86.8			85.1	85.6	85.6	86.6			86.8	86.2	86.0	8
6							80.4	79.9					86.2	85.7	80.0	79.2	86.2	86.5	83.6	82.8			85.5	85.3	83.2	82.6	80.2	7
7					79.6	77.2	79.6	77.3	78.8	78.0			79.9	79.4	79.3	78.1	77.9	78.3	79.6	79.8	79.2	78.4	81.1	79.7	80.0	79.8	79.2	7
8					74.6	73.9	76.2	74.7	74.2	75.1			77.8	78.3	78.0	78.5	77.1	76.4	79.4	81.3	80.7	80.0	81.2	80.2	84.1	83.7	83.4	8
9					85.3	84.5	86.0	85.2					86.2	85.0			83.5	81.0	84.6	80.5								
10					85.4	83.2	85.0	82.3					85.0	83.0														
11							80.7	78.3																				
12					77.7	78.4	79.7	79.3			80.4	80.7	81.3	80.7														
13					78.6	78.4	80.6	80.5					79.3	78.9					80.4	79.2			79.8	79.7	79.0	80.1		
14							81.9	81.0	80.9	81.0			83.7	81.2					83.8	82.5	82.8	82.3			80.0	81.0		
15					79.0	79.0	79.5	79.3					77.2	76.5					82.3	81.5					79.4	79.3		
16					77.0	78.0					77.5	80.5					76.5	79.8					75.4	77.7				
17					76.4	77.0	76.5	75.0					77.5	76.0			76.5	75.6	77.3	74.4								
18							81.3	82.1					81.2	79.7														
19	78.1	78.2	77.9	78.1			76.1	77.0	(No Body)																			
20	77.9	79.3	78.8	78.8			75.8	77.5	(No Body)																			

* All values are A-weighted sound levels in decibels (dB)

Table 4 (Continued)

Truck Number	Factory Test				Test 1						Test 2						Test 3						Test 4 *					
	Pass-By		IMI		Pass-By		IMI		Exhaust Relocated		Pass-By		IMI		Exhaust Relocated		Pass-By		IMI		Exhaust Relocated		Pass-By		IMI		Exhaust Relocated	
	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
21							79.3	78.3					77.8	77.4					80.3	79.6					80.6	80.9		
22							79.5	79.2					79.0	77.5					80.3	80.7					81.5	81.3		
23							81.5	80.6					81.0	80.7					80.8	80.2					80.1	80.0		
24							81.2	79.8					79.8	79.2					81.4	81.0								
25							81.8	80.0					83.0	81.0					81.7	81.7					80.7	80.8		
26							81.5	80.1					81.6	80.5					80.1	79.8								
27	77.7	77.4	77.7	78.5			78.2	77.2	(No Body)				79.7	80.2	79.2	79.7			77.9	77.3								
28	78.6	79.2	77.9	77.6			78.0	77.3	(No Body)				83.2	83.7	83.2	82.7			80.1	77.8	75.1	76.5						
29							85.2	84.2					81.1	81.2														
30					80.6	79.8	79.6	80.1					79.2	80.4					78.2	79.4			80.0	80.1	79.1	79.3		

*No further tests of the vehicles occurred.

Table 4 (Continued)

Truck Number	Test 5						Test 6					
	Pass-By		IMI		Exhaust Relocated		Pass-By		IMI		Exhaust Relocated	
	R	L	R	L	R	L	R	L	R	L	R	L
1			77.7	77.4	76.2	77.2						
2	81.5	81.2	81.0	79.7	79.5	77.6	82.4	81.9	82.7	80.2	77.7	78.0
3	83.4	83.9	82.3	82.6	81.5	81.9	83.6	83.2	84.0	84.2	83.9	84.3
4	83.1	81.5	80.8	79.7	76.9	76.6	81.9	81.4	81.1	79.2	72.0	77.2
5	83.5	84.2	83.4	83.6	82.0	83.9	83.8	83.5	84.4	85.4	84.5	85.5
6												
7												
8												
9												
10												
11												
12												
13	81.9	81.9	84.4	84.1								
14												
15	80.6	80.1	80.2	80.2								
16												
17												
18												
19												
20												

Figures 6 through 14 illustrate the noise level of the test vehicles as a function of kilometers of accumulated travel. Three curves have been plotted for those trucks which data for IMI and passby testing were also obtained. The two curves for IMI testing represent data acquired from the vehicle in the normal operating condition, and with the exhaust gas ducted away.

In reviewing these curves, it should be remembered that:

- o An increase in total vehicle noise with engine-related noise remaining constant indicates the change is the result of increased exhaust gas noise levels.
- o An increase in total vehicle noise <u>and</u> engine-related noise levels signifies that the change is the result of increased engine noise.

Further analysis and interpretation of the noise level data compiled in Table 4 is presented in the sections which follow.

3.2 <u>Comparison of Truck Noise Levels to Federal Noise Emission Standards</u>

Of the 26 vehicles subjected to two or more IMI tests, eight vehicles (Numbers 21 through 28) were manufactured in 1978 and, therefore, were required by the EPA New Truck Noise Emission Standards to exhibit an A-weighted exterior noise level of 83 dB or lower. The remaining 18 test vehicles were manufactured in 1977 and thus were required to meet the maximum A-weighted sound level standard of 90 dB specified in the Interstate Motor Carrier Noise Emission Standards.

With this in mind, Figure 15 presents a distribution of the measured stationary noise levels for the entire population of test vehicles. The upper graph is plotted from Test Number 1 data, while the lower graph is plotted from the final test results. The 83 dB level is delineated for easy reference, and levels have been rounded to the nearest dB. <u>All the trucks easily met the noise standards of the year in which they were manufactured, both before and after extensive time in service.</u> Of the six 1977 trucks which exceeded the 1978 standard at the beginning of the test, four remained in violation at the end and were joined by four more 1977 trucks which previously had met the standard. Of the 1978 trucks, only one (28) exceeded 83 dBA during any part of its service and the rest never rose closer than 1 dBA to the standard.

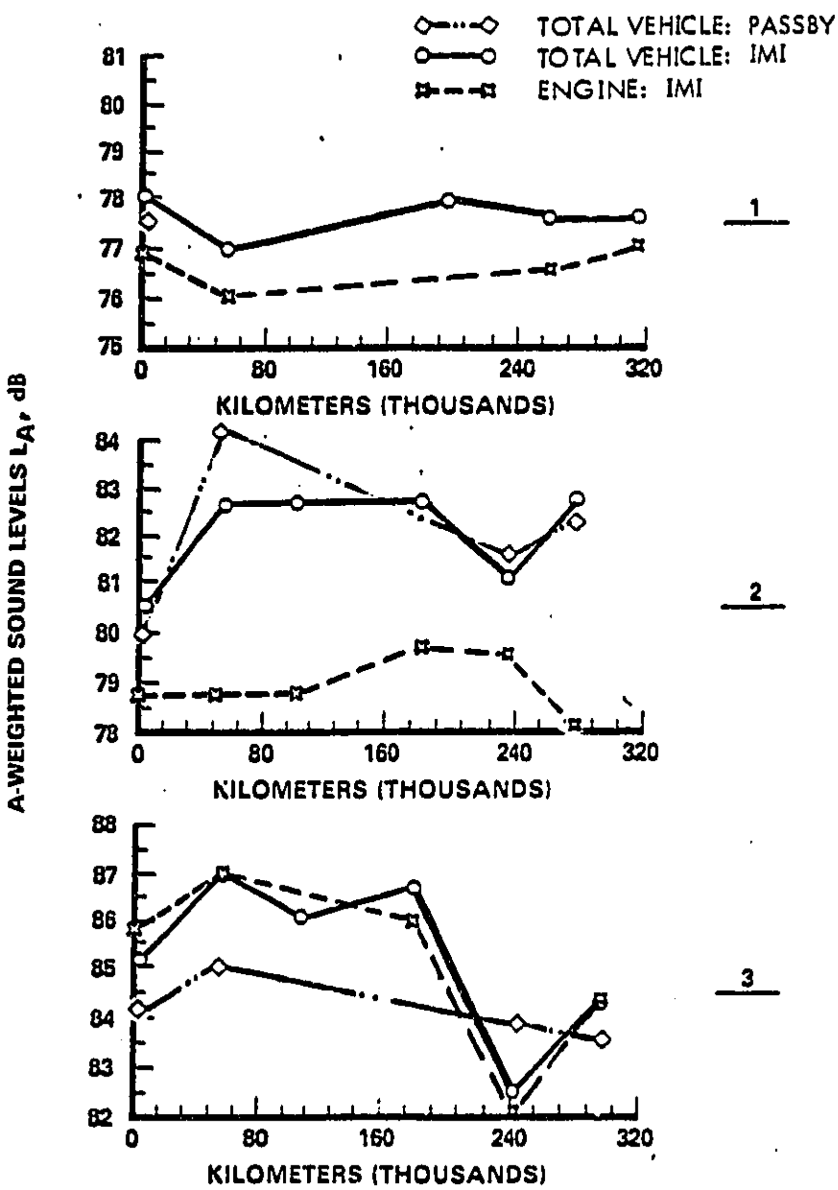

Figure 6. Vehicle Exterior Noise Levels versus Cumulative Kilometers

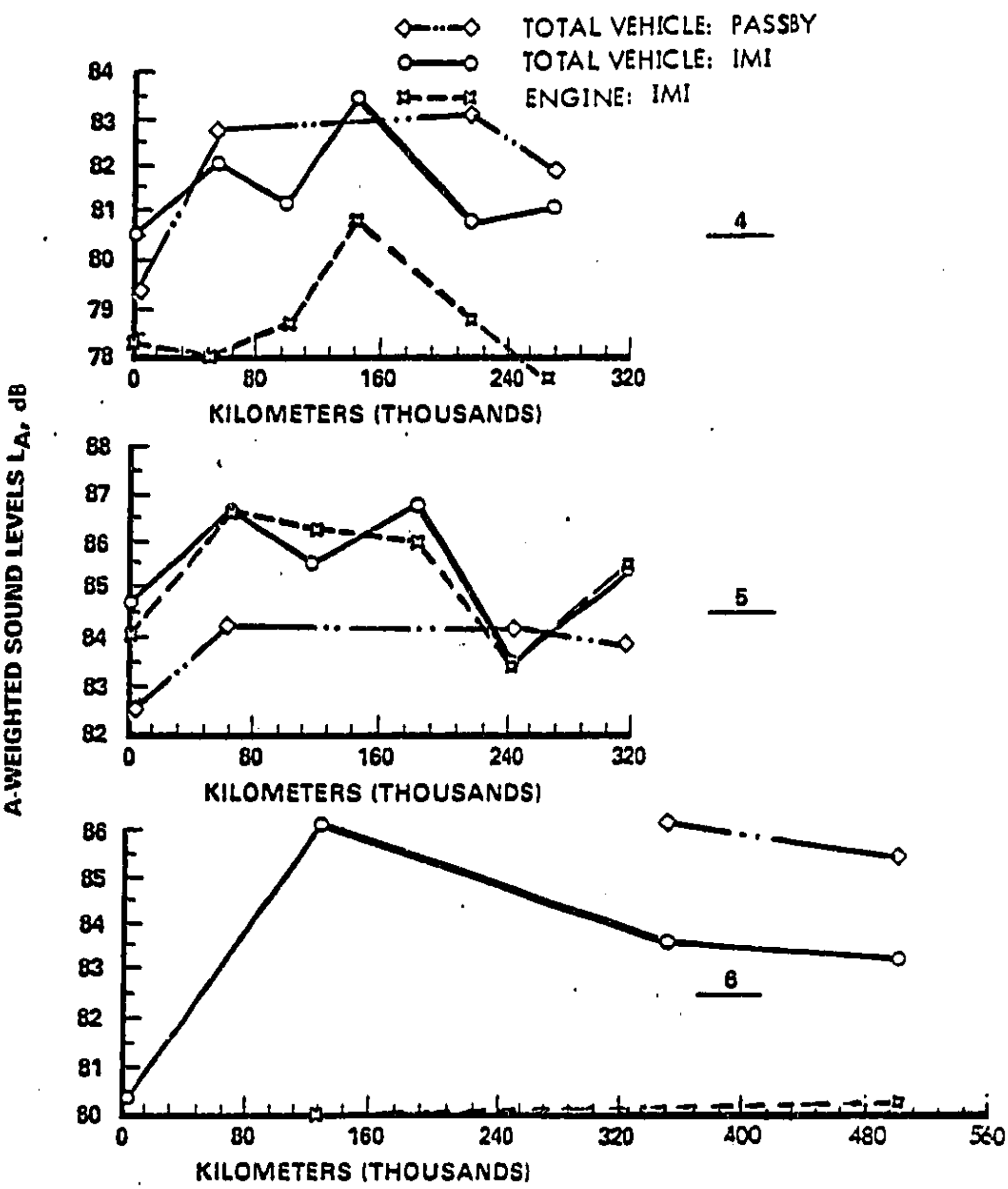

Figure 7. Vehicle Exterior Noise Levels versus Cumulative Kilometers

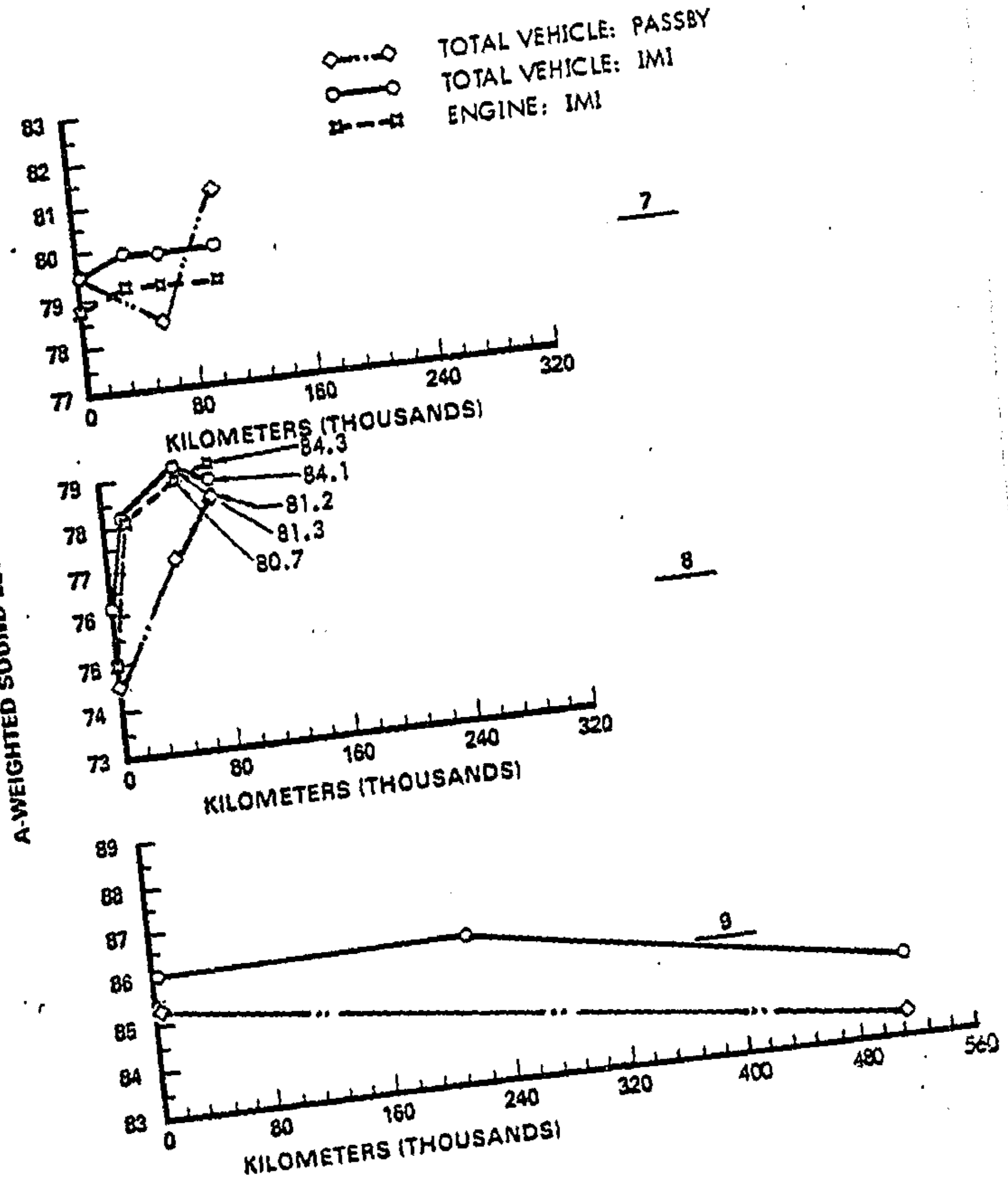

Figure 8. Vehicle Exterior Noise Levels versus Cumulative Kilometers

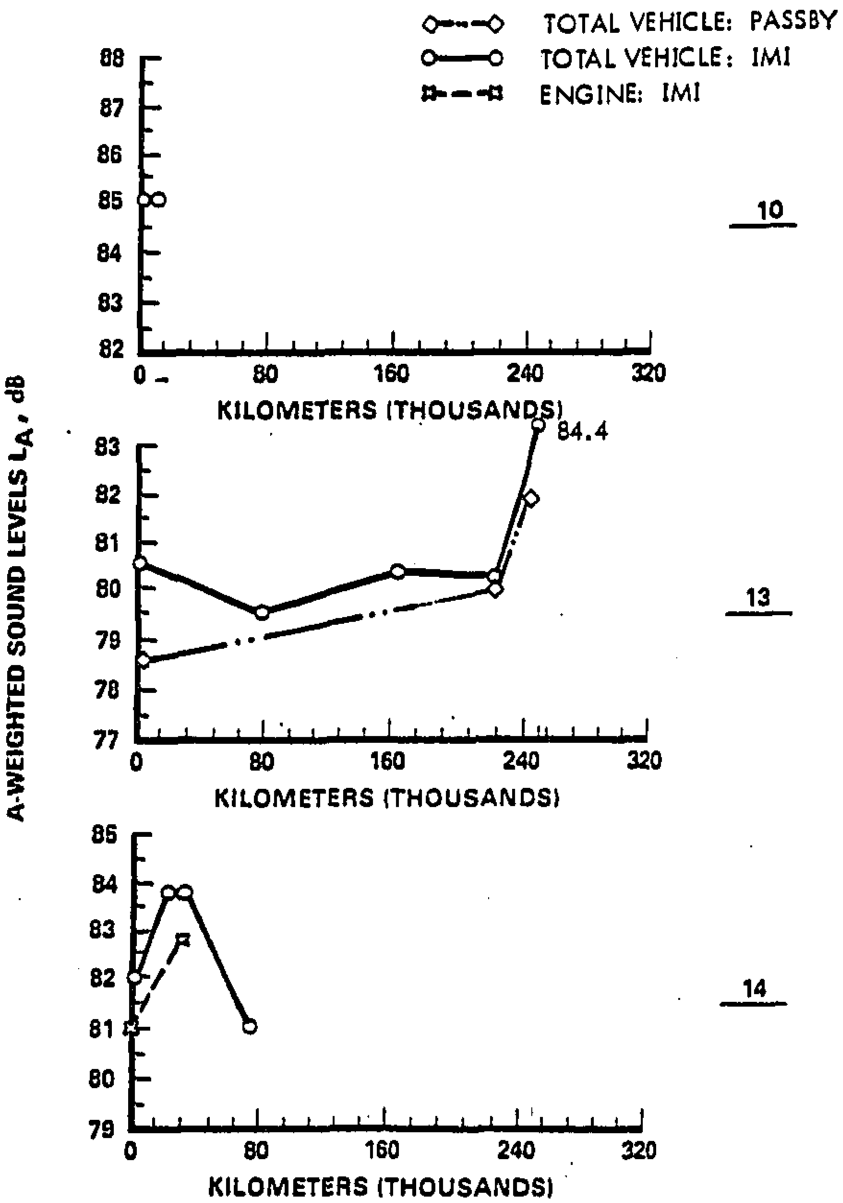

Figure 9. Vehicle Exterior Noise Levels versus Cumulative Kilometers

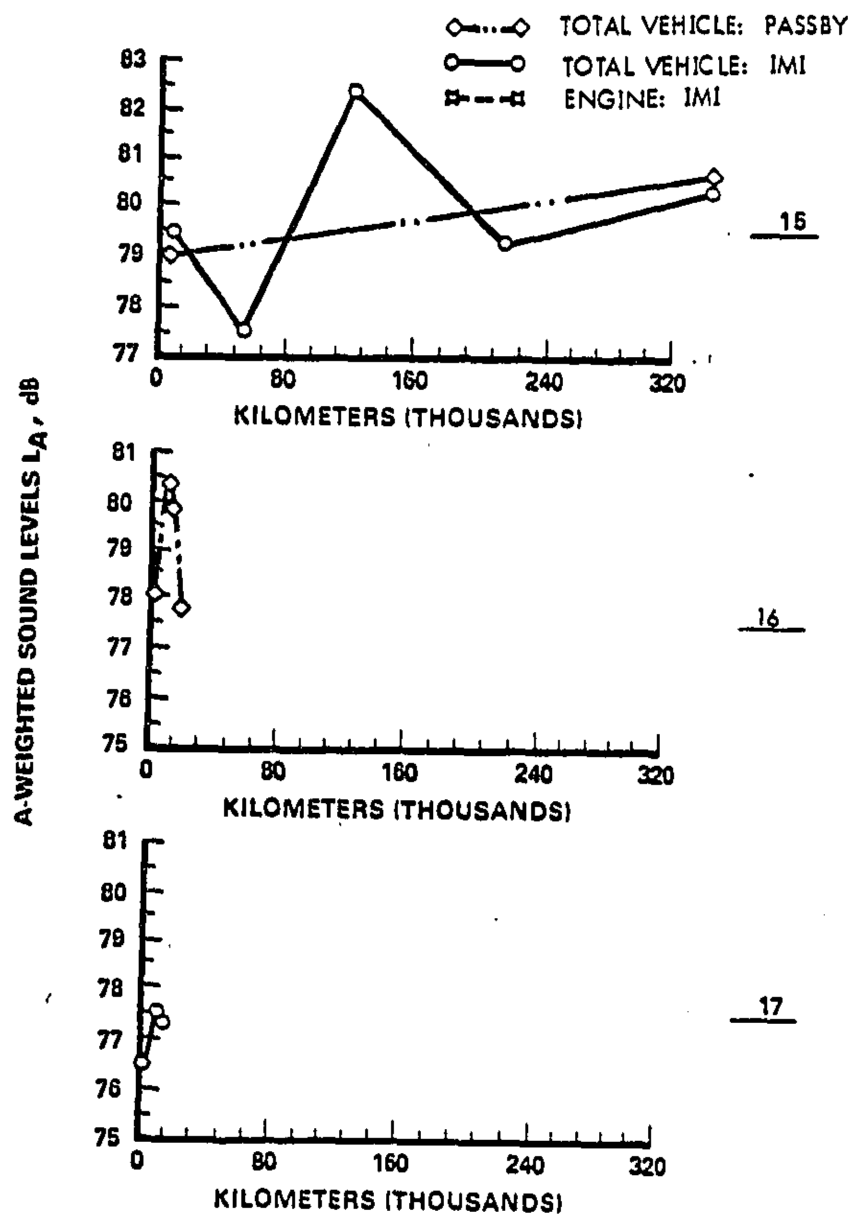

Figure 10. Vehicle Exterior Noise Levels versus Cumulative Kilometers

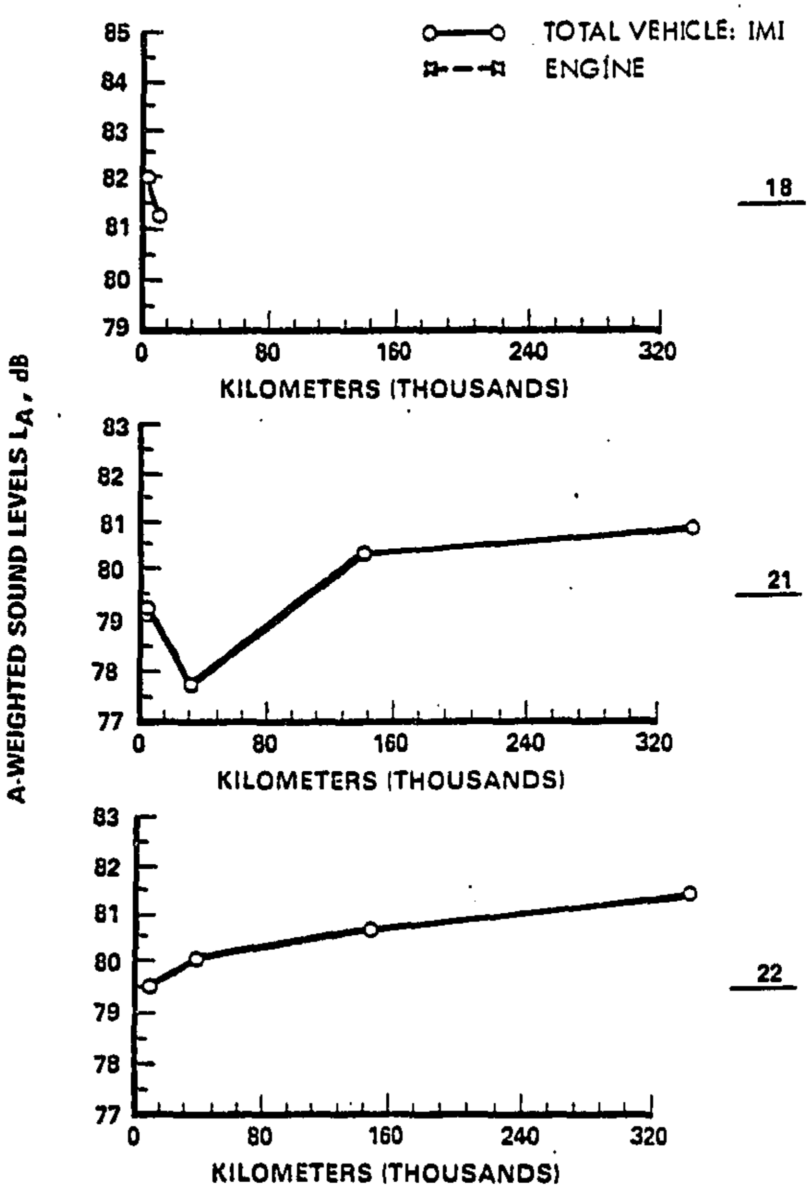

Figure 11. Vehicle Exterior Noise Levels versus Cumulative Kilometers

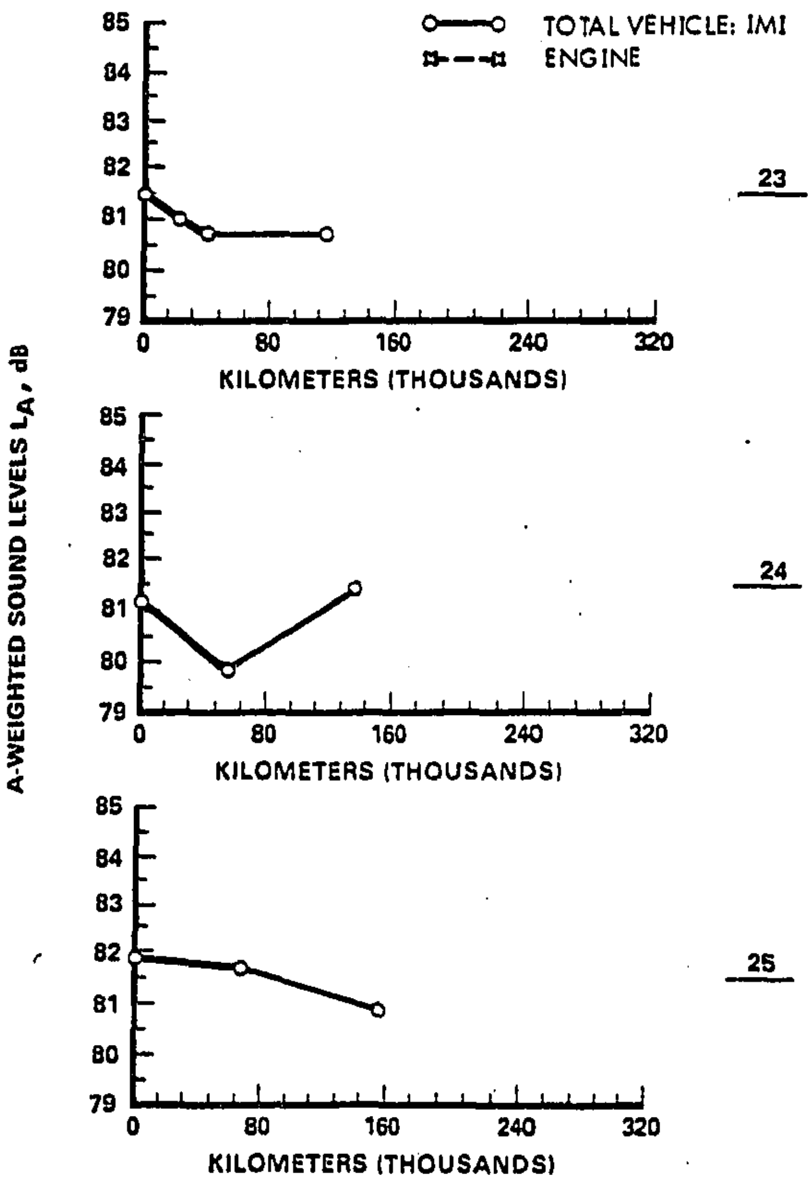

Figure 12. Vehicle Exterior Noise Levels versus Cumulative Kilometers

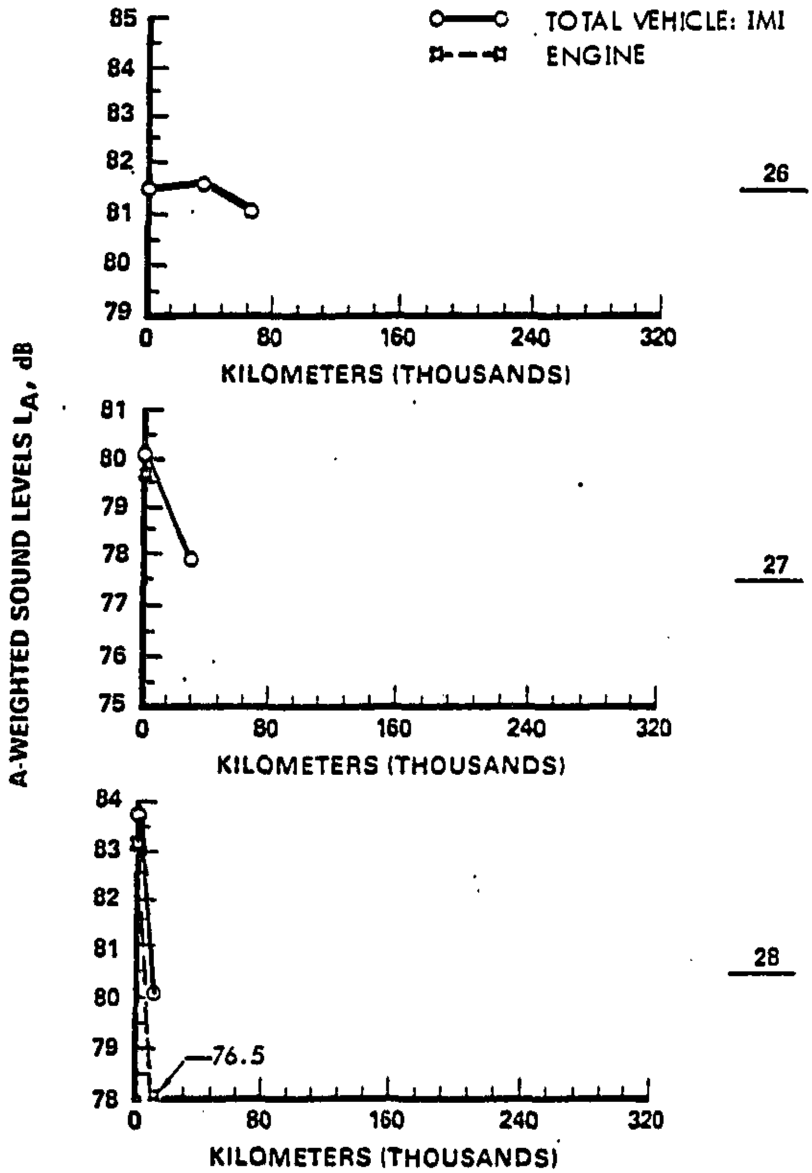

Figure 13. Vehicle Exterior Noise Levels versus Cumulative Kilometers

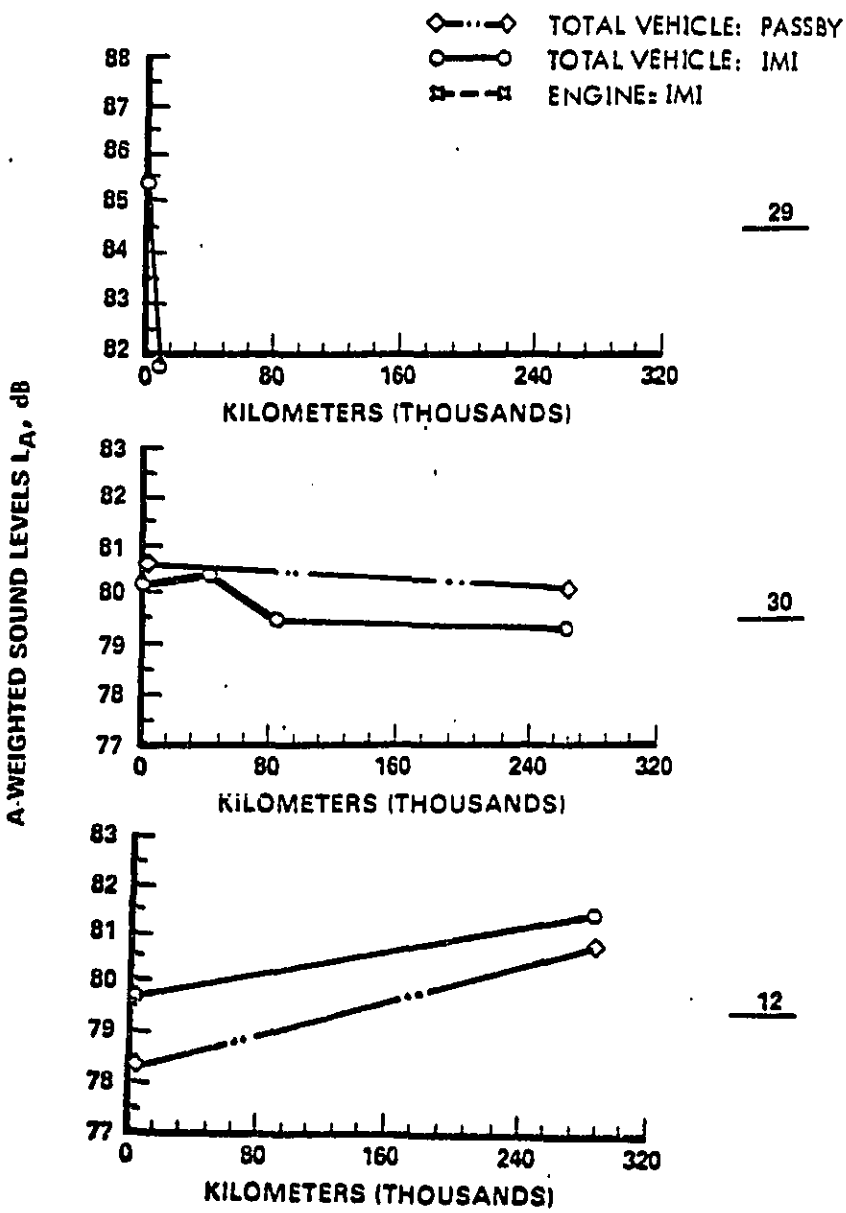

Figure 14. Vehicle Exterior Noise Levels versus Cumulative Kilometers

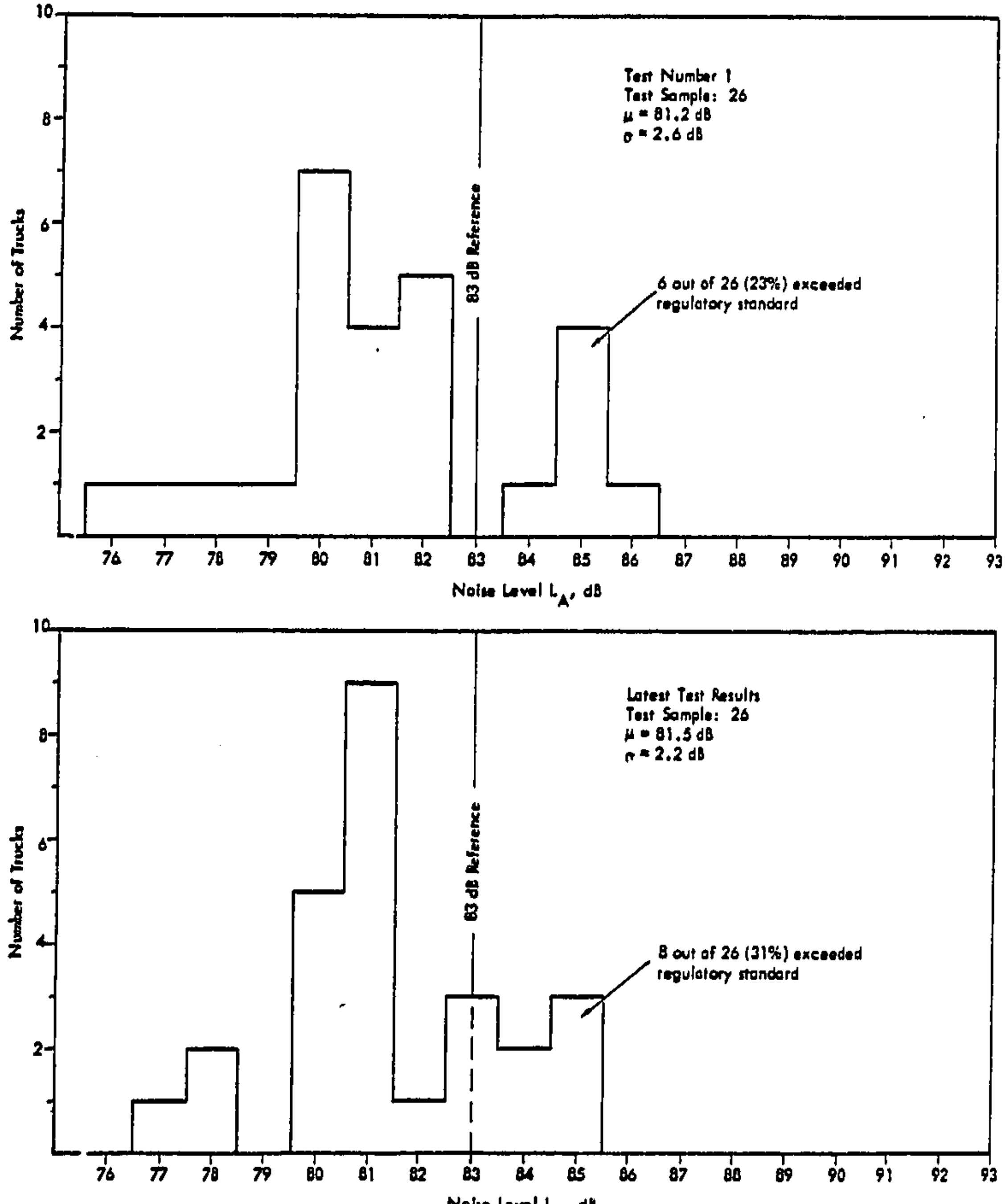

Figure 15. Measured IMI Noise Levels Compared to New Truck Regulations, 83 dB(A)

3.3 Total Truck Noise Degradation

A comparison is made of the change in total vehicle noise levels for each of the 26 trucks tested. The resulting information is summarized in Table 5. First, the change in noise level apparent between the first and last test is calculated for each truck. Second, because a greater change in noise level was sometimes apparent during an interim test, the maximum change in noise level is also presented for each truck. The distribution of maximum noise level variations is presented at the bottom of Figure 16, supplemented by data regarding the distribution of accumulated mileage and time in service for the sample population. A similar distribution is presented at the top of this figure for the change in noise level between the first and last noise measurement on each truck.

The average change from first test to last was approximately 0.3 dB, a difference reflected in Figure 15 by the change in average noise level from 81.2 dB to 81.5 dB. The average maximum difference in level between the first test and any subsequent test was 1.1 dB. This number is significant only in comparison to the average change, 0.3 dB, for it demonstrates the variability of measured levels about the apparent average change. It also shows, on the average, that all trucks had a measured decrease in level at some time during the test. This in itself makes it difficult to draw any relation between noise level and distance or time, because there will always be at least one point for each truck which deviates from this trend line by almost three times the amount of the total span of the averaged data. However, such a linear regression was performed between the measured levels and the distance traveled by the trucks. The resultant trend line had a slope of 0.27 dB/100,000 km and a correlation coefficient of 0.198. The low value of the correlation suggests that little or no confidence can be placed in the predictive abilities of what is already a very weak trend. The scatter about it is simply too great.

Partitioning the trucks on the basis of heavy or medium duty, and reexamining the changes in level revealed nothing further about the behavior of truck noise over the course of the tests. A similar division based upon whether a truck had a 2- or 4-cycle engine showed that the 2-cycle trucks experienced noticeably greater increases in level both on a first-to-last test and maximum change basis. However, only three 2-cycle trucks completed the test, so that even though the measured differences do exist, it seems risky to generalize from such a small data sample.

Table 5
Summary of Change in Exterior Noise Levels for All Test Vehicles

Vehicle No.	Change Between First and Last Test				Maximum Change					
					Pass-By			IMI		
	Pass-By Δ, dB	IMI Δ, dB	Mileage km	Test No.	Δ, dB	Mileage km	Test No.	Δ, dB	Mileage km	Test No.
1		-0.6	333,738	5				-1.2	51,200	2
2	+2.5	+2.1	268,521	6	+4.3	48,958	2	+2.2	48,958	2
3	-0.6	-0.9	281,148	6	+0.5	57,456	2	+2.1	57,456	2
4	+2.5	+0.5	270,190	6	+3.7	217,696	5	+2.9	144,128	4
5	+1.3	+0.6	317,561	6	+1.7	58,974	2	+2.0	58,974	2
6	-1.0	+2.8	502,643	4	-1.0	502,643	4	+5.8	127,153	2
7	+1.5	+0.4	97,008	4	+1.5	97,008	4	+0.4	97,008	4
8	+6.6	+7.9	69,070	4	+6.6	69,070	4	+7.9	69,070	4
9	-1.8	-1.4	513,395	3	+0.9	214,706	2	+0.2	214,706	2
10		0	12,668	2				0	12,668	2
12	+2.3	+1.6	278,224	2	+2.3	278,224	2	+1.6	278,224	2
13	+3.3	+3.8	249,485	5	+3.3	249,485	5	+3.8	249,485	5
14		-0.9	72,824	4				+1.9	24,480	3
15	+1.6	+0.7	346,392	5	+1.6	346,392	5	+2.8	120,829	3
16	-0.3		20,960	4	+2.5	6,870	2			
17	-0.5	+0.8	15,955	3	-0.5	15,955	3	+1.0	11,331	2
18		-0.9	10,776	2				-0.9	10,776	2

Table 5 (Continued)

Vehicle No.	Change Between First and Last Test: Pass-By Δ, dB	IMI Δ, dB	Mileage km	Test No.	Maximum Change: Pass-By Δ, dB	Mileage km	Test No.	IMI Δ, dB	Mileage km	Test No.
21		+1.6	344,139	4				+1.6	344,139	4
22		+2.0	345,398	4				+2.0	345,398	4
23		-0.7	115,075	4				-0.7	115,075	4
24		+0.2	136,637	3				+0.2	136,637	3
25		-1.0	157,162	4				+1.2	36,859	2
26		-1.4	66,161	3				+0.1	36,577	2
27		-2.3	32,562	2				-2.3	32,562	3
28		-3.6	12,773	2				-3.6	12,773	3
29		-4.0	10,830	2				-4.0	10,830	2
30	-0.5	-0.8	263,811	4	-0.5	263,811	4	+0.3	40,291	2

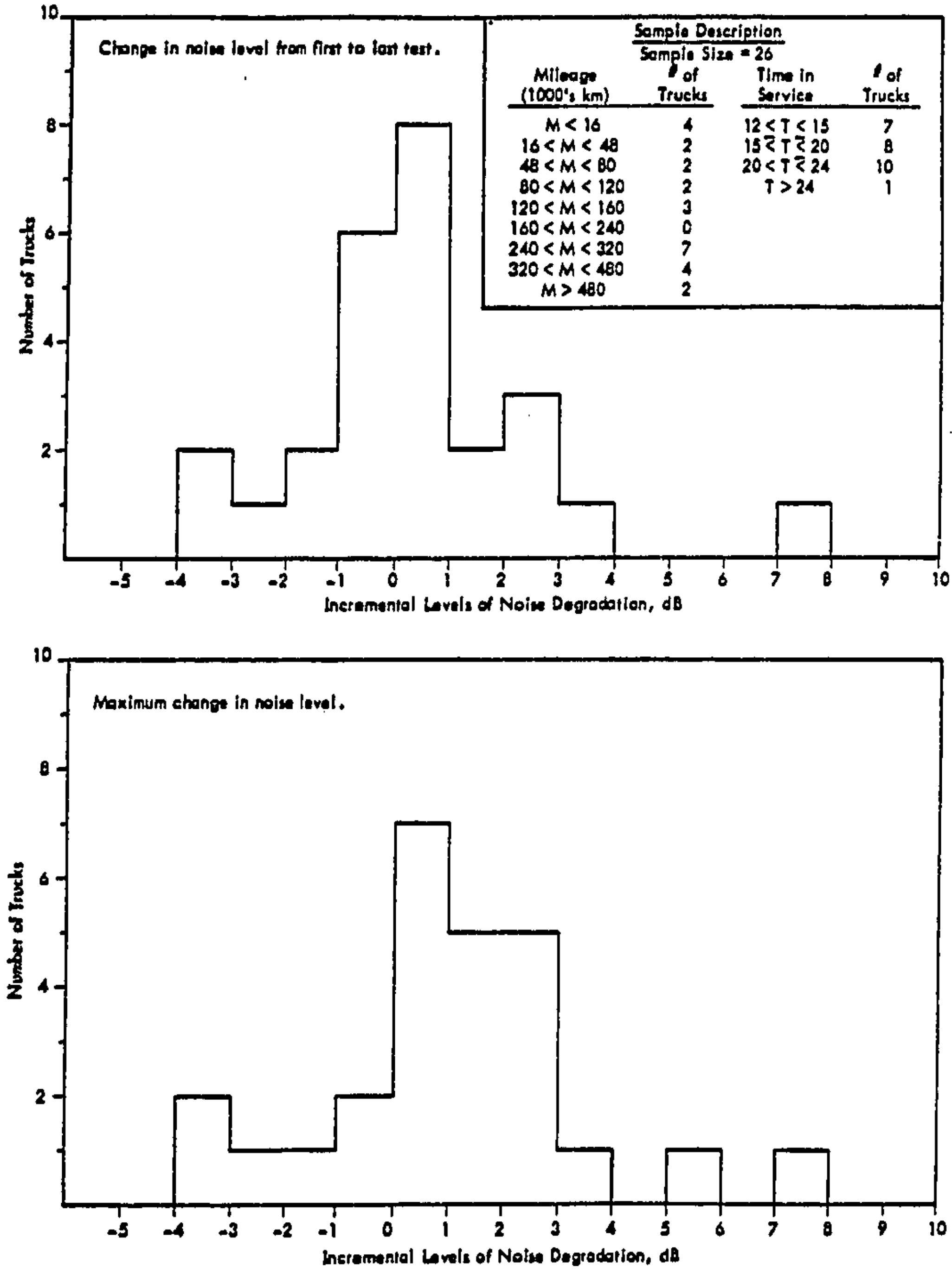

Figure 16. Distribution of Levels of Truck Noise Degradation as Measured Using IMI Stationary Test Procedure

Because the difference between average noise level from first to last test was so small (0.3 dB), it was reasonable to ask what confidence there was that this change was real, and not due to random statistical variation. A t-test for the difference of means was performed to answer this question. Its results showed only a 30 percent chance that the change was real. On this basis, it was concluded that the trucks showed no change in average noise level over the course of the tests.

3.4 Component Noise Degradation Analysis

As summarized in Section 2.0, an extensive series of measurements were performed to evaluate the contribution of individual component noise sources to overall truck noise degradation. Results of these tests are discussed below.

3.4.1 Change in Total Vehicle Noise Due to Exhaust System Degradation

Sufficient data were accumulated on 8 of the 10 vehicles for which exhaust gases were ducted away such that the following trends were apparent:

- Five of the trucks (Numbers 1, 3, 5, 7 and 8) showed no increase in exhaust gas noise level. Note, however, that two of these vehicles (Numbers 5 and 8) did exhibit an increase in overall noise due to an increase in engine noise, and one vehicle (Number 2) exhibited a decrease due to the same source.
- Three of the trucks (Numbers 2, 4 and 6) showed an increase in overall noise level because of an increase in exhaust gas noise. These vehicles all utilized the identical type of 2-cycle engine (Detroit Diesel Turbo V-6).

No clear trend is evident regarding the deterioration of exhaust system noise and its contribution to total truck noise degradation. It is apparent that the degree of exhaust noise degradation may be directly related to engine type. Additional data are necessary, however, before specific conclusions may be drawn.

3.4.2 Individual Truck Noise Analysis

Several of the trucks involved in this study exhibited changes in IMI test noise levels of greater than 1 dB over the length of the program. These vehicles are analyzed in greater detail here in an attempt to determine the specific sources of total truck noise degradation.

Truck Number 2

Data acquired for this vehicle using the IMI test procedure are summarized below:

Test Number	Distance (kilometers)	Maximum A-Weighted Sound Level, dB*
1	40	80.6
2	49,000	82.8
3	108,700	82.7
4	184,000	82.8
5	193,800	81.0
6	268,500	82.7

*Average of 2 tests.

The above data indicate that the total truck noise increased during the first 50,000 kilometers and then remained constant, with the exception of Test Number 5 where a noticeable drop in noise level was apparent.

Data from Test Number 5 showed a reduction in total truck noise with no change in engine noise level, thus indicating a reduction in exhaust gas noise. For Test Number 6, however, total truck noise returned to its previous constant level while engine noise decreased, indicating a significant increase in exhaust gas noise. This increase occurs for both IMI and passby testing and is apparent when one-third-octave spectra from Tests 1 and 6 are compared. These spectra (Appendix C) show an increase of 6 dB in the area of 200 Hz, which closely corresponds to the 210 Hz firing frequency of the V6, 2-cycle diesel when operating at 2100 RPM.

Narrow band analysis of the noise data from Truck 2 was performed to determine the actual engine RPM at which the noise measurements were made. It showed that changes in noise level were not attributable to RPM variations.

Maintenance information for each of the test vehicles is summarized in Table 6. Note that a muffler change is indicated before Truck Number 2 entered service. This occurred prior to Test Number 1 but after factory testing, such that

Table 6

Maintenance Summary

Vehicle Number	Maintenance Performed Which Might Affect Noise Sensitive Components
1	None
2	Replace Stemco Muffler with Donaldson P/N 00605 Exhaust Leak Repaired (208,000 km), Replace Shift Boot (220,000 km)
3	Replace Stemco Muffler with Donaldson P/N 000605, Replace Shift Boot (191,000 km), Replace Flexible Exhaust Pipe (63,000 km), (240,000 km), Repair Exhaust Leak (240,000 km)
4	Replace Stemco Muffler with Donaldson P/N 000605, Repair Engine Stop (25,300 km) Repair Governor (48,000 km) Tighten Clamps on Exhaust Stack (61,400 km) Repair Hood Support Bracket (109,000 km)
5	Replace Stemco Muffler with Donaldson P/N 000605 Exhaust Repair (64,000 km), (82,300 km) Hood repair (185,000 km) (209,000 km), (217,000 km)
6	None
7	Replace Muffler and Tailpipe (27,000 km) Repair Exhaust (31,400 km) Replace Exhaust Clamp (37,100 km) Secure Exhaust Pipes (60,000 km) Replace Left Side Exhaust Pipe (60,000 km) Repair Exhaust Leak at Crossover Pipe (68,300 km) Replace Exhaust Gasket on Left Manifold (72,200 km) Replace Muffler Exhaust Pipe and Tailpipe (71,200 km) Repair Exhaust System (84,600 km)
8	Exhaust Pipe Repair (44,800/49,600 km), Rebuild Engine (56,700 km)
9	Replace Muffler
10	None

Table 6 (Continued)

Vehicle Number	Maintenance Performed Which Might Affect Noise Sensitive Components
12	Rebuild Truck after Accident, Remove Engine Side Panel in Wheel Well Left Side
13	Overhaul Engine
14	None
15	Replace Injector Pump, Repair Exhaust, Remove Engine Side Panel in Wheel Well Left Side
16	None
17	None
18	None
21	Flexible Exhaust Pipe and C Clamp Replaced (213,000 km)
22	None.
23	None
24	None
25	None
26	None
27	Replace Carburetor (32,000 km)
28	None
29	None
30	None

it did not affect measurements related to noise degradation. Exhaust gas leakage was noted during visual inspection prior to performing Test Number 2, although no increase in noise levels were indicated. An exhaust leak repaired at 208,000 kilometers apparently had no relation to the lower noise levels recorded during Test Number 5, performed at 193,800 kilometers. As mentioned previously, the increase in total truck noise in Test Number 6 was apparently due to an increase in exhaust gas noise. These maintenance procedures were not to blame for the changes in noise.

Data accumulated on Truck Number 2 indicates that degradation of the overall vehicle noise level occurred as a result of increased exhaust gas noise levels. This is verified by the one-third octave band data which shows the increase occurring over a small frequency range, whereas an increase in engine noise would be associated with an increase in broadband noise levels.

Truck Number 6

Data accumulated using the IMI test procedure is compiled below for Truck Number 6:

Test Number	Distance (kilometers)	Maximum A-Weighted Sound Level, dB*
1	1,700	80.4
2	127,200	86.2
3	344,900	83.6
4	501,600	83.2

*Average of 2 tests.

The trend seen in this data is quite similar to that shown by Truck Number 2. Note that both vehicles utilize the identical type of engine (Detroit Diesel Turbo V6, 2-cycle). A noticeable increase in noise levels between Tests 1 and 2 is apparent for this truck. This coincides with the fact that, beginning with Test 2, the truck exhaust gas noise characteristics had a pronounced resonance occurring below maximum RPM during both IMI and passby testing. Since no relation between noise and test RPM could be discerned, it was concluded that significant noise degradation occurred during the course of the measurements.

Engine and exhaust noise were isolated first during Test 2 and then during Test 4. The constant separation in level between total and engine noise indicates that exhaust noise is the predominant source. This can be calculated on an energy basis for Test Number 2. Total vehicle noise level is 86 dB. When the exhaust gas component is removed, the noise level is 80 dB, representing engine noise. The exhaust gas noise level must therefore be about 85 dB in order that engine noise and exhaust gas noise add up (on an energy basis) to equal 86 dB.

A review of the maintenance logs (see Table 6) revealed that no major maintenance was performed on any noise sensitive components on Truck Number 6 during the course of the test program. However, exhaust gas leakage was noted from visual inspection performed during the final test sequence. The curves shown in Figure 7 indicate that exhaust leakage had no measurable effect on vehicle noise levels. Noise levels recorded for engine noise (exhaust gas noise ducted away) did not change from Test 2 to Test 4. The leakage was not present during Test 2 but was present during Test 4. It is therefore concluded that engine noise was high enough to mask any increased noise levels resulting from the leakage. Further analysis of Truck Number 6 is presented in Section 6.0.

Truck Number 8

IMI noise data for this vehicle is summarized below:

Test Number	Distance (kilometers)	Maximum A-Weighted Sound Level, dB*
1	600	76.2
2	11,300	78.3
3	56,300	81.3
4	69,100	84.1

*Average of 2 tests.

It should be noted that the noise level measured during Test Number 1 is most likely lower than normal because the engine was not operating as well as could be expected. Regardless, a noticeable increase in total truck noise is still evident in Tests 2 through 4. Referring to Figure 8, there is little difference between engine noise level and total vehicle noise level, indicating minimal noise contribution from the exhaust system.

A review of the maintenance records (Table 6) for this vehicle indicated an engine rebuild between Tests 3 and 4 and exhaust system repair before Test 4. There is no way of knowing whether the indicated repairs were the cause of the increase in vehicle noise levels.

An evaluation of the engine RPM in Figures C25 through C30 of Appendix C indicated that the engine was exceeding the factory rated RPM (4000) during these tests, as summarized below:

Test Condition	Engine RPM	
	Test 1 (600 km)	Test 4 (69,100 km)
IMI	4425 rpm	5250 rpm
Passby	3486	4069
Steady State	4106	5268

A significant difference is shown in the one-third octave spectra (Figures C31 and C32 in Appendix C) between IMI Tests 1 and 4. The engine firing frequency at 5250 RPM is 350 Hz. The fundamental engine firing frequency would therefore be 350 Hz/8-cyl. = 43.75 Hz. There are very pronounced peaks in the range of 40 Hz and 80 Hz for Test 4, but not at the corresponding firing frequency in Test 1, indicating a significant increase in noise level at the fundamental and the first harmonic of the engine firing frequency.

Test Vehicle Number 8 did not perform properly when delivered from the factory, and the performance deteriorated during in-service operation. The test data, both noise level and RPM, indicate that an improperly functioning engine governor allowed the engine to exceed factory rated RPM specifications, resulting in an increase in vehicle noise levels. The malfunction of the governor could be corrected by replacement or repair of the unit.

Truck Number 12

This truck was unique within the test program in that it was involved in an accident, completely rebuilt, and returned to service. Since only two measurements were performed on this vehicle (one before and one after the accident), establishment of a trend in the noise data was not feasible. However, with obvious reservations, conclusions may be drawn regarding the differences in noise level evident between Tests 1 and 2.

Results of the two IMI tests are summarized below:

Test Number	Distance (kilometers)	Maximum A-Weighted Sound Level, dB*
1	3,840	79.7
2	278,220	81.3

*Average of 2 tests.

Maintenance records indicate that the only difference between the configuration of the original and rebuilt truck was the removal of an engine panel on the left side. However, the increase in truck noise level between the first and second test was nearly equal on both sides of the vehicle, signifying that the panel removal had little effect.

Analysis of the tachometer readings revealed no major anomalies which might have affected the noise data.

A comparison of one-third-octave spectra (Figures C41 - C44 in Appendix C) suggests that engine noise caused the increase. While there is a peak at 100 Hz, corresponding to the 105 Hz firing frequency of this engine at 2100 RPM, it does not change level between tests. This eliminates exhaust noise as the primary cause. However, there was an increase in level from 700 to 1000 Hz. Since the increase was broadband, and the fan was not running during either test, engine noise remains as the only possible cause of the change.

Truck Number 13

Noise level data acquired through IMI testing is summarized below:

Test Number	Distance (kilometers)	Maximum A-Weighted Sound Level, dB*
1	13	80.6
2	81,960	79.3
3	163,600	80.4
4	222,400	80.1
5	249,500	84.4

*Average of 2 tests.

The trend evident in this data (see also Figure 9) would seem to indicate that a major change in the vehicle configuration occurred after performance of Test 4. Specifically, results of Test 5 showed that the overall vehicle noise level had jumped considerably. A review of the maintenance records revealed that the engine had been rebuilt after Test 4 (222,400 kilometers (138,380 miles)). During Test 5 it was noted that the "diesel knock" was more pronounced than in previous tests. Also, the maximum noise level occurred before maximum RPM was reached.

Narrow band analysis indicated that there were no major anomalies between measured versus actual RPM levels which might affect the noise data.

Review of one-third octave band data (Figures C49 through C52 in Appendix C) revealed an increase in sound pressure level in the range of 400 to 4000 Hz, indicating an increase in total truck noise due to an increase in engine noise as previously suspected.

Truck Number 21

Results of the IMI tests are presented below:

Test Number	Distance (kilometers)	Maximum A-Weighted Sound Level, dB*
1	1,110	79.3
2	37,980	77.8
3	163,600	80.3
4	344,140	80.9

*Average of 2 tests.

Total vehicle noise was relatively constant through the test program, with the exception of Test 2, where a slight reduction was apparent.

Maintenance records indicate that the flexible exhaust pipe C-clamp was replaced at 213,000 kilometers. This would have been between Tests 3 and 4. This did not have any major effect on vehicle noise.

Narrow band analyses (reference Figures C53 and C54) indicate the following RPM conditions during Tests 1 and 4:

Test Condition	Engine RPM	
	Test 1 (100 km)	Test 4 (344,100 km)
IMI	2175 rpm	2276 rpm
Steady State	2175	2276

A significant point shown with the narrow band spectra is that the maximum engine RPM corresponds with the steady state RPM indicating no overshoot characteristics for the governor.

A review of the one-third octave spectra in Figures C55 and C56 indicates a decrease in the 40 Hz area, but a consistent increase over the range of 150 - 2000 Hz. The broadband nature of the increase suggests engine noise was the primary source, with the 100 RPM difference between tests the cause of the increase.

Truck Number 22

Data from the IMI tests is summarized below:

Test Number	Distance (kilometers)	Maximum A-Weighted Sound Level, dB*
1	1,080	79.5
2	36,140	79.8
3	140,810	80.7
4	345,400	81.5

*Average of 2 tests.

No maintenance was performed that would affect any noise-sensitive components. A visual inspection at the final test did indicate exhaust gas leakage from the flexible exhaust piping.

Narrow band analyses (reference Figures C57 and C58 in Appendix C) revealed no major differences between measured versus actual RPM levels.

The one-third octave spectra (reference Figures C59 and C60 in Appendix C) show increases in sound pressure levels over a broad range from 400 to 4 kHz. There are no significant peaks shown in the spectra.

Although no increase in RPM is indicated, the broad range of one-third octave band noise level increases would indicate that engine noise was responsible for the increase in total vehicle noise.

To summarize, of the 14 trucks tested or analyzed for component degradation, four showed specific evidence of an increase (greater than 1 dB) in engine noise over time, and two showed specific evidence of an increase in exhaust gas noise over time. One vehicle (21) displayed a change greater than 1 dB, but this was attributable to RPM differences between tests.

3.4.3 Additional Component Noise Degradation Analysis: Truck Number 14

Truck Number 14 was examined during the component noise test program because it was equipped with a fixed fan. The component noise test configurations for this vehicle were as follows:

1. Total vehicle
2. Engine plus fan and exhaust
3. Engine plus fan and intake
4. Engine plus fan

Results of these tests are tabulated in Table 7. The data shown for Truck Number 14 is representative of a vehicle where fan noise is the predominant noise source.

Table 7

Stationary Test, Component Noise Levels
Truck Number 14, Test Number 1

Test Condition	A-Weighted Sound Level, dB			
	1	2	3	4
Kilometers	1,200	22,600	23,900	72,500
Total Vehicle	81.9	83.7	83.8	81.0
Engine, Fan and Exhaust	81.0	-	-	-
Engine, Fan and Intake	80.9	-	-	-
Engine and Fan	81.0	-	82.8	-

If the engine and fan noise levels of 81 dB are subtracted, on an energy basis, from the total vehicle noise level of 81.9 dB, the resultant contribution from the intake and exhaust sources is approximately 75 dB. This would indicate that small changes in fan and engine noise would have a noticeable effect on total vehicle noise. On the other hand, significant changes (4 dB or greater) in intake or exhaust component noise would have to occur before any measurable difference (1 dB or greater) would be noted in total vehicle noise. Engine and fan noise increased by 1.8 dB after the third test, indicating the source of total vehicle noise increase to be engine noise. From the first to the final test, total truck noise decreased by 0.9 dB. Engine RPM did not change, further indicating that the engine alone was responsible for the change in noise.

3.5 Correlation Analysis of Passby Versus Stationary Testing

Most of the noise tests performed during this program were stationary (IMI) tests. Passby testing was performed on eight vehicles by their respective manufacturers while the vehicles were still at the factory. These eight trucks plus four additional vehicles were subjected to repeat passby tests during this program. The results of all of the passby tests compared against corresponding stationary tests have been plotted in Figure 17. The resulting linear regression fit and 90 percent confidence intervals are also displayed in the figure.

Regarding the least-squares regression fit, the squared value of the correlation coefficient (i.e., coefficient of multiple determination) is .733, indicating that 73 percent of the variation in stationary noise levels is explained through associated variation in passby levels. Further, the correlation coefficient, R, is significantly different from zero beyond the 99 percent level, indicating that this equation can be utilized with confidence to predict stationary noise levels for a truck based upon associated passby noise data.

The data shown in Figure 17 exhibits mean levels of 81.4 dB for passby tests and 81.7 dB for stationary tests, a difference of only 0.3 dB. Note, however, that the resulting regression fit displays a slope of 0.83 (a slope of 1.00 would indicate perfect correlation between stationary and passby noise levels over the entire range of data). Therefore, while the data compare closely in the vicinity of 82 dB, over a wider range the data begin to disperse, indicating that the noise level measured using IMI test procedure is typically not equivalent to the level measured under the passby test procedure.

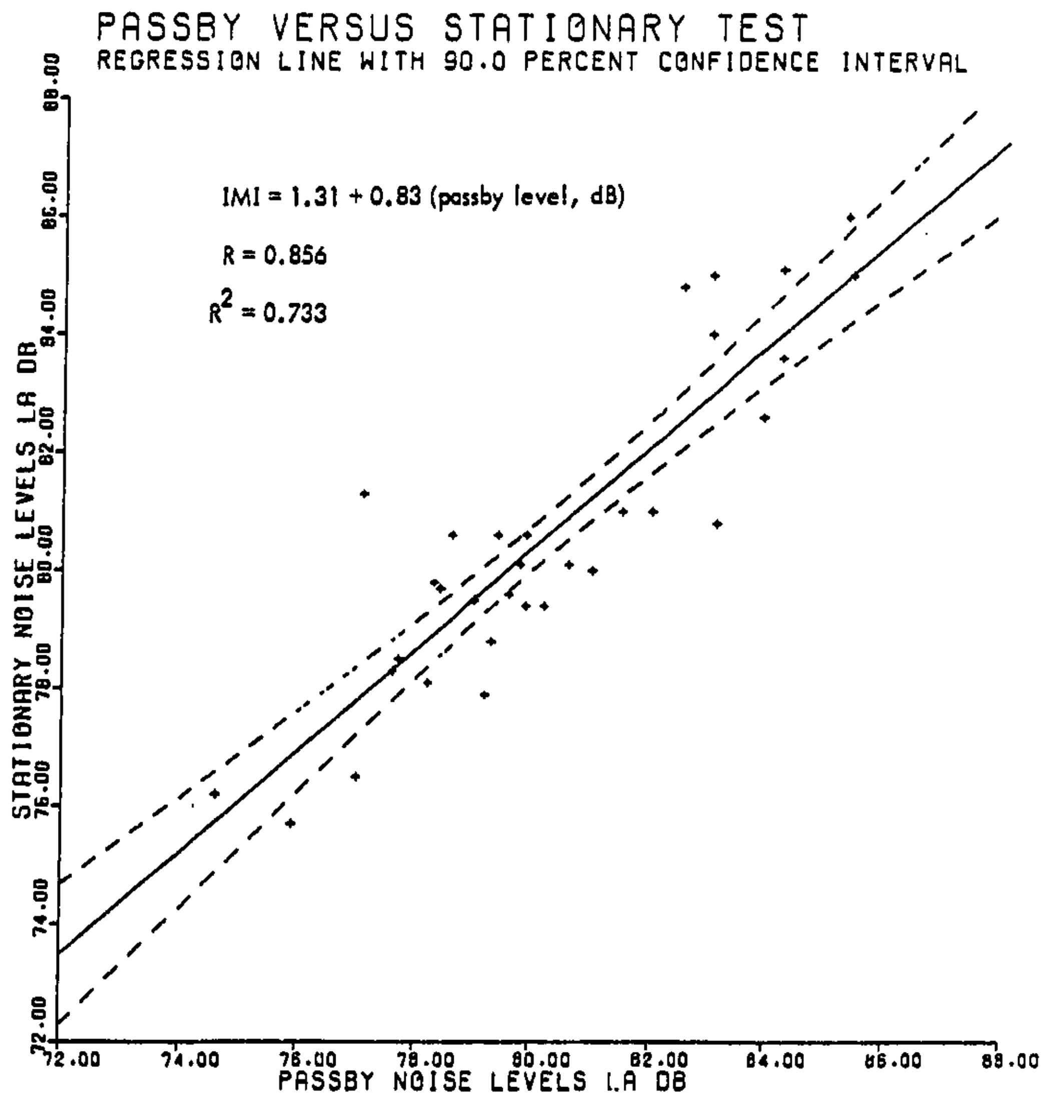

Figure 17. Passby Versus Stationary Test

3.6 Factory Versus Wyle Test Results

As mentioned earlier, factory measured data were obtained for eight of the 30 test vehicles. These data are used here for the purpose of identifying possible variations between new truck noise levels as measured at the factory and those measured at the customer facility prior to the truck entering service. Table 8 summarizes the results of this comparative analysis. Maximum variation between the factory and Wyle initial test results for any one truck is 2.6 dB for the passby tests and 1.1 dB for the IMI tests. In general, correlation between the factory and field noise measurements is very good, thus indicating that the procedures employed in this test program coincide well with the qualification procedures employed by the truck manufacturers.

3.7 Interior Noise Levels

A tabulation of interior noise level data is given in Table 9. Of the 26 vehicles tested, 10 exhibited an increase in interior noise level, while 15 showed a decrease. One truck, Number 10, exhibited no increase in interior level. Therefore, while many of the vehicles exhibited increased interior noise levels, a majority of the trucks tested displayed interior noise environments which actually improved with time.

Table 10 presents a comparison of the change in exterior noise level versus the change in interior noise level for each truck. The data suggest no consistent pattern. Of the 26 trucks involved in the testing, 14 of the vehicles displayed changes in interior noise levels which opposed the associated change in exterior noise level (e.g., Truck Number 2 exhibited a +2.1 dB change in exterior level and a -3.5 dB change in interior level). Of the remaining 12 vehicles, five showed coincidental increases, six showed coincidental decreases, and one remained unchanged.

Table 8

Factory Data Versus Wyle Data, L_A (dB)

Vehicle Number	Pass-By Test, dB			IMI Test, dB		
	Factory	Wyle	Δ	Factory	Wyle	Δ
2	81.0	79.9	-1.1	80.0	80.6	+0.6
3	83.0	84.2	+1.2	84.0	85.1	+1.1
4	82.0	79.4	-2.6	81.0	80.6	-0.4
5	83.0	82.5	-0.5	85.0	84.8	-0.2
19				78.1	77.0	-1.1
20				78.5	77.5	-1.3
27				78.5	78.2	-0.3
28				77.9	78.0	+0.1
		Mean	-0.5 dB		Mean	-0.19 dB
		Standard Deviation	1.6 dB		Standard Deviation	0.80 dB

Table 9

Interior Noise Levels L_A, dB

Truck Number	Test Number					
	1	2	3	4	5	6
1		78.5	77.5	80.7	80.5	
2		87.3	85.9	81.8	85.3	83.8
3		84.2	84.1	84.3	86.5	82.9
4		84.4	83.7	83.0	85.4	83.1
5		83.9	84.6	83.0	86.7	81.4
6		85.1	87.8	83.8		
7		87.0	82.5	82.9		
8		82.4	84.0	92.0		
9		87.7	83.3			
10		85.0	85.0			
11	85.0					
12	80.7	83.5				
13	75.4	74.9	78.5	77.0	76.0	
14	86.7	87.5	87.8	85.6		
15	83.5	80.5	84.5	82.3	81.5	

Table 9 (Continued)

Truck Number	Test Number					
	1	2	3	4	5	6
17	79.2	80.8	80.0			
18	87.5	84.6				
19	88.5					
20	85.0					
21	80.4	79.0	81.9	83.1		
22	84.5	84.5	82.2	81.0		
23	83.5	85.0	84.7	82.5		
24	84.0	86.4	83.7			
25	83.5	85.0	86.0	83.9		
26	83.5	84.9	86.4			
27	87.2	87.0	82.6			
28	82.8	83.2	85.0			
29	85.8	83.9				
30	78.0	78.9	82.9	79.0		

Table 10
Change in Exterior and Interior Levels

Truck Number	Exterior Noise ΔL_A, dB (1)	Interior Noise ΔL_A, dB (1)
1	-0.6	+2.0
2	+2.1	-3.5
3	-0.9	-1.3
4	+0.5	-1.3
5	+0.6	-2.5
6	+2.8	-1.3
7	+0.4	-4.1
8	+7.9	+9.6
9	-1.4	-4.4
10	0	0
12	+1.6	+2.8
13	+3.8	+1.6
14	+0.9	-1.1
15	+0.7	-2.0
17	+0.8	+0.8
18	-0.9	-2.9
21	+1.6	+2.7
22	+2.0	-3.5
23	-0.7	-1.0
24	+0.2	-0.3
25	-1.0	+0.4
26	-1.4	+2.9
27	-2.3	-4.6
28	-3.6	+2.2
29	-4.0	-1.9
30	-0.8	+1.0

(1) Change in A-weighted sound levels from initial test to current test results.

4.0 EXISTING DATA ON TRUCK NOISE DEGRADATION

Supplemental data on truck noise degradation were solicited from publications and through direct contacts with the trucking industry. Data were found from two truck noise degradation programs performed by two separate organizations.[5, 6] Other manufacturers and operators expressed personal opinions on truck noise degradation, but none had supporting data. Opinions indicated that some believed trucks became noisier after they had been in service, while others thought they became quieter.

Two truck noise degradation programs have been performed in recent years which resulted in the publication of data. International Harvester measured noise levels of the four heavy duty trucks involved in the DOT Quiet Truck Program.[6] Wyle Laboratories performed a truck noise degradation program for the Motor Vehicle Manufacturers Association.[5]

All four of the International Harvester trucks had been modified for noise reduction on the DOT Quiet Truck Program. Two of the trucks had partial engine enclosures while the other two had full engine enclosures. Results of this program are shown in Figure 18. The number of kilometers over which this data were taken is high enough to consider a trend being established with regard to noise degradation. The results have been interpreted by International Harvester as showing a maximum change of 0.5 dB in noise level. Increases in noise levels above 0.5 dB were the result of damage and are so indicated on the graphs.

The Wyle/MVMA data were accumulated on eight heavy duty vehicles over a much shorter period of time. The maximum kilometers accumulated on a given truck was 64,000 kilometers. All vehicles involved in the program were production vehicles being used in normal service. Results are shown in Table 11 and indicate an average increase in total vehicle noise level of 0.5 dB. Both of these test programs indicate a very small increase in noise levels. In the case of the previous Wyle data, the trend over such a low mileage is not statistically reliable since, as indicated in the last column of Table 11, the observed changes in level could have occurred by chance with a probability of 30 to 80 percent.

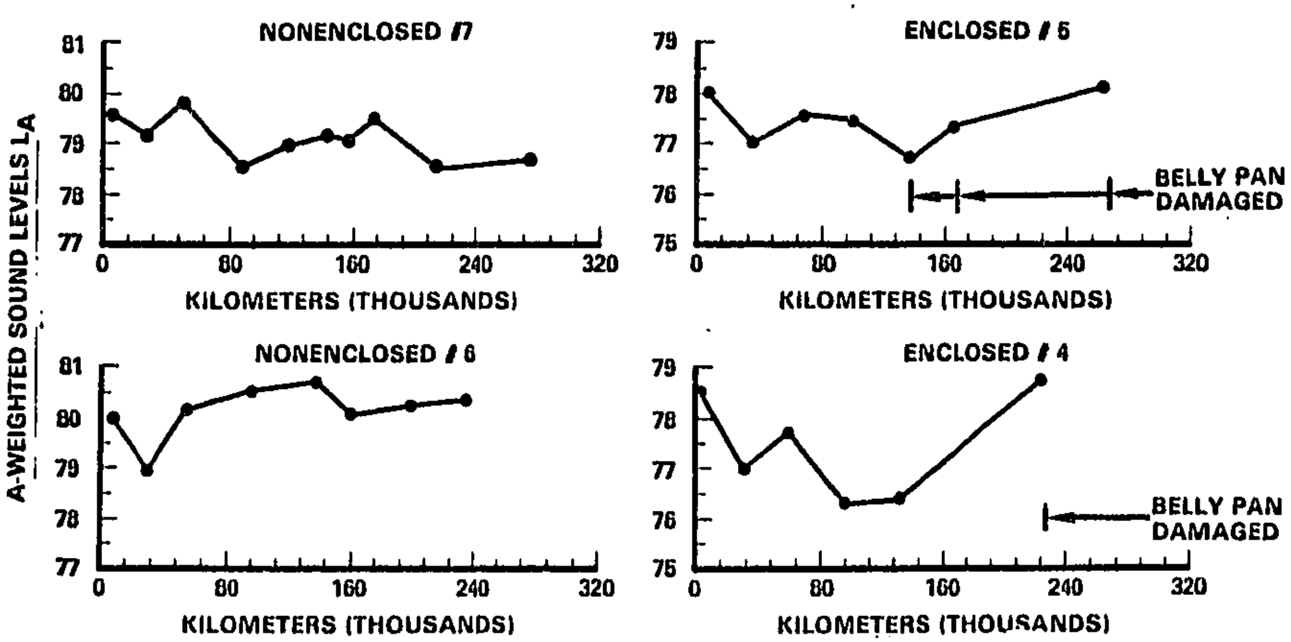

Figure 18. Vehicle Exterior Noise Levels versus Cumulative Kilometers
Source: International Harvester (Reference 6)

Table 11

Summary of Observed Changes in Average Noise Level with Cumulative Kilometers

Source: Wyle Report to MVMA, Reference 5

APPROXIMATE KILOMETERS COMPLETED	NUMBER OF VEHICLES	AVERAGE CHANGE FROM INITIAL VALUE (dB)	STANDARD DEVIATION (dB)	PROBABILITY THAT CHANGE WAS DUE TO CHANCE (%)
16,000	8	+0.4	1.1	35
32,000	7	+0.5	1.0	30
48,000	7	+0.2	1.1	60
64,000	4	-0.2	1.7	80

It is not advisable to consider the results of these two previous programs for application to present day truck noise degradation for the following reasons:

- International Harvester trucks were not representative of production vehicles.
- The Wyle/MVMA test program was too short and the data too sparse to place any reliance on the indicated trends.

5.0 COMPONENT AND VEHICLE NOISE DEGRADATION RELATED TO PROPER MAINTENANCE AND OPERATIONS

Information has been compiled on both the recommended and actual maintenance and operational procedures associated with each test vehicle in order to assess their effects on component and vehicle noise degradation. Sources for this information include the following:

- Arrangements for testing of the 30 trucks utilized in this program included a request to each vehicle owner for a copy or access to the maintenance records for each vehicle. Response to this request varied from agreement to supply copies of the records to verbal communication of maintenance performed.
- A sample of drivers was contacted to accumulate information on typical vehicle operating procedures.
- Manufacturer's recommended maintenance and operational procedures for the various engine types considered in this study were obtained from either the factory or local manufacturer's representatives.
- Manufacturer's data on component noise specifications were also acquired through the respective representatives.

5.1 Manufacturer Recommended Operational Procedures

Factory operational procedures for the different diesel engines are very similar for all manufacturers. Warnings are given to not overspeed the engine when using it as a brake on a downhill grade. Efficient operating ranges for highway driving are recommended at three-quarter to full rated RPM. Specific recommendations by manufacturers include:

- Detroit Diesel
  - a. Run the engine at 10 to 20 percent below governed RPM for highway cruising speed.
  - b. In the city and other reduced speed zones, match engine speed to the lower load requirements to conserve fuel and lower vehicle noise level.

c. Avoid "overspeeding" the engine.

d. The recommended range of engine speeds during cruise for various engines is shown in Table 12.

o <u>Cummins</u>

a. For improved operating efficiency (fuel economy and engine life), operate in top gear at reduced RPM rather than in the next lower gear at maximum RPM.

b. Cruise at partial throttle whenever road conditions and speed requirements permit.

c. Care should be exercised, when using the engine as a brake, not to overspeed the engine.

o <u>Caterpillar</u>

a. Cruising speed should be between three-quarter and full governed RPM.

b. On upgrade, downshift until a gear is reached in which the engine will pull the load without lugging.

c. On downgrade, do not allow engine speed to exceed high idle.

5.2 Manufacturer Recommended Maintenance Procedures

Manufacturers all supply a recommended schedule of maintenance with their respective vehicles. The owner is given a range of maintenance intervals from which to select, based upon fleet operational characteristics. Table 13 lists the specified change or adjustment schedule for the most important engine components. Daily inspections are also recommended for oil level and coolant, depending upon the number of miles driven.

5.3 Manufacturer Data on Component Noise Specifications

Literature published since the issuance of the Background Document[7] in support of the New Truck Noise Standards has been primarily on muffler configurations. By using the muffler manufacturers' specification sheets, the matrix can be developed as in Table 14 to show the lowest noise level muffler systems for the engines used in this program. These data, when combined with results from the noise degradation-remote exhaust testing, would enable one to project noise degradation for these engine-muffler configurations.

Table 12

Recommended Range in Engine Speeds During Cruise

Engine	Governed Speed (RPM)	Highway (RPM)	City (RPM)
Series 71 & 92	2100	1650 to 1850	1400 to 1600
Series 71 & 92 Fuel Squeezers	1800 to 2100	1400 to 1900	1250 to 1600 8V-92TT 1400 to 1600
Series 53	2400 to 2800	2250 to 2400	1800 to 2000

Table 13

Factory Recommended Maintenance

Make	Oil Change	Oil Filter Replacement	Fuel Filter Replacement	Valve Adj.	Injector Pump Adj.
GM					
Detroit Diesel (D1)	*4,000-6,000	4,000-6,000	8,000-12,000	50,000	50,000
Cummins (C1)	10,000	10,000	10,000	50,000	50,000
(D2) Gas (4500-6500)	3,000	**3,000	12,000	***12,000	---
INTERNATIONAL HARVESTER					
Diesel (I2)	4,000	8,000	4,000	16,000-20,000	10,000
Gas (I2)	2,000	4,000	2,000	8,000-10,000	---
MACK TRUCK					
+++Diesel (M3)	16,000	16,000	180,000	200,000	300,000
CUMMINS					
Diesel (C1)	10,000	10,000	10,000	50,000	50,000
CATERPILLAR					
(C2) 3208 Diesel	+6,000	6,000	24,000	24,000	As Needed
3306 Diesel	+10,000	10,000	As Needed	100,000	As Needed
3406 Diesel	+10,000	10,000	As Needed	100,000	As Needed
1100 Diesel	+6,000	6,000	24,000	++6,000	As Needed

*Initial Oil Change at 3,000 Mi. and 4,000-6,000 Mi. thereafter
**After Initial 3,000 Mi. Check, every 6,000 Mi. thereafter
***After Initial 12,000 Mi. use 50,000 Mi. thereafter
+Intervals Depend on Sulphur Content. If between .4% and 1.0% reduce interval by 1/2. If content is above 1.0% use 1/4 of the mentioned intervals.
++Every 6 months after initial adjustment regardless of mileage.
+++Guidelines depend heavily on type of usage. These intervals are for E.S.I. usage.

Table 14

Exhaust Noise Levels for Engines Used in Noise Degradation Test Program
(Taken from Muffler Manufacturers' Specification Sheets) L_A, dB

	Muffler Manufacturer		
Engine	Donaldson	Walker	Stemco
Cummins NTC 350	73 Dual	76	73.5
DD 6V92 TT	71	78	
CUM VT 903	72	75	
Ford Gas V361			
Cat V8 3208	69	70 Dual	68
CUM NTC 290	71		73.5
Mack END7675		73	66.5
CUM NTC 250	71	72	70

*All of the specified noise levels are referenced to a 50-foot noise measurement at a test site complying with the Federal noise measurement specification 40 CFR 205.

The cooling fan is another component for which only limited noise data are available from a manufacturer. Only one fan manufacturer, who was working with a truck manufacturer to reduce overall truck noise levels, was able to provide such data. He revealed that fan noise has been successfully reduced to a level where the overall truck noise level of 83 dB was not affected by having the fan on or off. The fan used slightly more than 3 HP. In this case, fan noise was not expected to be a contributor to observed degradation of truck noise levels. For fans with higher noise levels which contribute significantly to the overall levels, changes in fan noise levels with use are not likely to be significant unless airflow through the fan changes. Thus, any degradation in overall truck noise is unlikely to be attributed to changes in fan noise. However, fan noise does increase overall truck noise where fan clutches are used and the fan clutch is engaged.

5.4 Vehicle Operational Procedures

The vehicles involved in this program are typically utilized in the following modes of operation:

- Line Haul - "slip seat" operation
- Line Haul - single driver
- Pick up and delivery - shift work by two or more drivers
- Pick up and delivery - single driver

Discussions were held with various drivers and shop managers to acquire direct feedback on the operation of vehicles in their fleets. Typically, line haul operators will tend to be more experienced than those who drive smaller pick up and delivery vehicles. This difference in experience translates into a difference in level of knowledge of truck operation and maintenance.

Experienced line haul drivers know the speed/RPM relationship in each gear and thus will use the tachometer rather than the speedometer as a more accurate measure of speed. In comparing this with pick-up and delivery operations, one fleet found the use of automatic transmissions saved money because of the too frequent clutch changes or transmission repairs required with standard transmission.

A distinct difference was noted in the care and operation of vehicles driven by the same driver versus those used by many drivers. Pride resulted in an overall cost savings for the carrier because of better care and maintenance by the driver.

Most heavy duty drivers who were questioned indicated driving habits corresponding to factory recommended procedures. Medium duty trucks are mostly involved with traffic conditions which govern the type of operation. The inherent nature of city traffic operations is more severe than line haul operation.

The present trend of motor carriers is toward the use of high-torque-rise engines which allow use of transmissions with fewer gears. Fuel consumption has been the primary goal of this trend, but noise reduction has been a spin-off. One manufacturer, General Motors, relates engine operation directly to noise levels; "in city and reduced highway zones, cruise on Series 71 and 92 engines between 1400 and 1600 RPM and Series 53 between 1800 and 2000 RPM. By utilizing a gear that will enable you to do this, you will increase public acceptance by reducing noise level."[8]

One other concept being used by some motor carriers is to "de-rate" the engine by reducing the maximum allowable RPM. This procedure will allow the driver to operate the engine only at engine speeds below maximum rated RPM which corresponds to the factory recommended mode of operation.

The results of driver contact and shop manager interviews reveal a specific trend in actual vehicle operation which tends to correspond with factory recommended operation. While individual drivers will tend to form their own habits, the use of high torque engines and the de-rating of engines by some carriers appears to help considerably in confining operational procedures to those recommended by the factory.

Two large motor carriers cited problems associated with drivers operating new trucks which are much quieter inside the cab. Drivers are used to listening to the engine and monitoring the audible cues of engine performance. Specific instances were quoted where the engine had developed a mechanical problem but the driver continued driving resulting in extensive damage to the engine. It was the feeling of these motor carriers that noise reduction had presented them with another problem in the operation of vehicles.

5.5 Vehicle Maintenance

Actual Versus Factory

All the motor carriers within this program have Preventive Maintenance (P-M) schedules established and procedures for collecting driver comments on any vehicle problems. Medium duty and some heavy duty trucks used in local mountain areas had P-M schedules every 12,800 kilometers (7936 miles). Heavy duty vehicles ranged from 48,000 to 80,000 kilometers (29,760 to 49,600 miles) for their P-M schedules. One carrier utilizing heavy duty vehicles specifies 64,600 kilometers (39,680 miles) or one month as his inspection interval. All the P-M discussed above was compatible with factory recommended procedures.

Maintenance Performed Versus Noise Sensitive Components

A review of maintenance records at each test interval indicated only three types of noise sensitive component repair or replacement.

- Replacement of injector pump on a heavy duty diesel; no change in noise level.
- Replacement of muffler on heavy duty diesel; noise levels reduced.
- Engine rebuilt on heavy duty diesel and medium duty gasoline; noise levels increased.
- Engine side panel removed on heavy duty diesel; no record of when panel was removed so no relationship to change in noise levels can be determined.
- Repair hood on heavy duty diesels; noise level increased on one truck, decreased on another.
- Replace carburetor on medium duty gasoline; noise level reduced.
- Replacement of muffler and exhaust pipe on medium duty gasoline engine truck; accomplished just prior to measurement; no data to determine prior effects.
- Tightening of exhaust pipe connections; no measurable difference in noise level.

- o Replacement of shift boot inside cab of heavy duty diesel; noise level increased on one truck and decreased in another. Table 11, presented in Section 4.0, page 58, summarizes the maintenance performed on each vehicle.

6.0 COMPONENT MODIFICATION: TAMPERING, REMOVAL OR REPLACEMENT OF PARTS

An analysis of component tampering on a truck must take into consideration the concepts associated with truck purchasing. Trucks are selected to perform an established task, defined by the type of cargo, terrain, weather conditions, type of operation, and the present type of trucks in service. These constraints, combined with operators' prior experience, will determine the engine size and type, transmission, differential, exhaust system, intake system, fan drive and accessories such as air conditioning that are specified for the vehicle. The actual truck which is delivered to the motor carrier is a preselected vehicle with these desired components. It is not surprising to find, therefore, that most of the motor carriers contacted indicate no major cases of tampering, removal, or replacement of noise-sensitive parts.

However, discussions with motor carriers did reveal the following types of accepted component modifications or replacements:

- Substitution of mufflers at the dealer to correspond with existing types used on the present fleet,
- Reduction of the governed RPM of the engine,
- Replacement of exhaust pipe clamps.

A review of the literature indicates that components which are sometimes added to the trucks after purchase include turbochargers and engine noise covers, as well as different fan clutches which are substituted for original equipment to ensure fleet uniformity. However, no specific instances of these component additions or substitutions were reported by the vehicle operators cooperating in this program.

Engine RPM is typically not changed for noise emission purposes, but rather to enhance engine life and fuel economy. However, decreasing the maximum RPM of the engine can reduce the noise level of the truck. As noted earlier, the engine manufacturers recommend operation of the truck at 3/4-to-full throttle to achieve maximum efficiency. Although comments were received from some of the drivers indicating their displeasure with operating a vehicle de-rated to 1900 RPM from 2100 RPM, none of these drivers expressed any desire to try to readjust the RPM as they realized it was beyond their control to introduce such changes.

Exhaust leaks are sometimes reported by drivers. Other exhaust leaks show up during preventive maintenance checks. During this program exhaust gas leakage was documented through visual observation (see Section 3.4). When the trucks were subjected to noise testing, however, there generally was no indication that the noise level had increased. Most exhaust leaks were eventually corrected by simply tightening the clamps or installing sheet metal sealing clamps during preventive maintenance checks.

6.1 Muffler Substitution

Inquiries to vehicle operators revealed muffler substitution as a common form of component modification which results in changes in total vehicle noise levels. While muffler manufacturers indicate that no deterioration in muffler performance is likely before 160,000 kilometers (100,000 miles), variations in the insertion loss characteristics of different muffler types were evident in this study.

Muffler substitutions were made on four trucks in order to assess the effects on total vehicle noise levels. Two of these vehicles, Numbers 6 and 7, were involved in the noise test program described in Section 3.0, while the other two, Numbers 40 and 41, were used only for muffler substitution testing. A complete description of these vehicle configurations was provided in Table 1.

Mufflers used in this substitution study were procured from truck parts suppliers by specifying the truck model and engine. In order to reflect industry practice, no efforts were made to use the guides published by muffler manufacturers in selecting the quietest muffler. Note that none of the parts suppliers mentioned noise levels relative to muffler selection.

Stationary IMI tests, performed in accordance with the procedures outlined in Section 2.4 were conducted after each new muffler configuration was installed. Results of these measurements are summarized in Table 15. Factory-measured IMI noise levels are presented along with information regarding the factory installed muffler (where possible).

Regarding Truck Number 6, a 2.1 dB reduction in noise level was achieved when a Donaldson Super Stack was installed in series with the existing muffler. A Super Stack is a tailpipe extension lined with acoustical absorption material. A further reduction of 0.9 dB was obtained when a new Donaldson muffler was used

Table 15

Change in Stationary Runup Noise Levels of Selected Trucks Exposed to Muffler Substitutions

Vehicle Number and Description	Factory	Muffler Configuration				Maximum Change (dB)
		Substitute 1	Substitute 2	Substitute 3	Substitute 4	
#6 Freightliner COE Diesel V-6, 2-cycle Single Vert. Muffler	83.2 (1)*	81.1 (2)	82.0 (3)	80.2 (4)	-	-3.0
#7 Ford Conv. Gas V-8 Single Horiz. Muffler	79.9 (5)	79.7 (6)	82.5 (7)	-	-	+2.6
#40 Freightliner Conv. Diesel V-8, 4-cycle Single Vert. Muffler	85.8 (8)	86.1 (9)	85.9 (10)	96.2 (11)	86.2 (12)	+0.4
#41 Freightliner Conv. Diesel V-6, 2-cycle Single Vert. Muffler	81.7 (8)	81.9 (9)	84.9 (12)	80.4 (10)	83.5 (11)	+3.2

*Muffler Type and Part No.:

(1) Not available
(2) Existing muffler plus Donaldson Super Stack 16021
(3) Donaldson 11165
(4) Donaldson 11165 plus Super Stack 16021
(5) Not available
(6) Maremount TDT 20 566
(7) Maremount KE 4118G
(8) Donaldson MPM09 0183F7
(9) Walker 22829
(10) Riker 43-003-001
(11) Heavy Duty A8 080074
(12) Stemco

along with the Super Stack, thereby enabling a total reduction in vehicle noise level of 3.0 dB. Truck Number 6 was the only vehicle out of the four tested for which muffler substitution led to a decrease in total vehicle noise level. Noticeable reductions were anticipated, however, as exhaust noise represents the dominant source on this vehicle (see Figure 7).

In contrast, Truck Number 7, a medium duty truck with a gasoline-powered V-8 engine, exhibited significantly different noise emission characteristics. Its engine and exhaust noise contributed almost equally to total vehicle noise. Substitution of two types of mufflers produced by the same manufacturer led to quite different results. As revealed in Table 15, the second of the two Maremount mufflers proved less efficient, resulting in a 2.6 dB increase in total vehicle noise. These data would suggest a wide variation in the insertion loss characteristics of mufflers available for medium duty trucks.

Baseline component noise data was not acquired for trucks 40 and 41, thus eliminating the possibility of assessing beforehand the relative contribution of exhaust noise to total vehicle noise. Regardless, these similar vehicles exhibit comparable trends within the muffler substitution tests. Note that each muffler tested on Truck Number 40 was also tested on Truck Number 41. Compared against the factory-tested noise levels, two of the mufflers, Walker and Riker, produced little or no reduction in noise levels on both vehicles. The remaining two mufflers exhibited different characteristics between the two vehicles. Both the Heavy Duty and Stemco mufflers had essentially no effect on the overall noise level of Truck Number 40. However, the identical mufflers caused a noticeable rise in the noise level of Truck Number 41, compared to that measured with the stock muffler installed. Explanation of this phenomena may be found in the engine type. Recall in Section 3.4, it was noted that those trucks in the test program having Detroit Diesel V-6 turbo, 2-cycle engines exhibited significant increases in exhaust gas noise levels. Further analysis of one of these vehicles, Truck Number 6, revealed a marked resonance in the exhaust system noise. Addition of a tailpipe extension with absorptive lining eliminated this resonance and reduced total vehicle noise. Truck Number 41 employed the identical type of 2-cycle diesel engine as Truck Number 6, and exhibited the identical exhaust resonance characteristics. The Walker and Riker mufflers did not affect this resonance condition, while the Heavy Duty and Stemco mufflers enhanced the resonance, leading to jumps in total vehicle noise. Based on these data, it would appear that additional care must be taken in selecting the exhaust system for a 2-cycle engine to ensure minimization of exhaust gas noise. Use of a tailpipe extension having absorptive lining is recommended with the 2-cycle engine in order to reduce apparent resonance characteristics.

7.0 FAN CLUTCH EVALUATION

The fan clutch has become a very significant noise reduction device on heavy duty trucks within recent years. This has occurred because:

- o Fan clutch reliability has been dramatically improved resulting in increased confidence in the product by truck manufacturer and user;
- o Test programs by various organizations have shown a definite fuel savings when fan clutches are used;
- o The Interstate Motor Carrier Noise Regulation allows testing with the fan clutch in the off-mode.

In order to assess the impact of this retrofit device on reducing truck noise emissions, current information on fan clutch usage, acceptance, maintenance and projected usage has been compiled and reviewed. Results of this evaluation are presented in this section.

Published literature on fan clutch evaluation was acquired from three sources: International Harvester (for U. S. Department of Transportation);[6] Wyle Laboratories (for Motor Vehicle Manufacturers Association);[5] and Regular Common Carrier Conference Maintenance Committee cooperating with the Society of Automotive Engineers and the U. S. Department of Transportation.[9]

The results of the International Harvester study were presented in the EPA Background Document for New Truck Noise Emission Standards[7] and are the most comprehensive to date. Program objectives were to determine total fan-on time and noise significant fan-on time. No data were collected that would allow the determination of noise levels with the fan on and off. It was concluded that the significant fan-on time never exceeded 1 percent of the engine time. The "significant" fan-on time was defined as the time that the fan speed exceeded two-thirds of its maximum possible speed for a modulating-type fan clutch and 1600 rpm for on-off clutches. Figure 19 depicts the results of the International Harvester Test Program.

The data shown in Figure 19 were accumulated for the on-off clutches by using elapsed time meters on the engine and fan clutch. A multichannel tachograph was also used to monitor engine rpm and provide an event marker

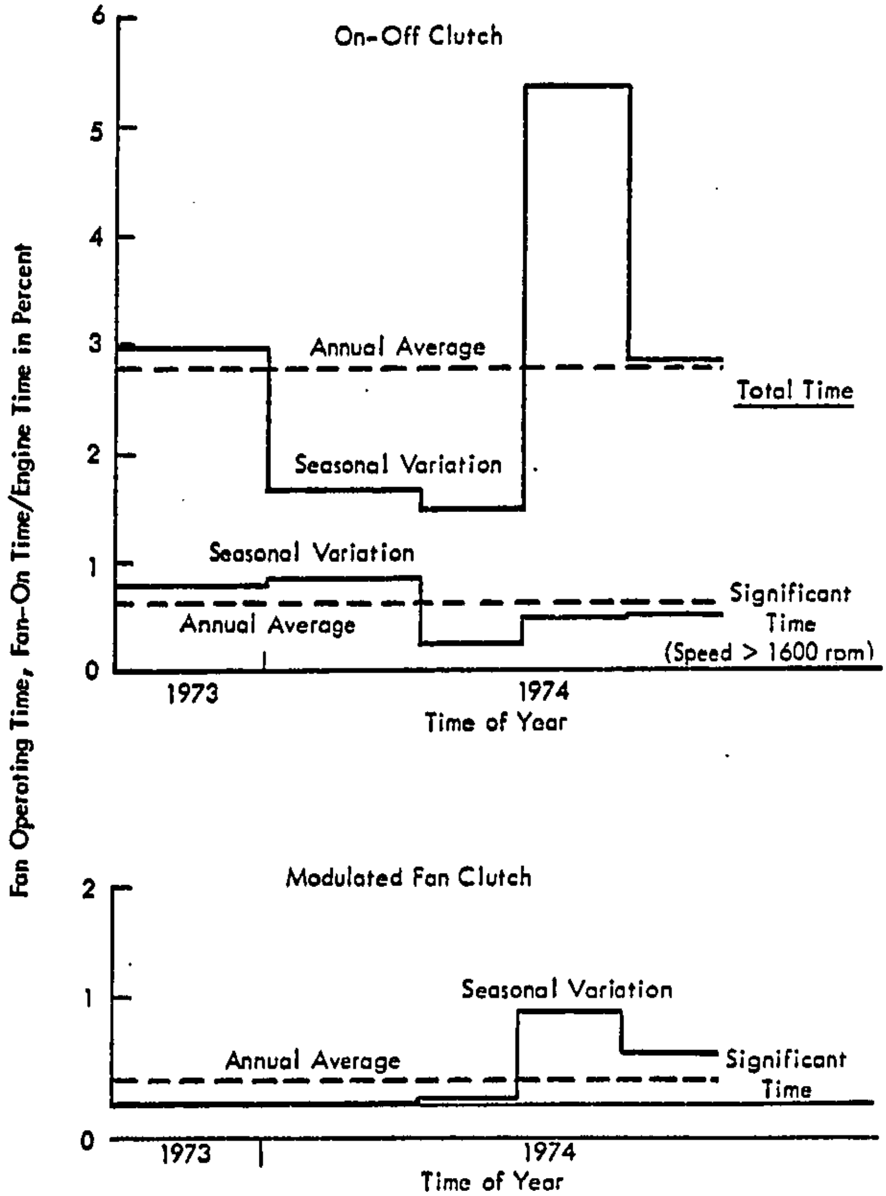

Figure 19. Fan Clutch Operating Time (Reference 5)

indicating clutch engagements. The top curve represents the total fan-on time as a percentage of engine-on time. The lower curve depicts fan-on time occurring above 1600 rpm, which is "significant fan-on time" by definition.

Data for the modulating-type fan clutch were recorded on a strip chart recorder. Parameters recorded were engine rpm, fan rpm, coolant temperature and ambient temperature as a function of time. The "significant fan-on time" curve represents the time duration relative to the total engine (in percent) for which the fan speed exceeded two-thirds of its maximum possible speed.

Consideration must be given as to what total truck noise level was used in establishing the significant fan-on time. This IH project was completed in 1974. Figure 20, taken from the Background Document,[10] shows that 95 percent of the trucks manufactured in 1973 produced levels less than 88 dB, with the remaining 5 percent ranging up to 92 dB.

The typical heavy duty truck configuration in 1973 had two major noise sources: the cooling system (fan), and the exhaust. The trucks on which fan noise was the predominant noise source had direct driven fans. The fan drive ratios used ranged from 1.0 to 2.0, meaning that if, for example, the engine was rated at 2100 rpm, the fan speed range would be from 2100 to 4200 rpm, depending on the drive ratio used.

Extensive component noise analysis performed during the DOT Quiet Truck Program resulted in data relating fan rpm to fan noise.[6, 11, 12] These results indicated that for those truck configurations where total vehicle noise ranged from 86 to 88 dB, fans operating at less than 1600 rpm would not be contributing to total truck noise. It was on that basis International Harvester used 1600 rpm in determining significant fan-on time for the fan clutch evaluation program.

In order that fan noise have no influence on total vehicle noise, it must be 10 dB below the total truck noise level. Thus, it can be estimated that with a truck noise level of 86 dB in 1973, the fan noise level would have to have been on the order of 76 dB. New 1978 trucks are required to meet an 83 dB level. Based on the 10 dB-down criteria, the fan noise would be required not to exceed 73 dB. Fan noise varies approximately 1.6 dB per 100 rpm.[6] Therefore, in order that fan noise would not influence new truck noise levels, the new significant rpm would be

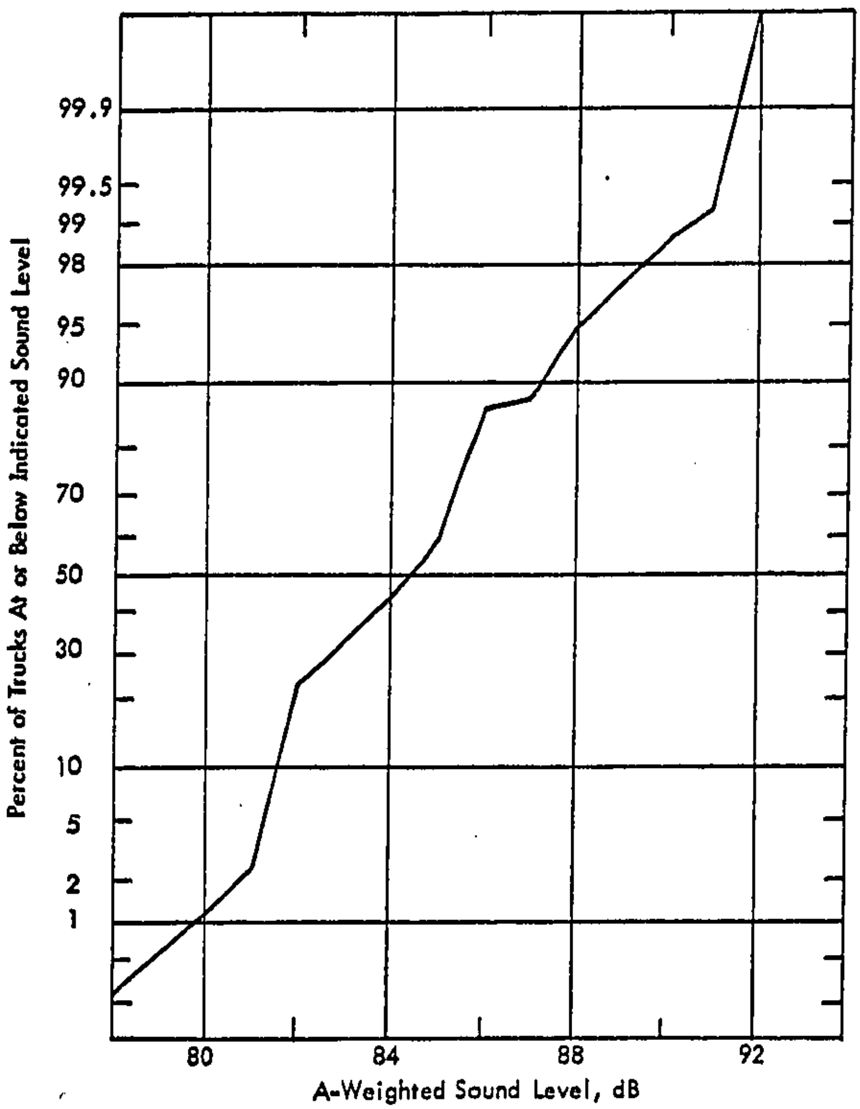

Figure 20. Cumulative Distribution of New Diesel Truck Noise Levels (Reference 10)

1400 rpm. This would indicate that significant fan-on time may be higher than the 1 percent for present vehicles shown in the International Harvester test results.

The study done by Wyle for the Motor Vehicle Manufacturers Association[5] indicated a fan-on time of 13.8 percent of engine-on time for summer, and 2.6 percent for winter. Seven of the eight fan clutches monitored were on-off type. No fan rpm measurements were recorded so it is not possible to assign a noise significant fan-on time to these data.

A Fuel Economy Demonstration study was performed in St. Louis by the Regular Common Carrier Conference Maintenance Committee in 1977. Fan on-time was not monitored, but fuel consumption testing with and without a fan clutch resulted in a 3.7 percent decrease in fuel consumption.[9]

Seven of the major manufacturers of fan clutches were contacted under this study. Based upon discussions with these manufacturers, the following observations can be made:

- Most of the fan clutch manufacturers have done testing by themselves or had it performed by some other organization such as RCCC or International Harvester. International Harvester, under the DOT Quiet Truck Program, tested 24 trucks with on-off and modulating type fan clutches.[6] One manufacturer indicated that they are in the process of setting up a lab for a fan clutch noise testing.
- Manufacturer estimates as to the number of 1978 trucks equipped with fan clutches vary from 52 to 60 percent for Class VII and VIII trucks. Truck users estimate that 80 percent would be using fan clutches to meet the 1978 Interstate Noise Regulation.[9] Almost all the fan clutch manufacturers agreed, that in 1982, approximately 90 percent of the Class VII and VIII trucks will be equipped with a fan clutch.
- Noise degradation as a result of in-service use of the truck fan clutch is very small. Most of the manufacturers agreed that there is not enough test data to prove or disprove that noise levels increase or decrease as the fan clutch is engaged.
- Noise reduction from 2 to 6 dB can be obtained by the use of fan clutches.

- o Failure of the fan clutch system will cause an increase in noise levels. However, most of the manufacturers point out that the failure rate of the fan clutch is less than 1 percent. Failure usually occurs in the bearings, loss of viscous fluid, or air leaks in the clutch.
- o All of the manufacturers pointed out that the fan clutch not only reduces noise but saves fuel from 5 to 12 percent. Therefore, fuel economy would be expected to be the dominant selling point for use of fan clutches.

Table 16 presents a summary of operational and noise data collected from the following manufacturers of fan clutches, not necessarily presented in the same order as shown in the table: Horton, Schwitzer, Rockford, Evans, Eaton, Facet, and Bendix.

Table 16

Summary of Operational and Noise Data Collected from Manufacturers of Fan Clutches

Manufacturer	Type of Fan	Time On %	Noise Reduction	Predicted % for Classes VII & VIII		Warranty Kilometers/Year	Failure %	Fuel Saving %
				1978	1982			
A.	Modulated	1.25	3-6 dB In-Cab	25-30	90		< 1	-
B.	On/Off	3.0	-	75	100		< 1	6-10
C.	On/Off	5.0	2 dB Exterior	55-60	95	All Have	0.9	12
D.	On/Off	5.0	-	-	-	160,000	-	10
E.	On/Off	1.0 2.0	3 dB Exterior	52	90	or	-	10
F.	On/Off	5.0	-	-	-	More	-	5
G.	On/Off	-	-	-	-		-	5.33

8.0 REFERENCES

1. U. S. Environmental Protection Agency, "Environmental Protection Agency - Noise Emission Standards for New Medium and Heavy Duty Trucks," Title 40, Code of Federal Regulations, Chap. I, Part 205, 41 FR 15544, April 13, 1976, as Amended at 41 FR 17732, April 28, 1976; 42 FR 11835, March 1, 1977.

2. U. S. Department of Transportation, "Department of Transportation Bureau of Motor Carrier Safety - Regulations for Enforcement of Motor Carrier Noise Emission Standards," Title 49, Code of Federal Regulations, Chapt. II, Part 325, 40FR 42437, September 12, 1975, Effective October 15, 1975, Amended 41 FR 10227, March 10, 1976; 41 FR 28267, July 9, 1976.

3. U. S. Department of Transportation, "Department of Transportation, Federal Highway Administration Vehicle Interior Noise Levels," Title 49, Code of Federal Regulations, Chapt. III, Subchapter B, Part 393.94, 38 FR 30880, November 8, 1973; as Amended at 40 FR 32335, August 1, 1975; 41 FR 28628, July 9, 1976.

4. Davy, B., Sharp, B., Plotkin, K. and Sutherland, L., "A Study of the Effect of Environmental Variables on the Measurement of Noise from Motor Vehicles," Wyle Research Report WRC 74-18, for the Motor Vehicle Manufacturers Association, 1974.

5. Brown, R., "Deterioration Factors Related to Vehicle Noise and Measurement of Automatic Engine Cooling Airflow Control Duty Cycles," Wyle Research Report WCR 75-14, for the Motor Vehicle Manufacturers Association, October 1975.

6. U. S. Department of Transportation, "Truck Noise IV-A, Project Summary - The Reduction of Noise Levels on the International Harvester Quieted Truck," Report No. DOT-TST-76-89, Final Report, June 1976.

7. U. S. Environmental Protection Agency, "Background Document for Medium and Heavy Truck Noise Emission Regulations," EPA Report No. 550/9-76-008, March 1976.

8. Detroit Diesel Allison, <u>Detroit Diesel Engines Driver's Handbook 1978</u>, USA.

9. American Trucking Association, Meeting Notes of RCCC Subcommittee, San Diego, December 1977.

10. U. S. Environmental Protection Agency, "Background Document to Proposed Interstate Motor Carrier Regulations," Fed. Reg. Vol. 38, No. 144, Part I.

11. Bender, E. K., "Source Analysis and Experiments with Noise Control Treatments," U. S. Department of Transportation Report No. DOT-TST-74-20, 1974.

12. U. S. Department of Transportation, "Truck Noise V-A - Noise Reduction Tests and Development Performed on the White Motor Corporation Quieted Truck," Report No. DOT-TST-75-61, Final Report, January 1975.

APPENDIX A

Photographs of Test Vehicles and
Test Site Locations

Figure A1. Vehicle Configuration for Truck Numbers 2, 3, 4, 5

Figure A2. Vehicle Configuration for Truck Numbers 6, 9

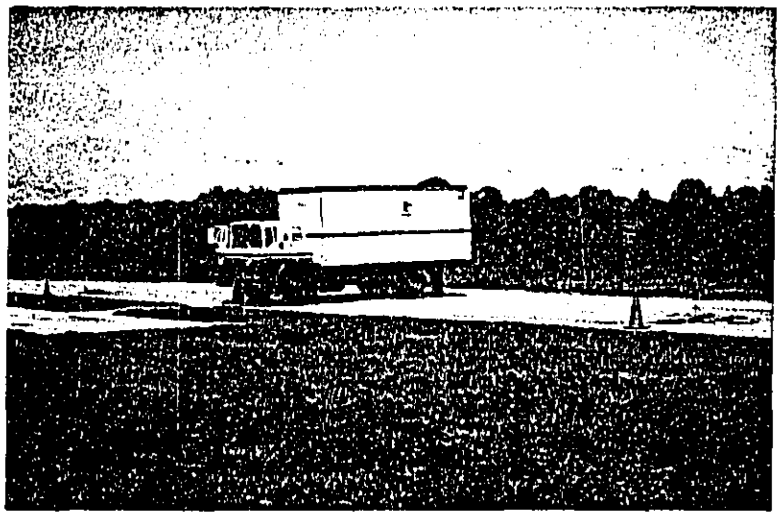

Figure A3. Vehicle Configuration for Truck Numbers 7, 8

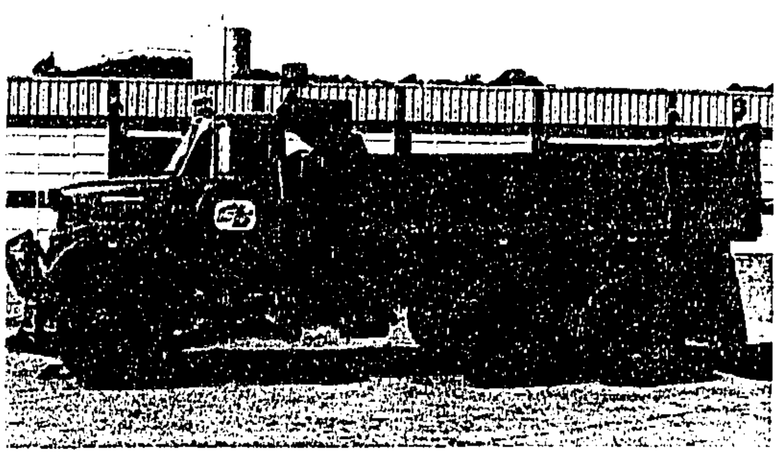

Figure A4. Truck Number 10

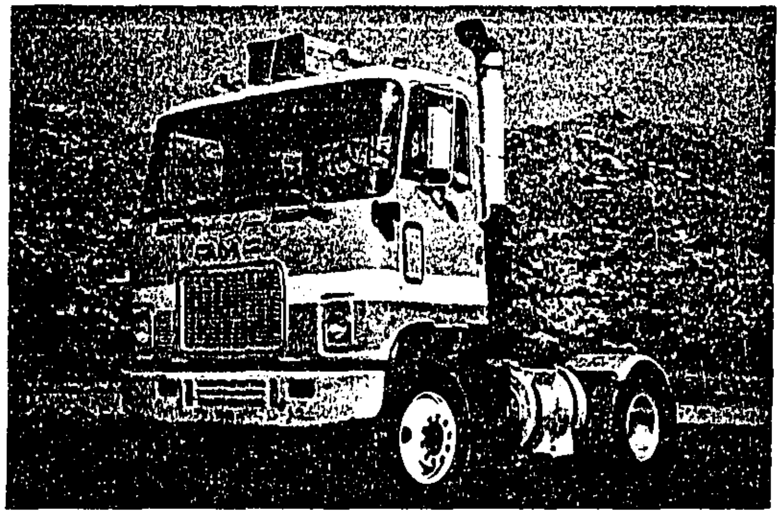

Figure A5. Truck Number 11

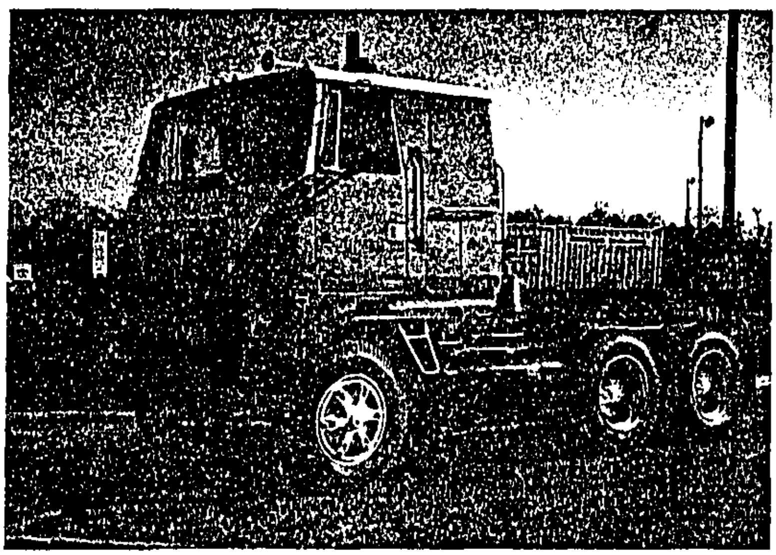

Figure A6. Truck Number 13

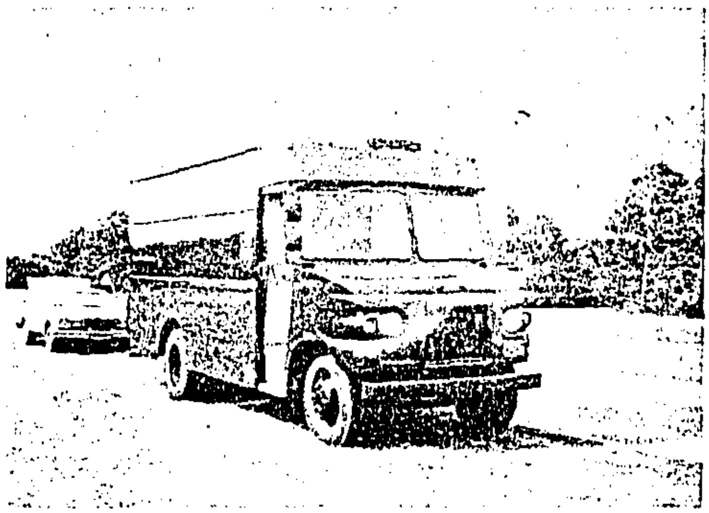

Figure A7. Truck Number 16

Figure A8. Truck Number 17

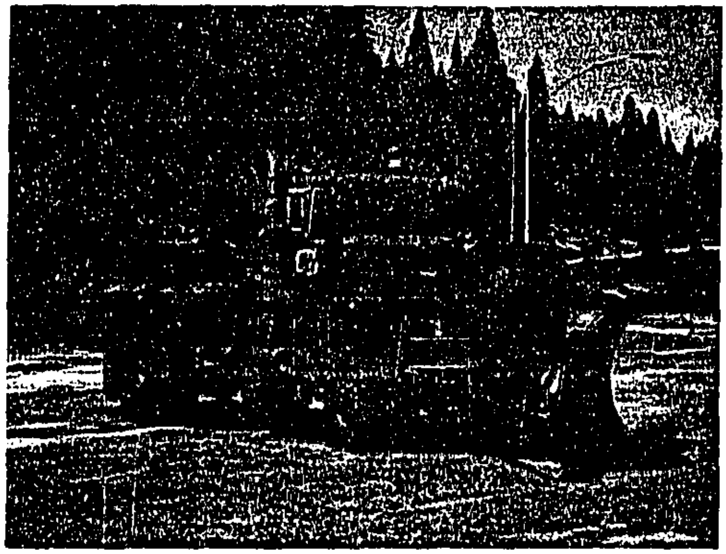

Figure A9. Truck Number 18

Figure A10. Vehicle Configuration for Trucks 21, 22

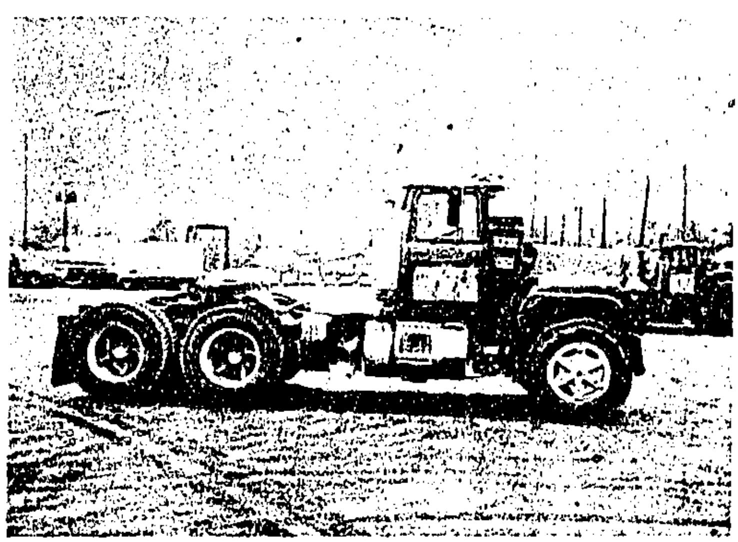

Figure A11. Vehicle Configuration for Truck Numbers 23, 24, 25, 26

Figure A12. Test Site for Truck Numbers 2, 3, 4, 5

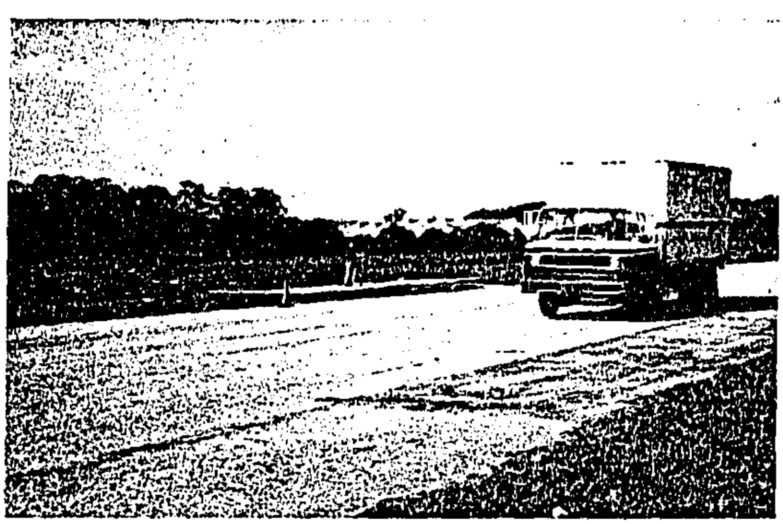

Figure A13. Test Site for Truck Numbers 7, 8

Figure A14. Test Site for Truck Numbers 6, 9

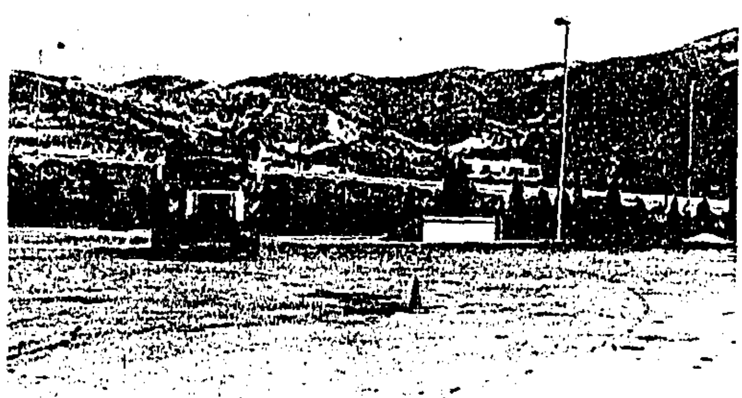

Figure A15. Test Site for Truck Number 10

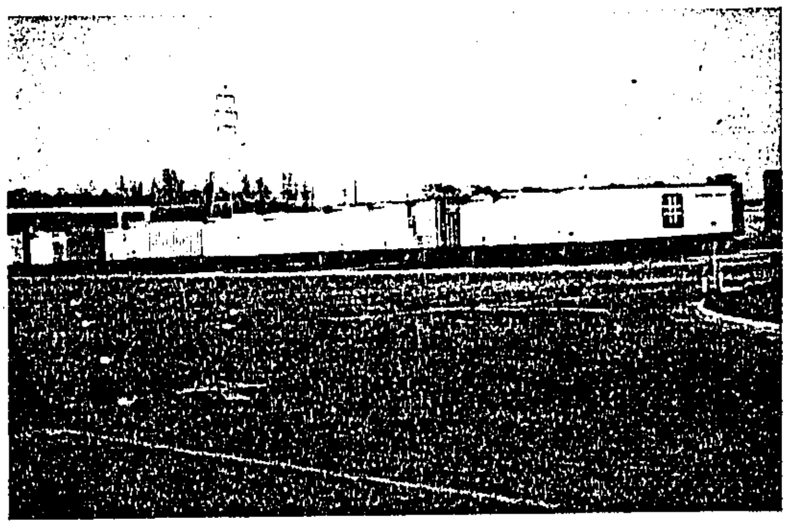

Figure A16. Test Site for Truck Numbers 12, 13, 15

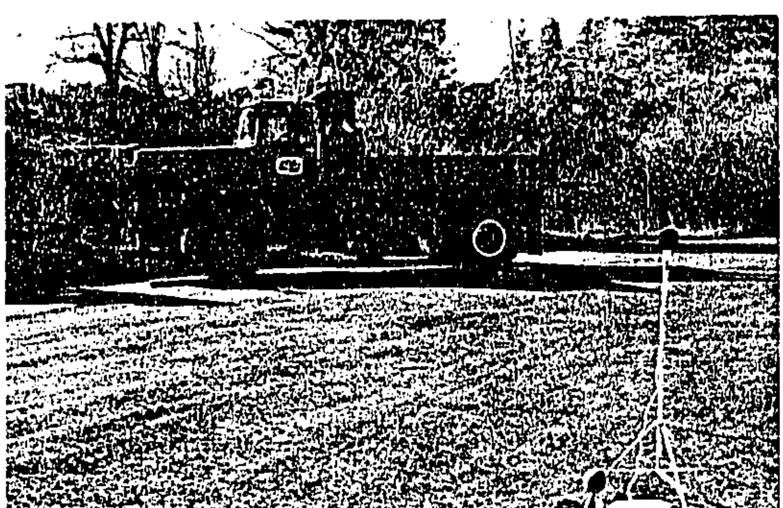

Figure A17. Stationary Test Site for Truck Number 17

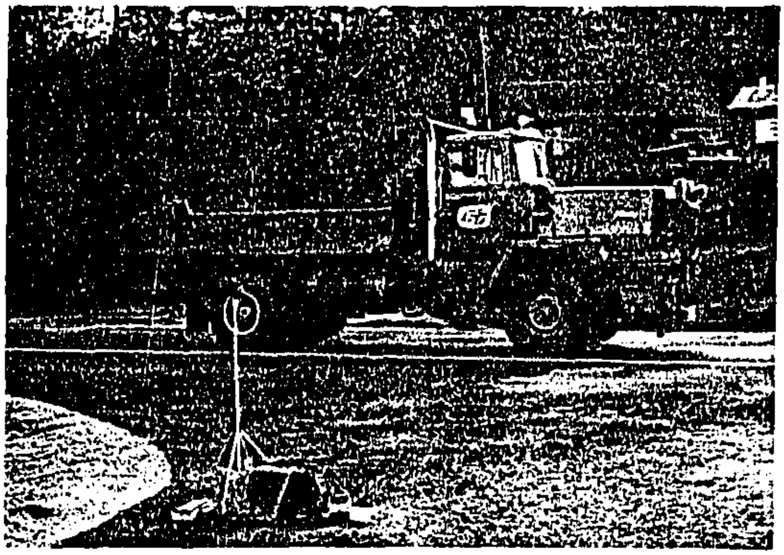

Figure A18. Pass-By Test Site for Truck Number 17

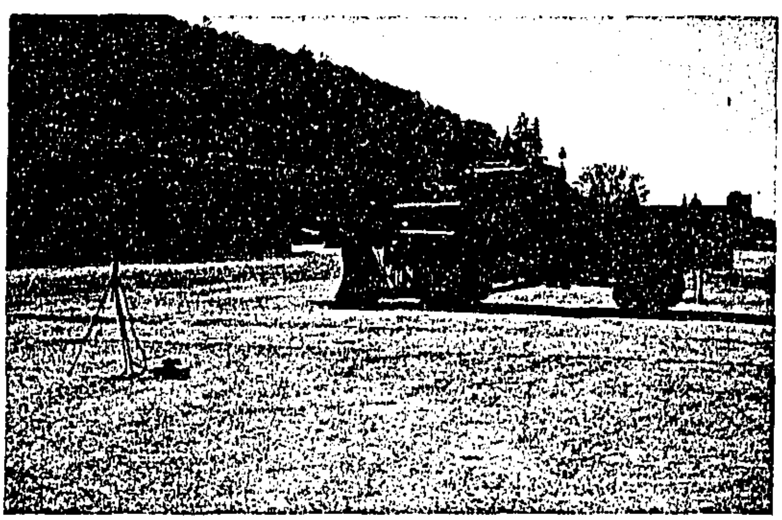

Figure A19. Stationary Test Site for Truck Numbers 18, 29

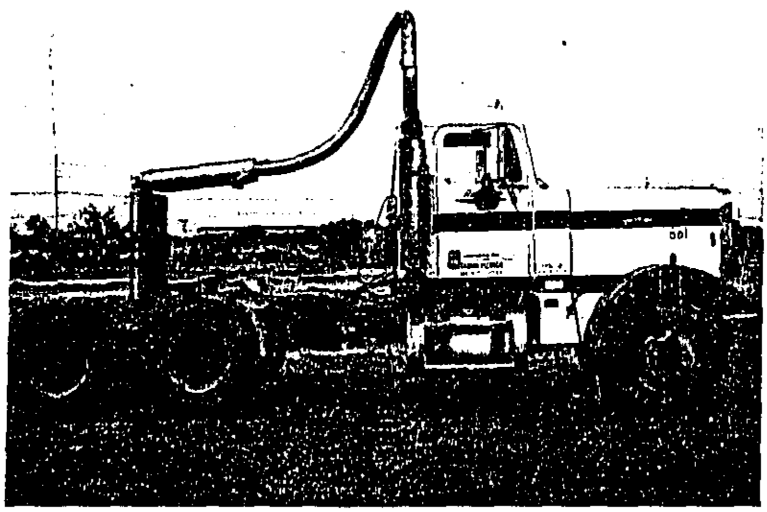

Figure A20. Exhaust Ducting Used on Truck Numbers 2, 3, 4, 5

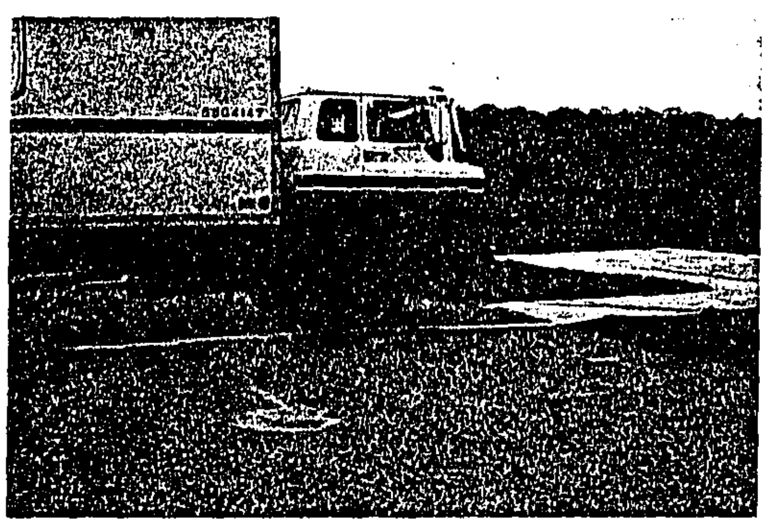

Figure A21. Exhaust Ducting Used on Truck Numbers 7 and 8

APPENDIX B

Stationary Test Site

Paving Specification

APPENDIX B

Stationary Test Site

Paving Specification

Background Document for Medium & Heavy Truck Noise Emission Regulations
(EPA Report No. 550/9-76-008, March 1976)

The surface shall be flat within ±0.05 meters (±1.97 in.)

Type 404 Asphaltic Concrete (3" nominal thickness)

Composition -

Aggregate Size

Sieve	% Passing
1/2	100%
3/8	90 - 100%
#4	45 - 75%
#16	15 - 45%
#50	3 - 22%
#200	0 - 8%

Bituminous Content	- 4.5 to 9.5%
Sealant	- R-P-335-D (Federal Specification)
Trade Name	- Jennite (Example)
Application	- 2 coasts applied without dilution by squeegee

APPENDIX C

Spectral Data Analysis

APPENDIX C

Spectral Data Analysis

The level and spectral content of truck noise is directly related to engine RPM. Engine RPM was monitored during testing with the tachometer installed in the instrument panel or a temporary installation just for the test duration. One vehicle, Number 6, had no permanent or temporary tachometer installation because of no tachometer drive gear on the injector pump.

It was therefore desirable to determine engine RPM from another source to substantiate the tachometer readings.

The following data analysis procedure was used to determine maximum engine RPM from the recorded noise data.

Figure C1 illustrates the instrumentation used for the data reduction.

A narrow band (1-1/4 Hz) analysis was performed using the Nicolet Mini-Ubiquitous Spectrum Analyzer. Graphs were plotted using the x-y plotter. Analysis of the data to determine RPM was performed by displaying two traces on the CRT of the analyzer. A trace was taken from a steady state condition of the engine and another from the point of maximum engine RPM during either passby or IMI testing. The cursor of the Ubiquitous Analyzer has two functions and both were used in determining maximum engine RPM. First, the cursor can identify any frequency on the trace displayed. Secondly, the cursor will identify the harmonics of that frequency. Traces were used from the steady state as a basis for analyzing the maximum RPM because it was found that most of the steady state traces exhibited very distinct peaks corresponding to the engine firing frequency and its subharmonics.

Engine RPM was calculated from the firing frequency (Hz) using the following relationships for the respective types of engines:

- o 2-cycle, 6-cylinder engines: RPM = 10 x (Frequency in Hz)
- o 4-cycle, 8-cylinder engines: RPM = 15 x (Frequency in Hz)
- o 4-cycle, 6-cylinder engines: RPM = 20 x (Frequency in Hz)

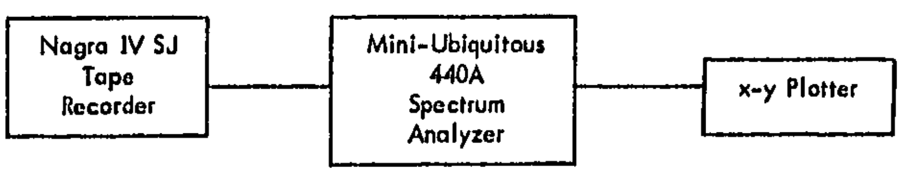

Figure C1. Instrumentation Used for RPM Determination

The curves shown in Figure C2 can be used as an example in demonstrating the RPM identification procedure. Curve B, engine steady state running condition, was first displayed and the trace evaluated by scanning with the cursor. An approximate range of engine RPM was known for this vehicle because the engine is factory rated at 2100 RPM. A distinct peak is shown at 203.7 Hz on trace B with a subharmonic peak at 33.95 Hz. The conversion factor for this engine is 10. If we consider 203.7 Hz as resulting from the firing of the engine, the RPM would be by 2037. If we consider 33.95 Hz as a subharmonic and convert it to RPM directly by multiplying by 60, we again arrive at 2037 RPM, indicating this frequency represents the engine RPM fundamental.

Curve A was then evaluated in the same manner using the cursor as the means of identifying frequency. Above 212.5 Hz, there is a definite dropoff which we considered characteristic of the transient signal occurring from the acceleration mode of the engine. Similar to Curve B, there is a distinct subharmonic peak occurring at 35.42 Hz. The maximum engine RPM is therefore identified at 2125 RPM by Curve A.

This procedure was followed in determining engine RPM for selected vehicles in this test program.

A second type of analysis was performed using one-third octave spectra. These spectra were then used on a comparative basis to determine if any change in frequency content had occurred from the beginning to the end of the test program.

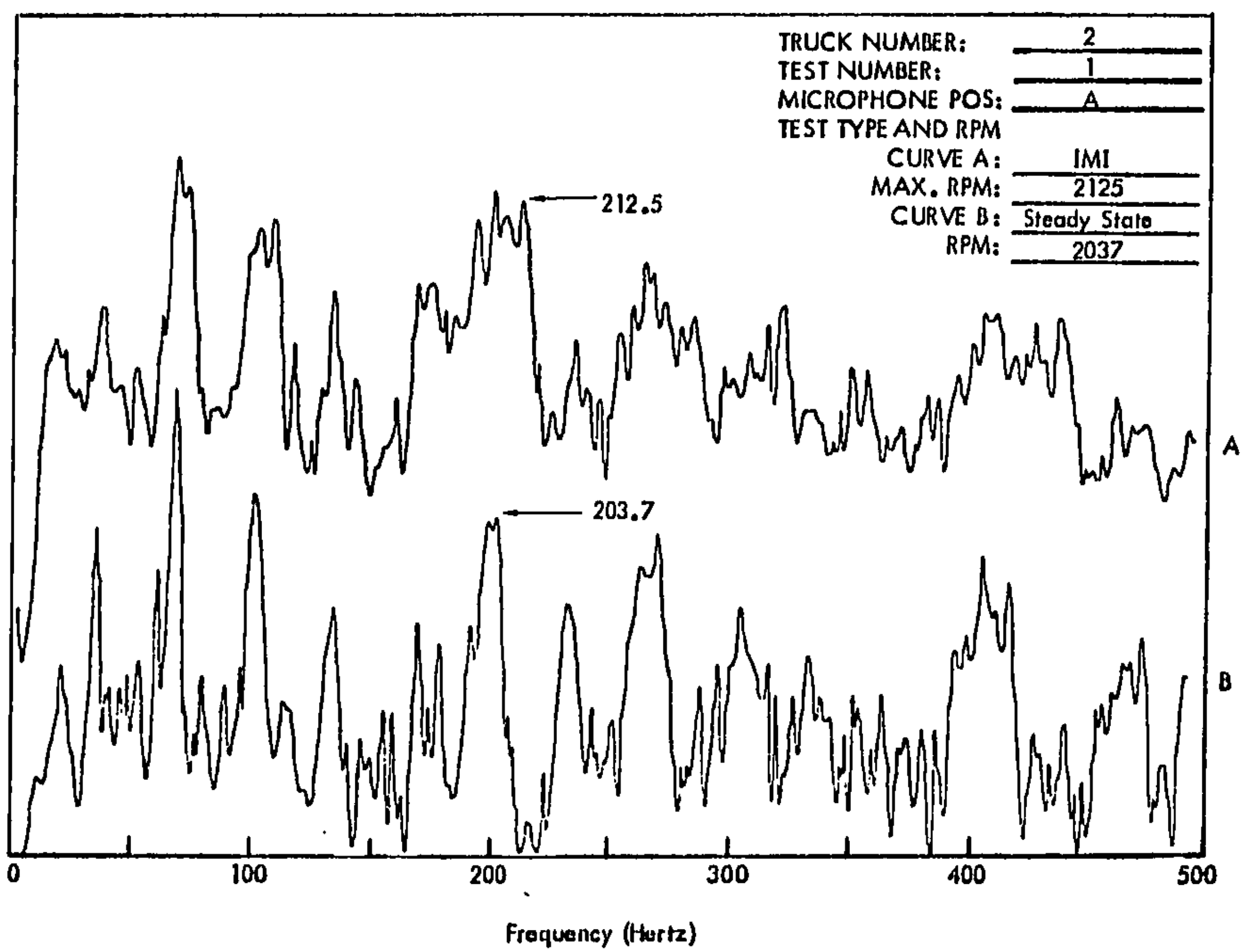

Figure C2 . Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

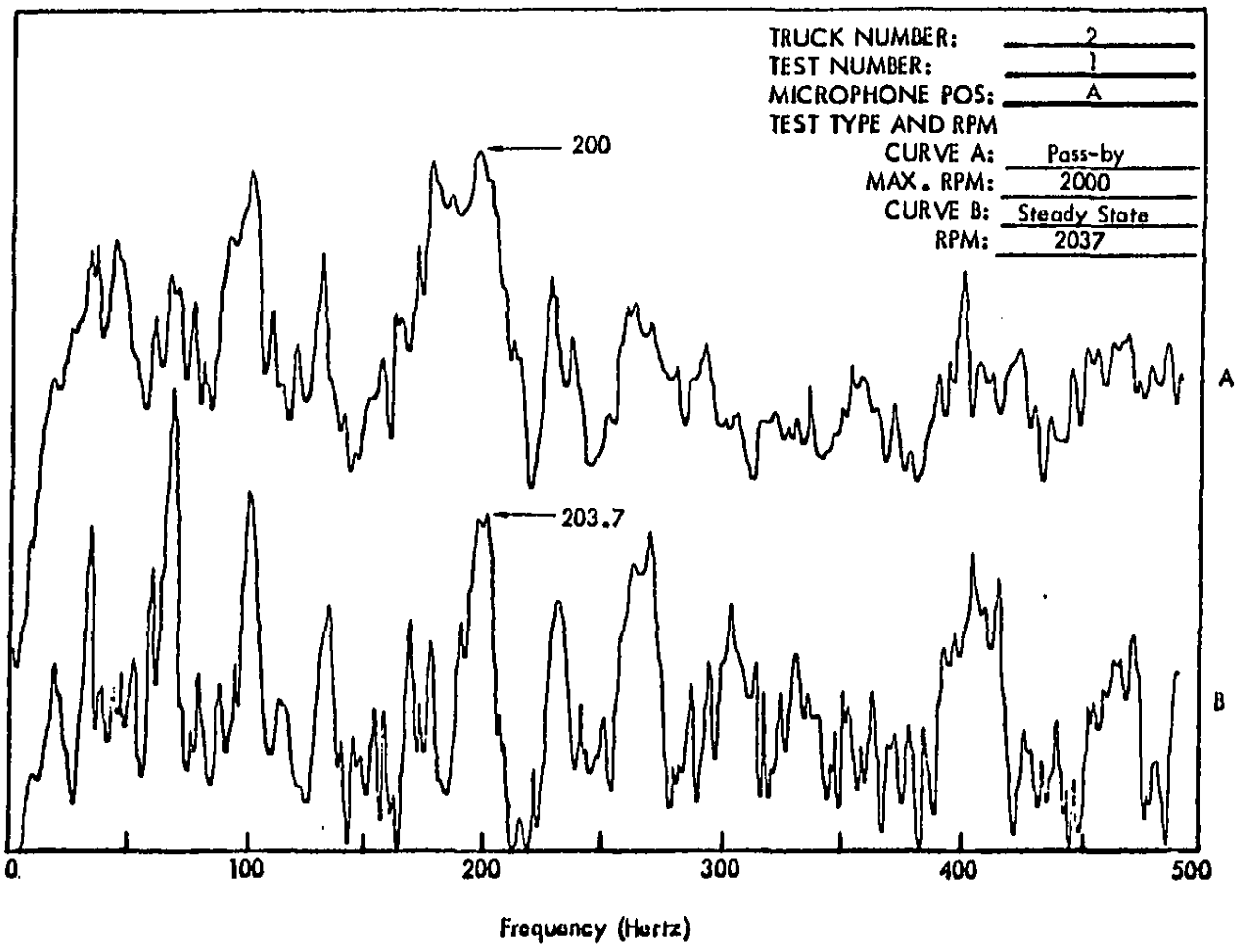

Figure C3 . Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

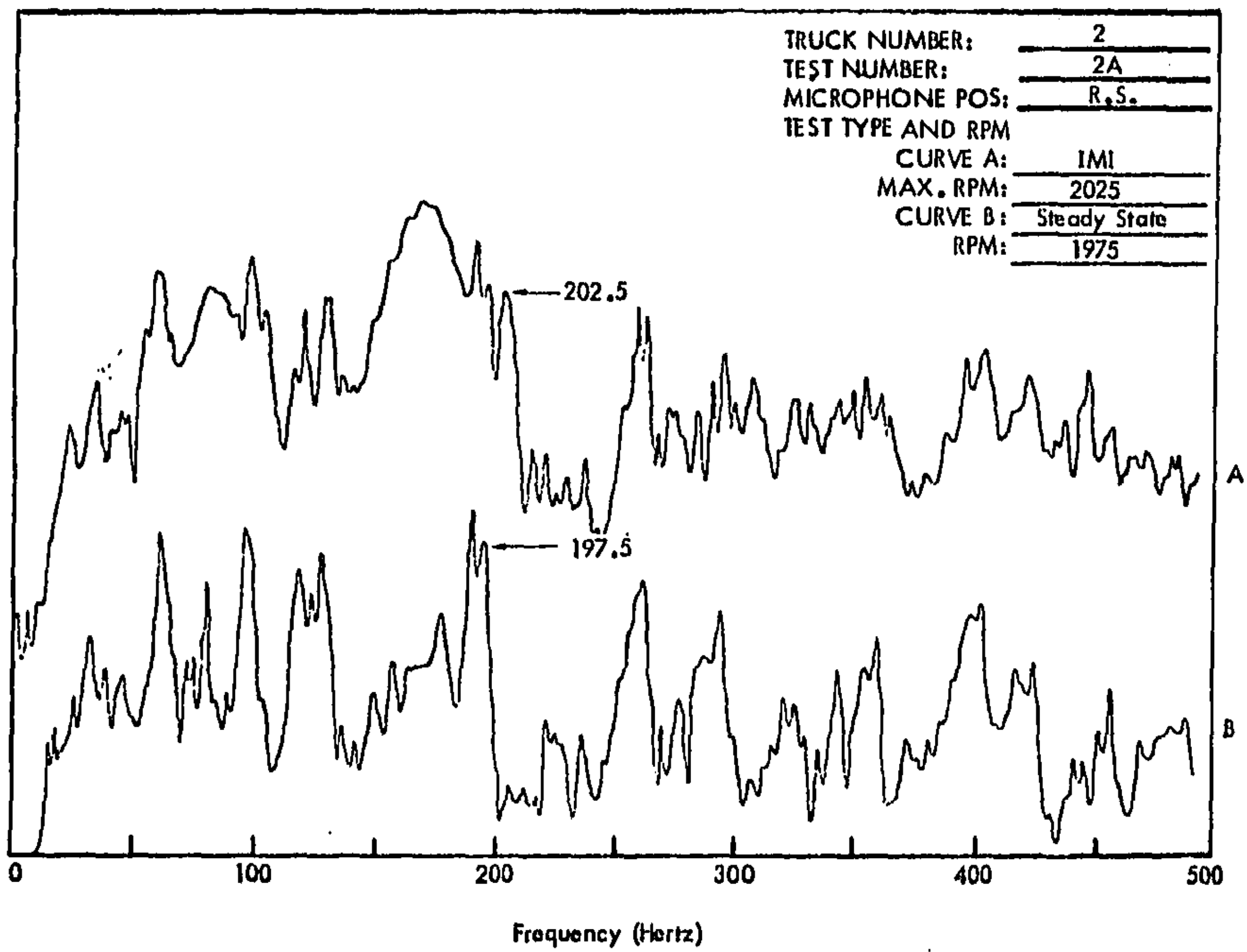

Figure C4. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

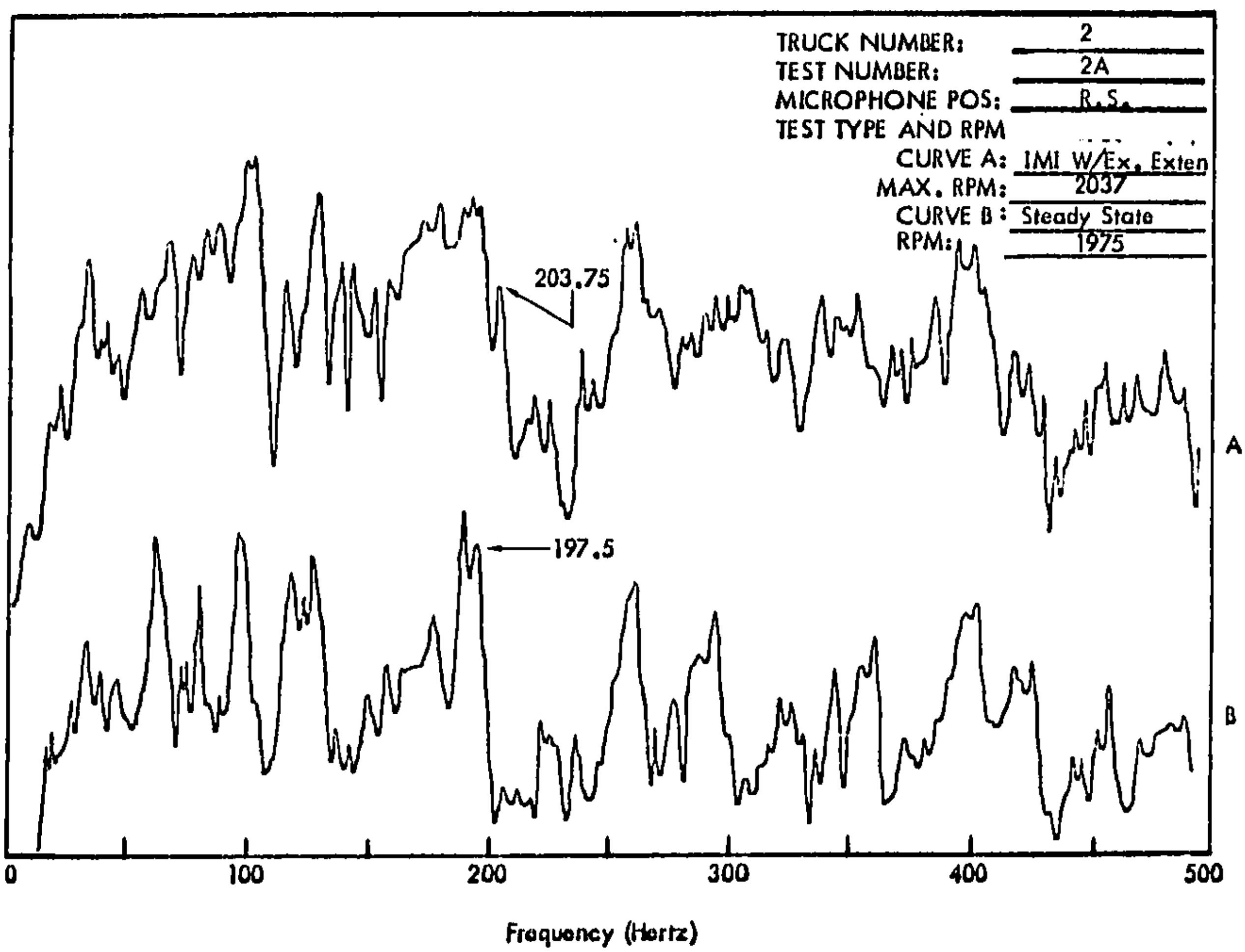

Figure C5. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

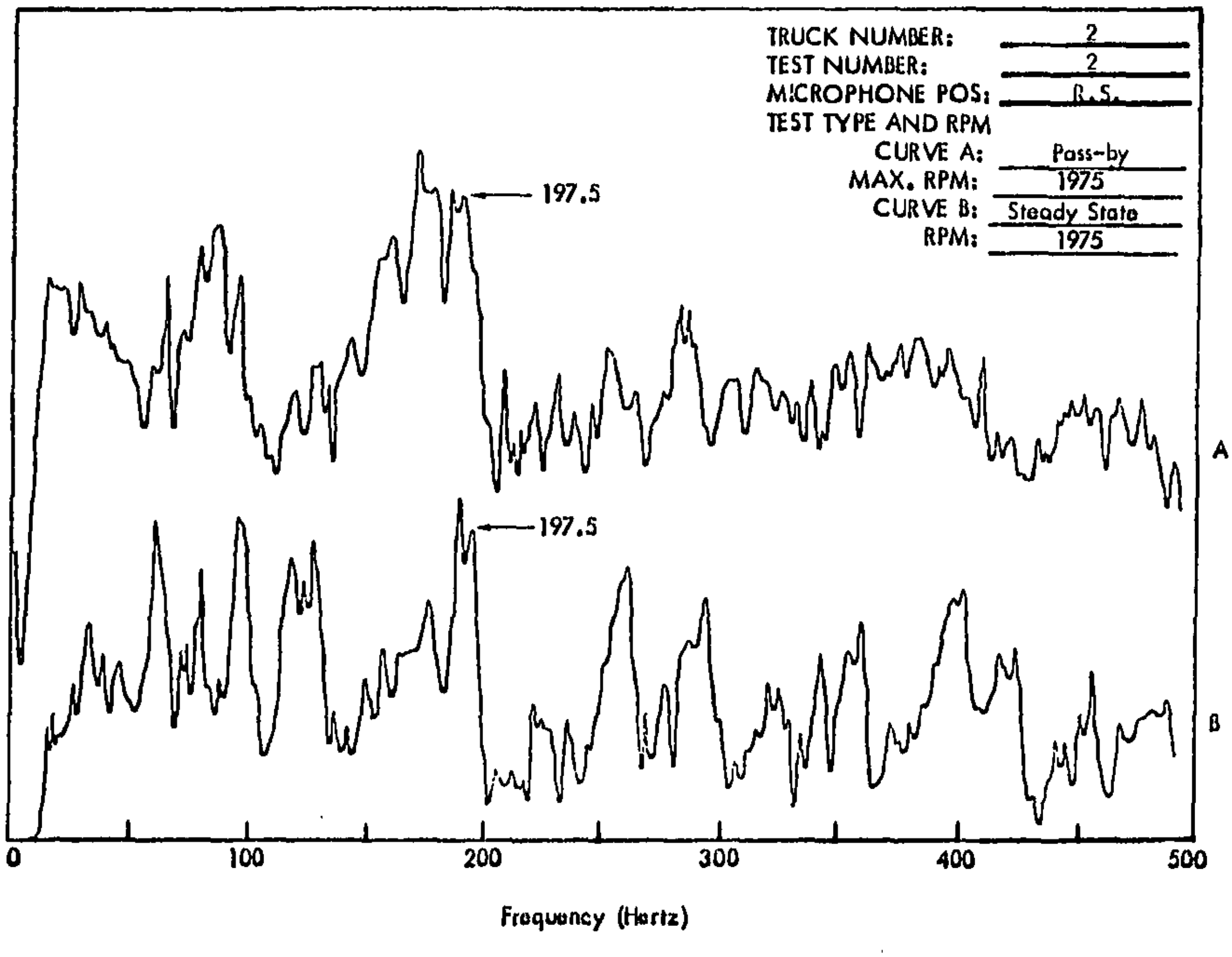

Figure C6 . Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

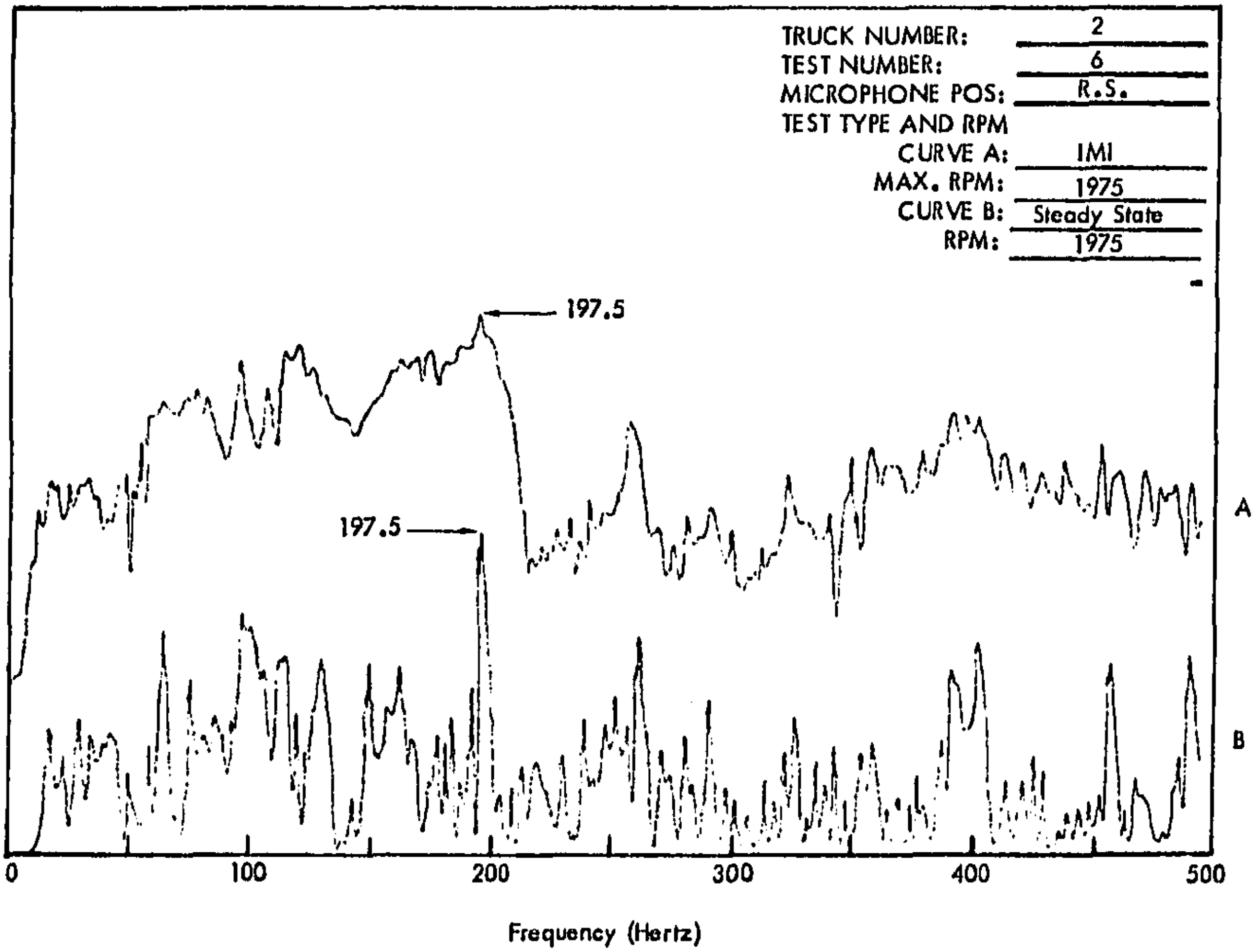

Figure C7 . Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

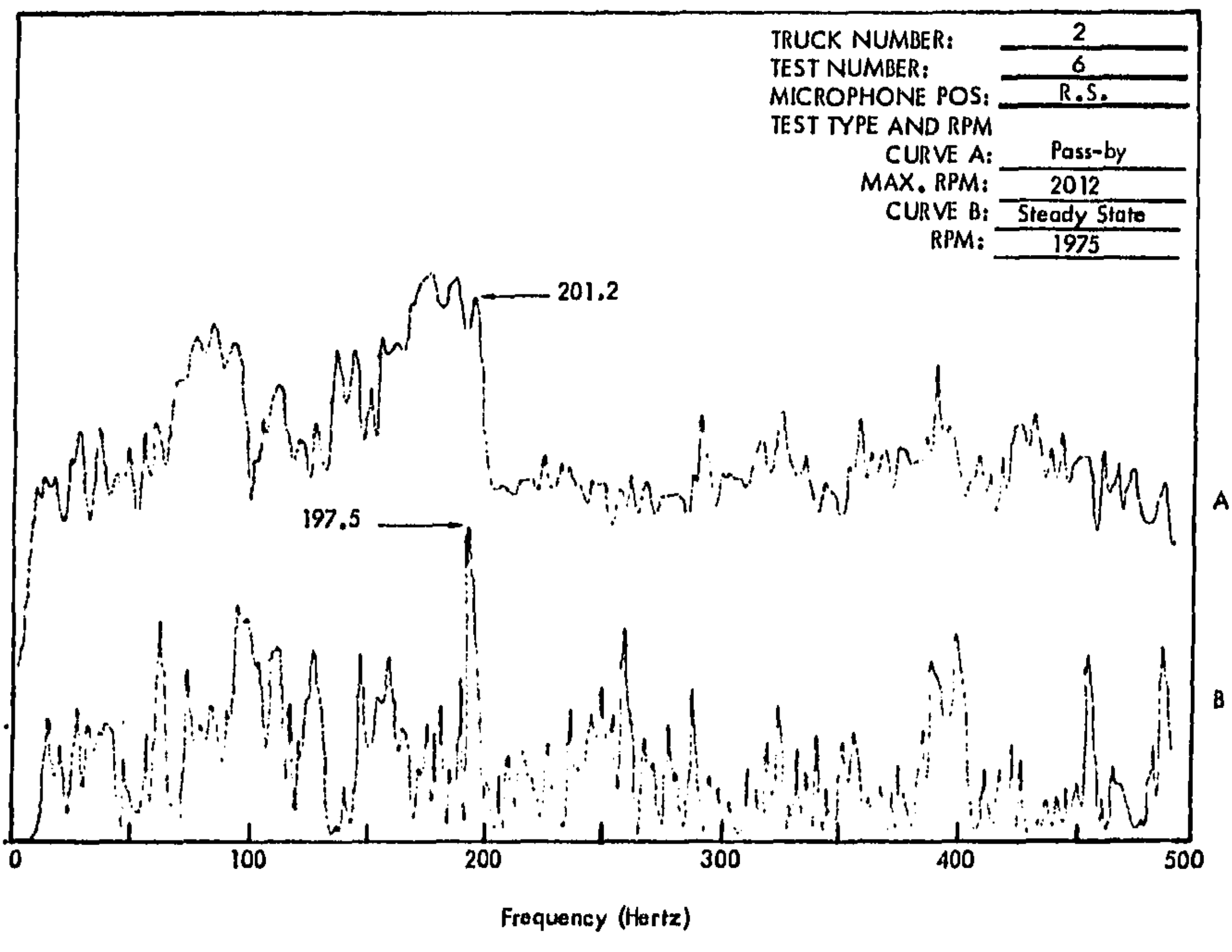

Figure C8 . Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

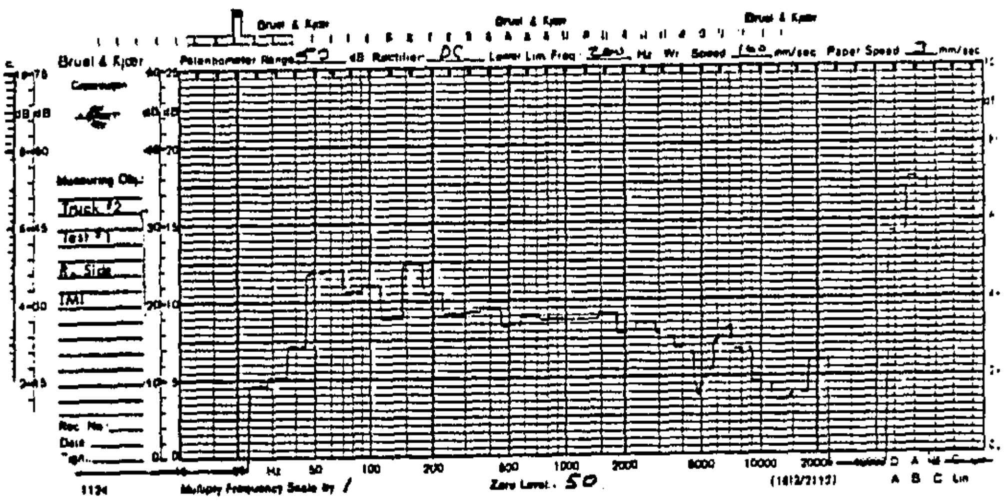

Figure C9. One-Third Octave Spectrum
Truck Number 2 Test Number 1

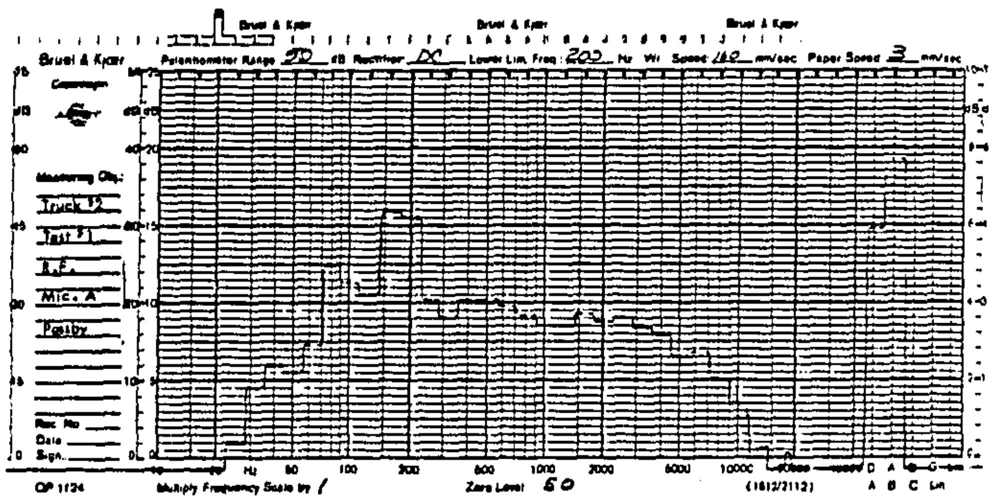

Figure C10 One-Third Octave Spectrum
Truck Number 2 Test Number 1

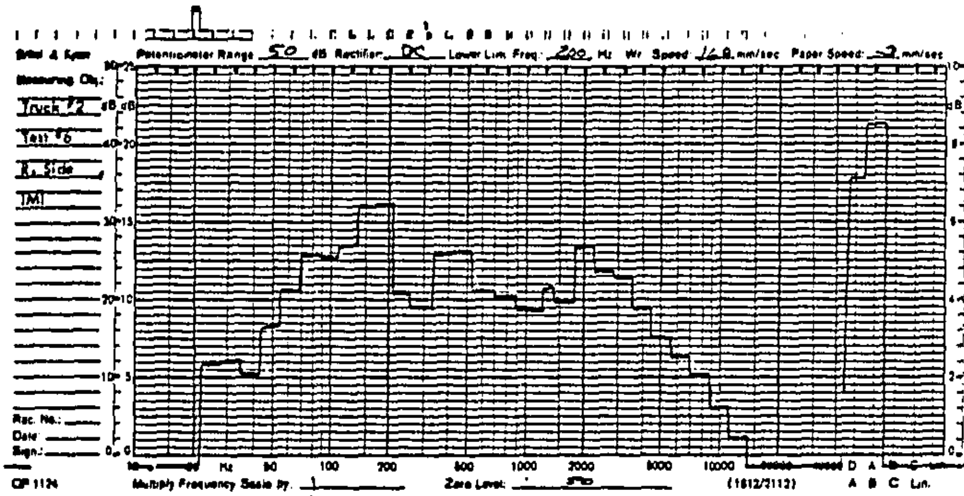

Figure C11. One-Third Octave Spectrum
Truck Number 2 Test Number 6

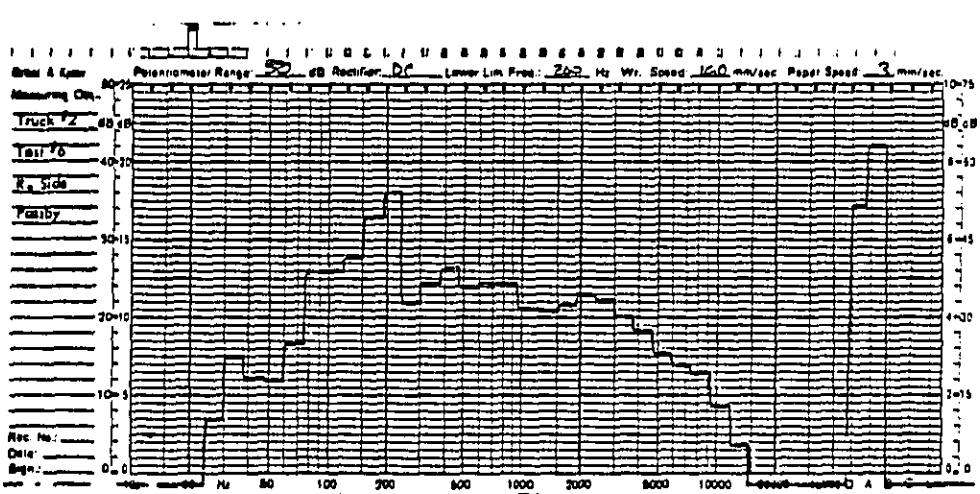

Figure C12. One-Third Octave Spectrum
Truck Number 2 Test Number 6

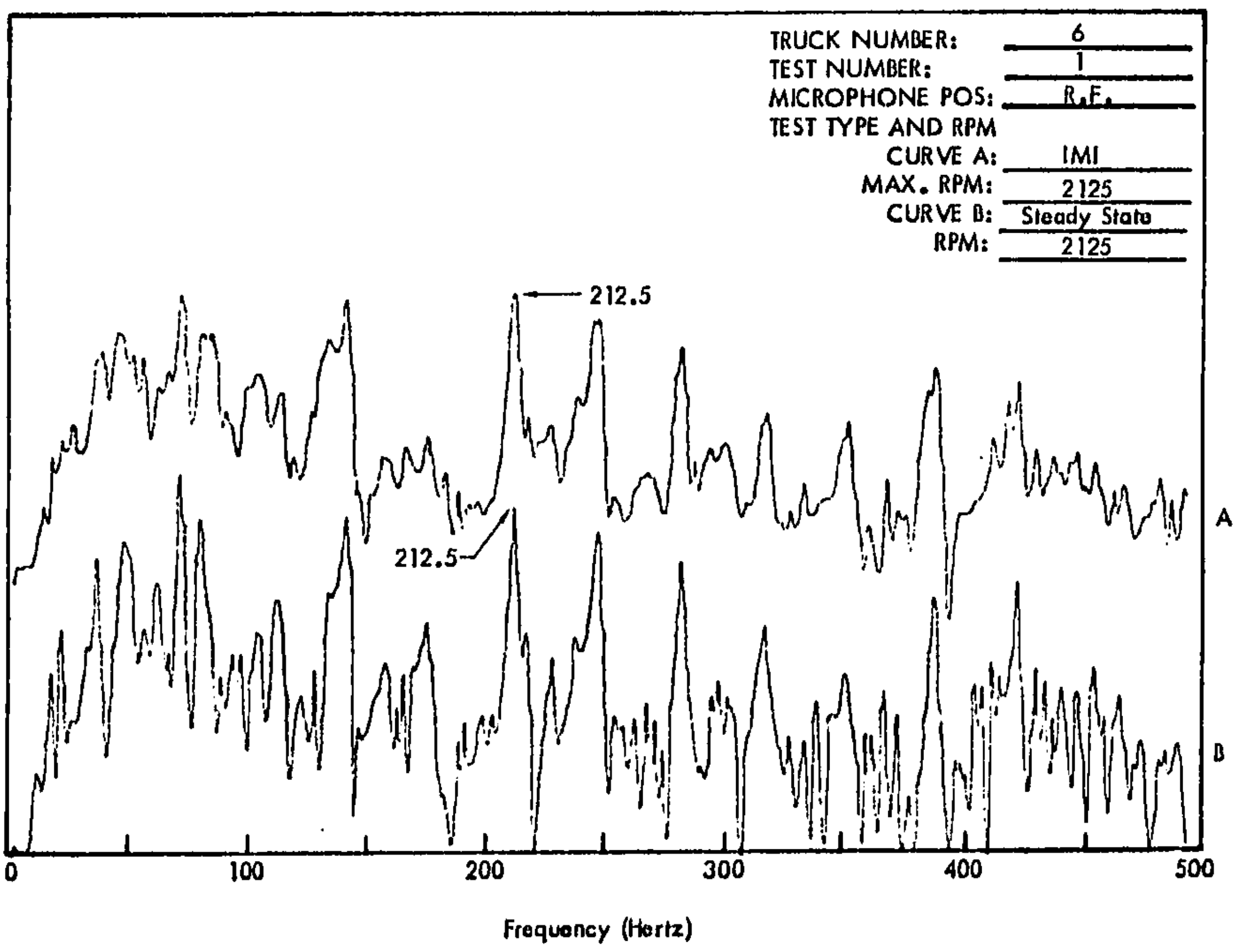

Figure C13. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

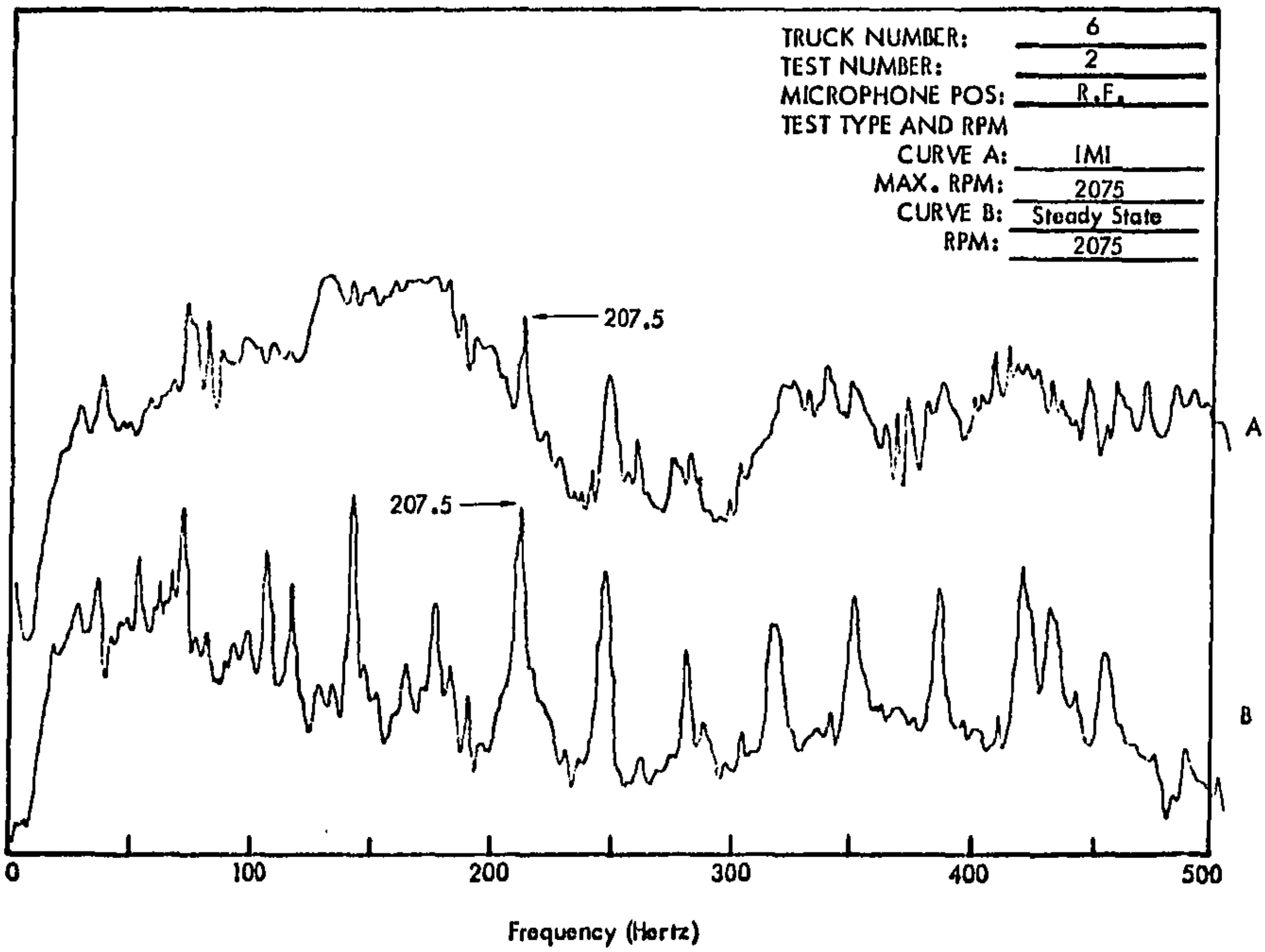

Figure C14. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

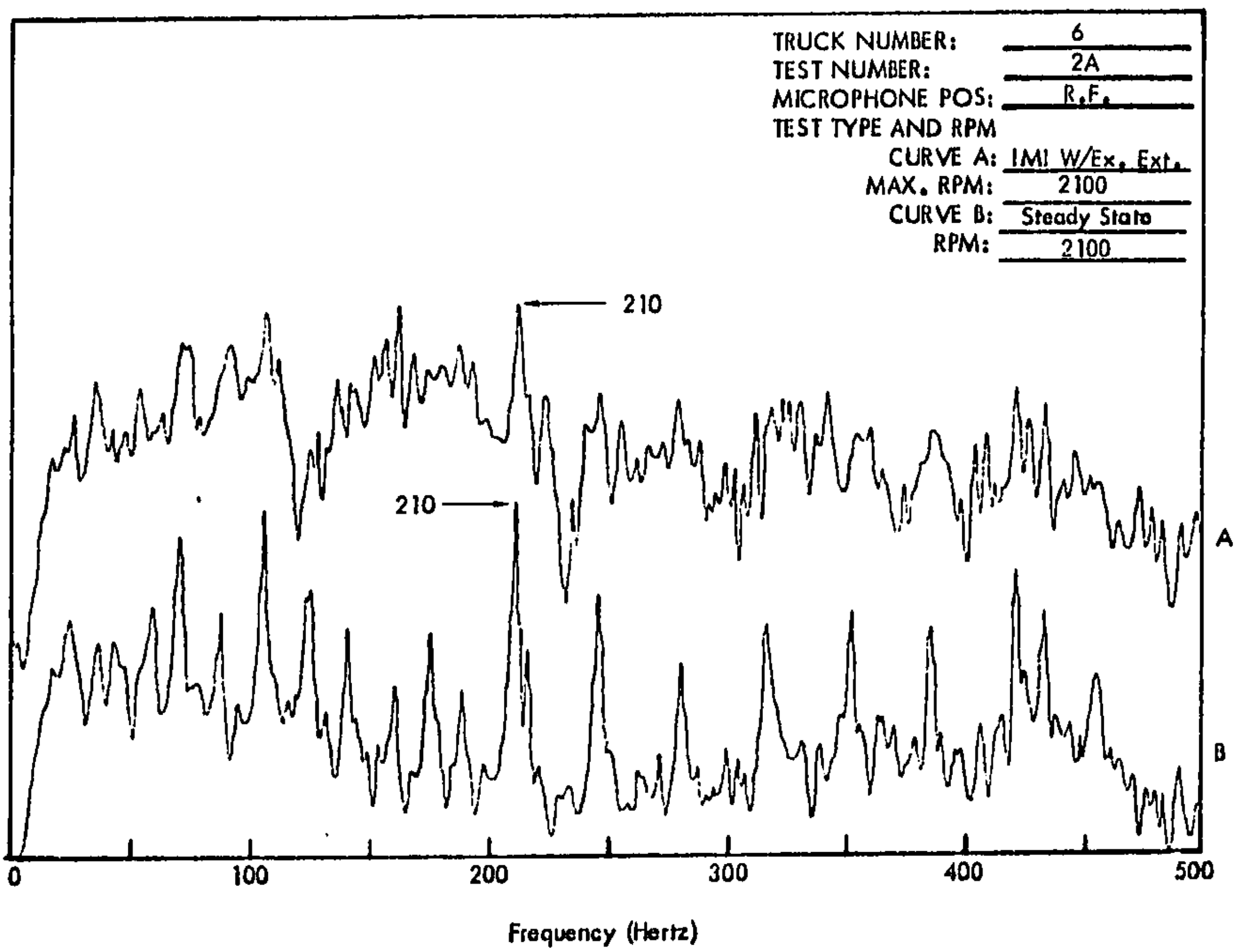

Figure C15. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

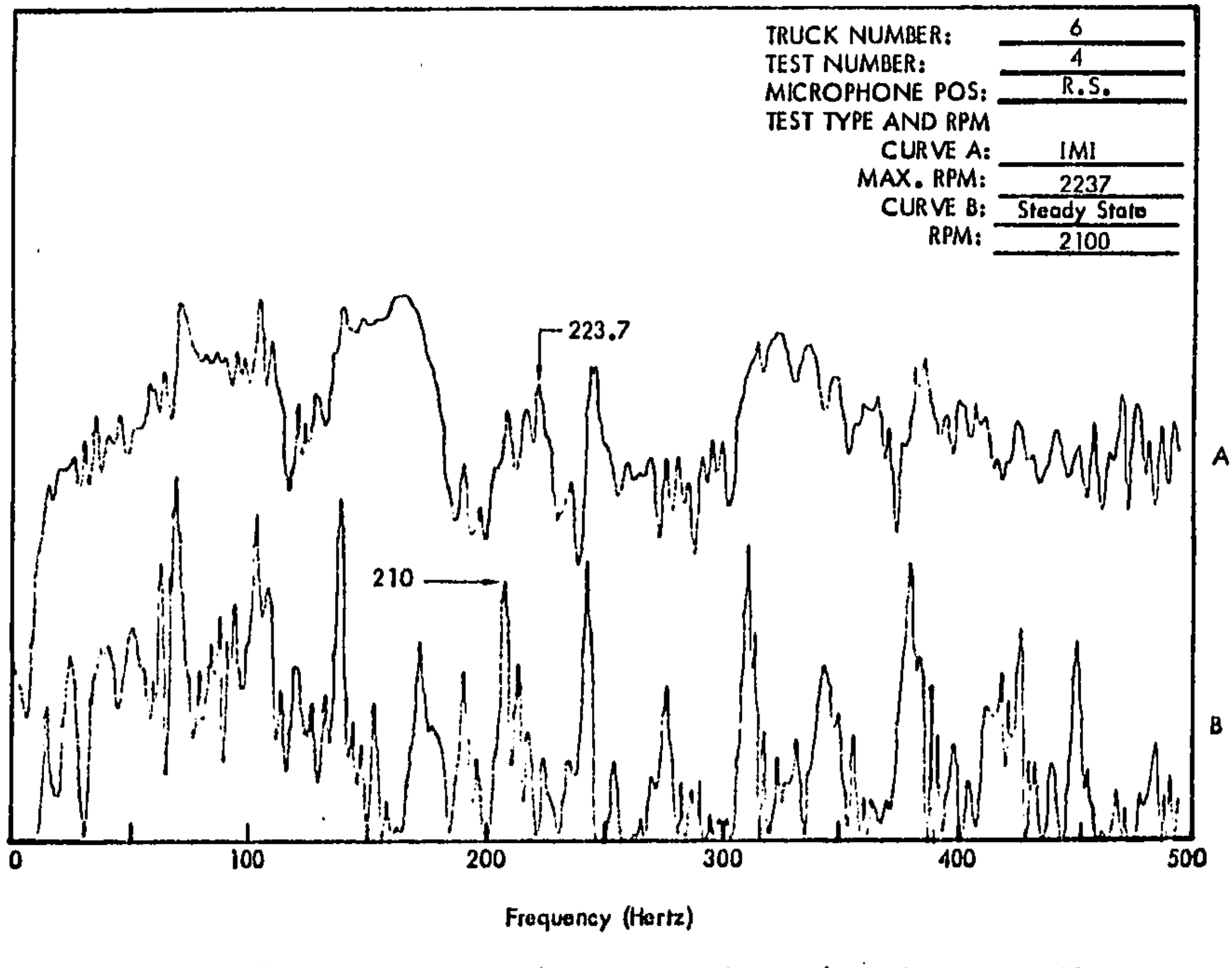

Figure C16. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

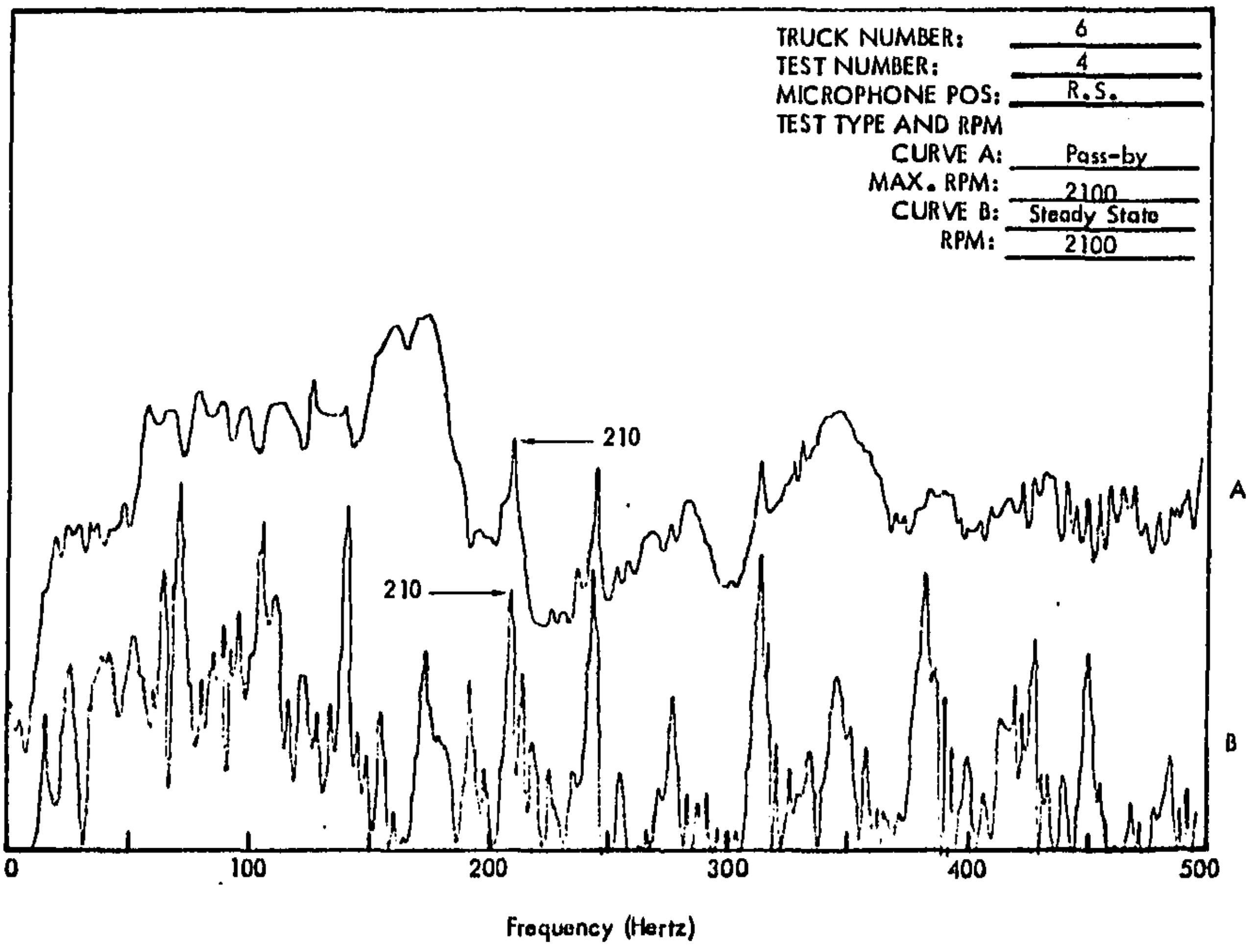

Figure C17. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

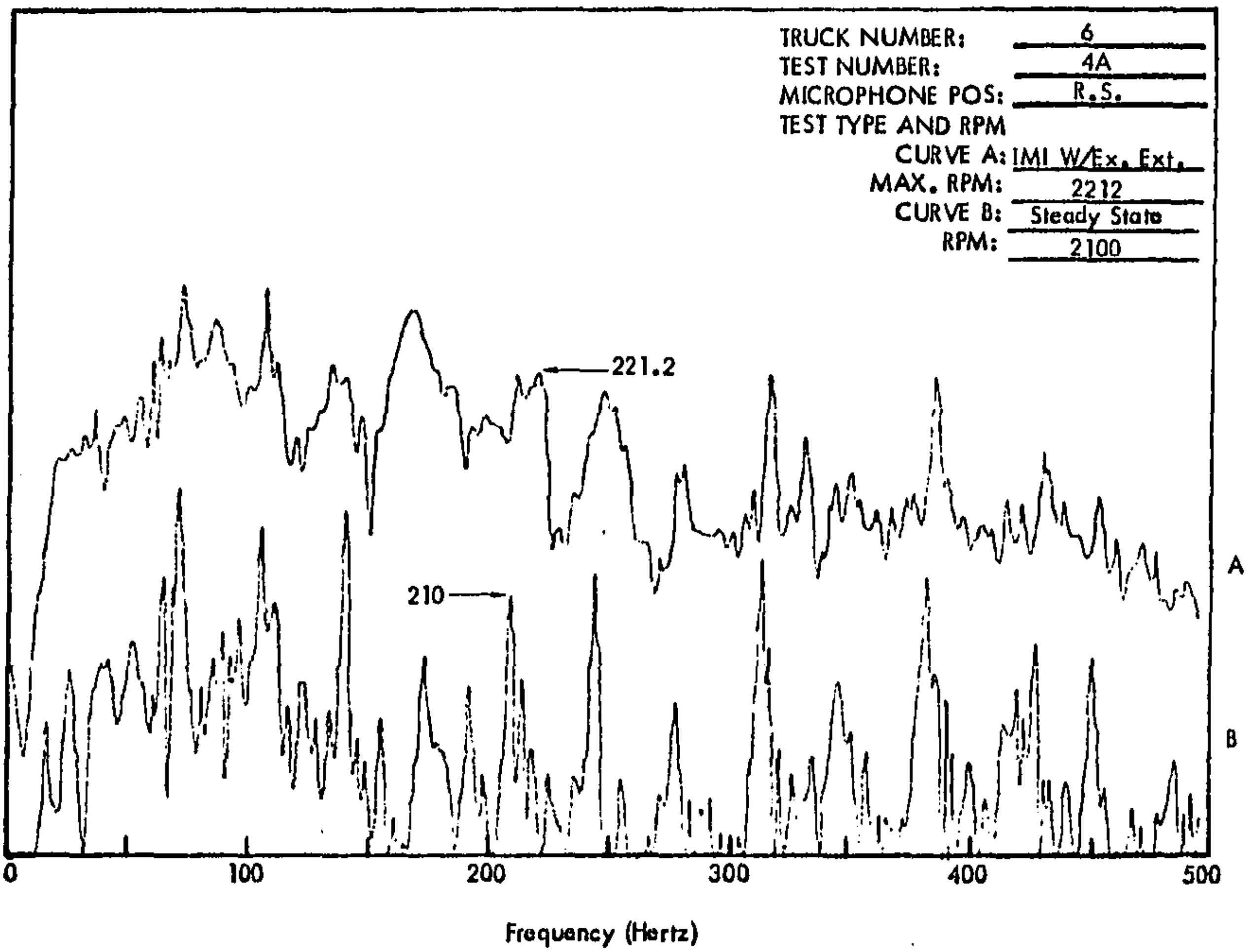

Figure C18. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

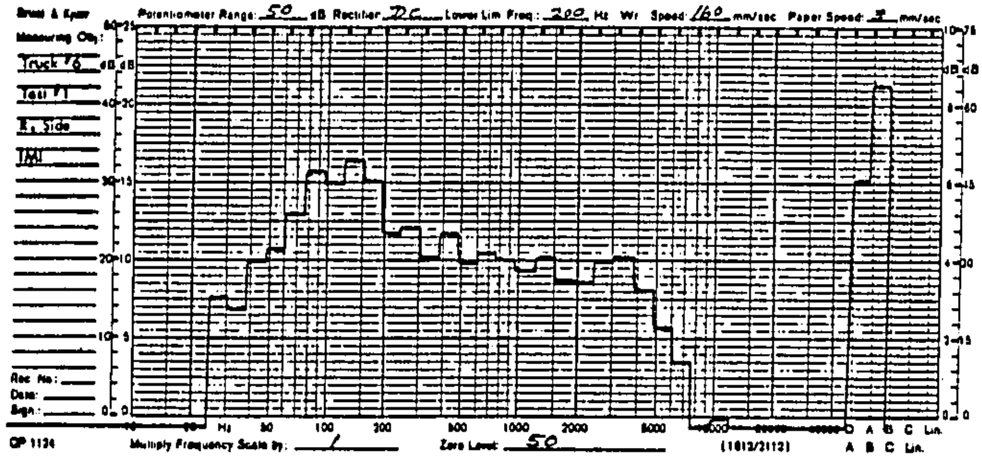

Figure C19. One-Third Octave Spectrum
Truck Number 6 Test Number 1

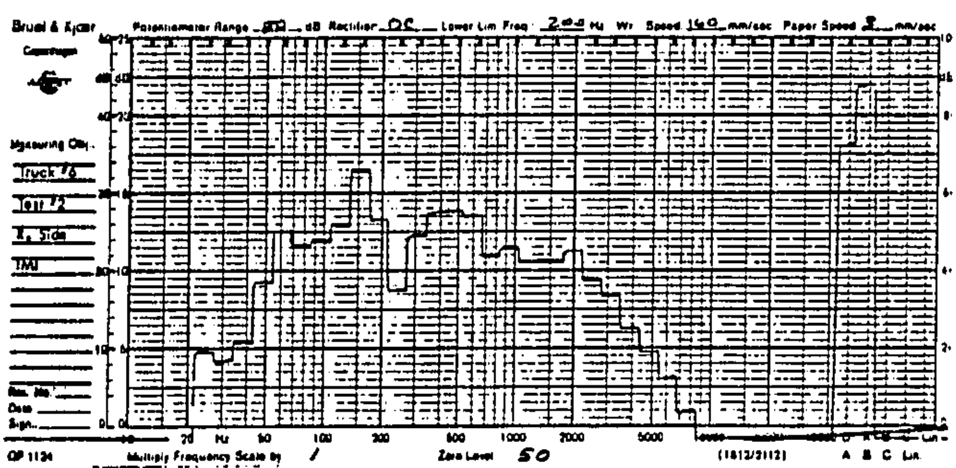

Figure C20. One-Third Octave Spectrum
Truck Number 6 Test Number 2

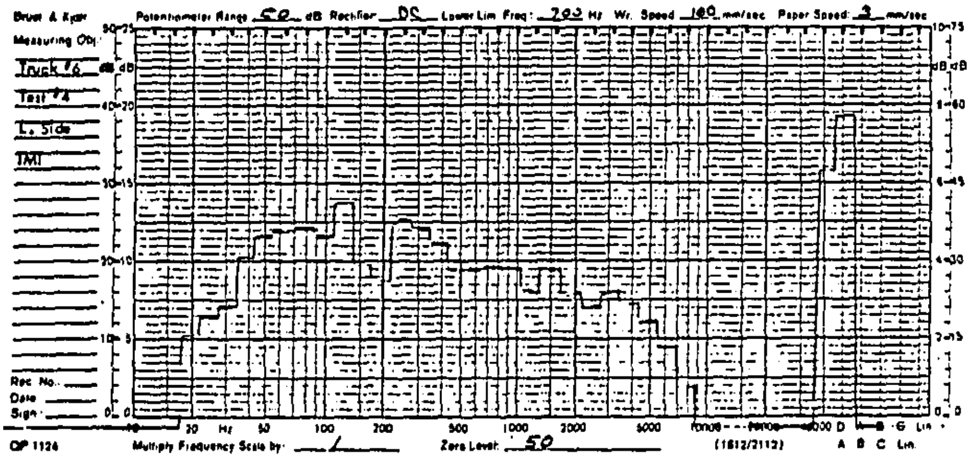

Figure C21. One-Third Octave Spectrum
Truck Number 6 Test Number 4

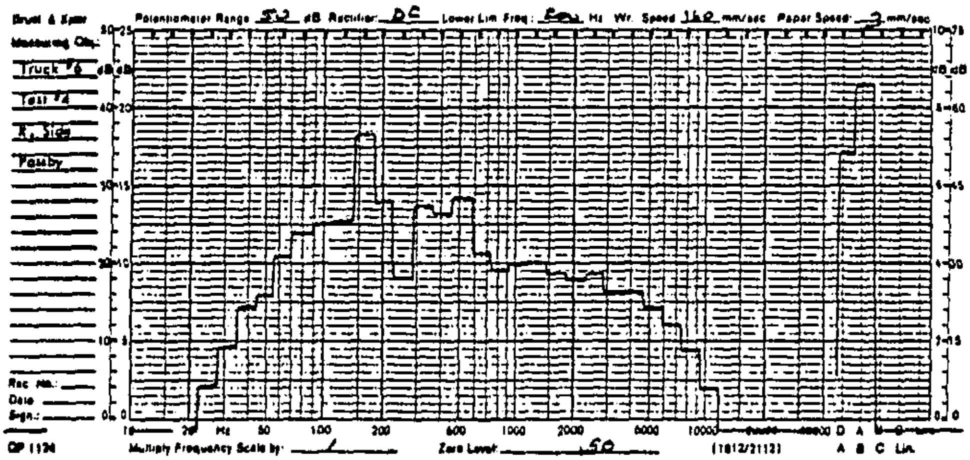

Figure C22. One-Third Octave Spectrum
Truck Number 6 Test Number 4

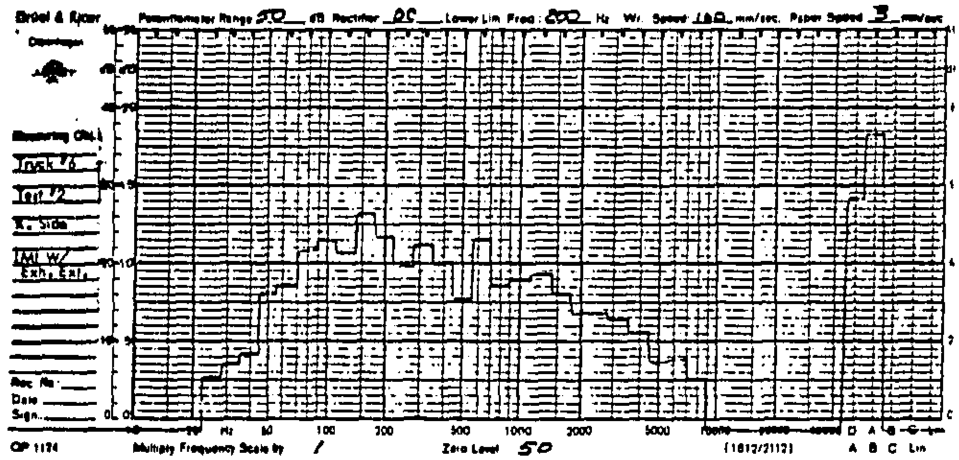

Figure C23. One-Third Octave Spectrum
Truck Number 6 Test Number 2

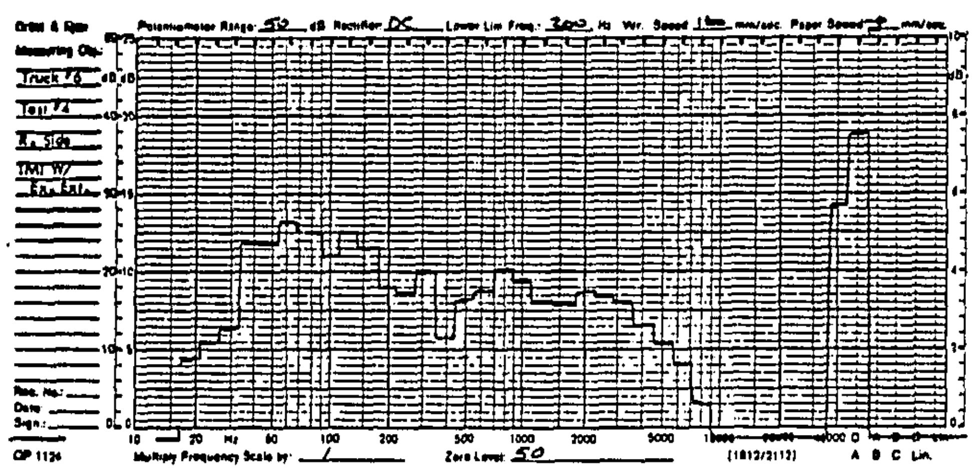

Figure C24. One-Third Octave Spectrum
Truck Number 6 Test Number 4

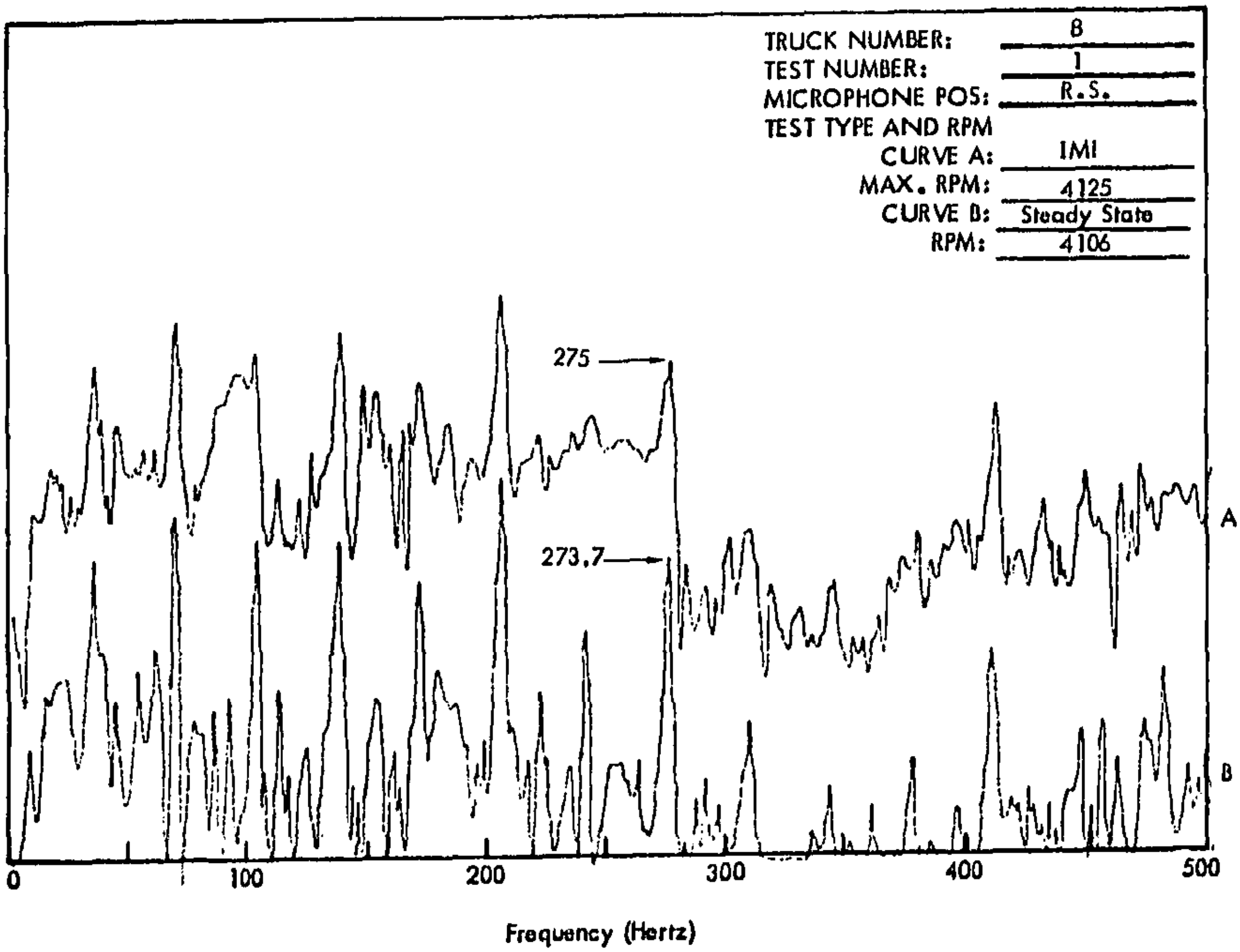

Figure C25. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

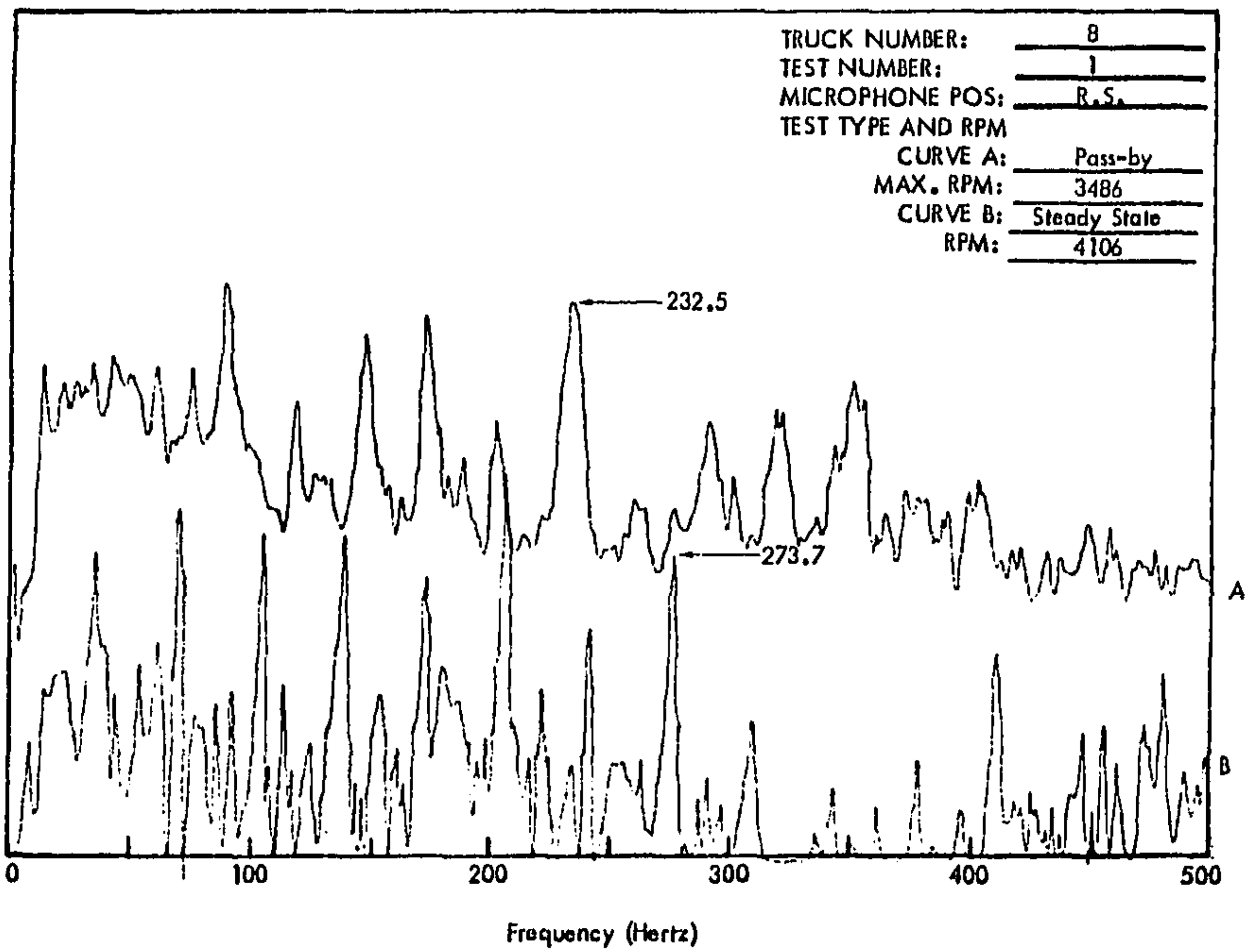

Figure C26. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

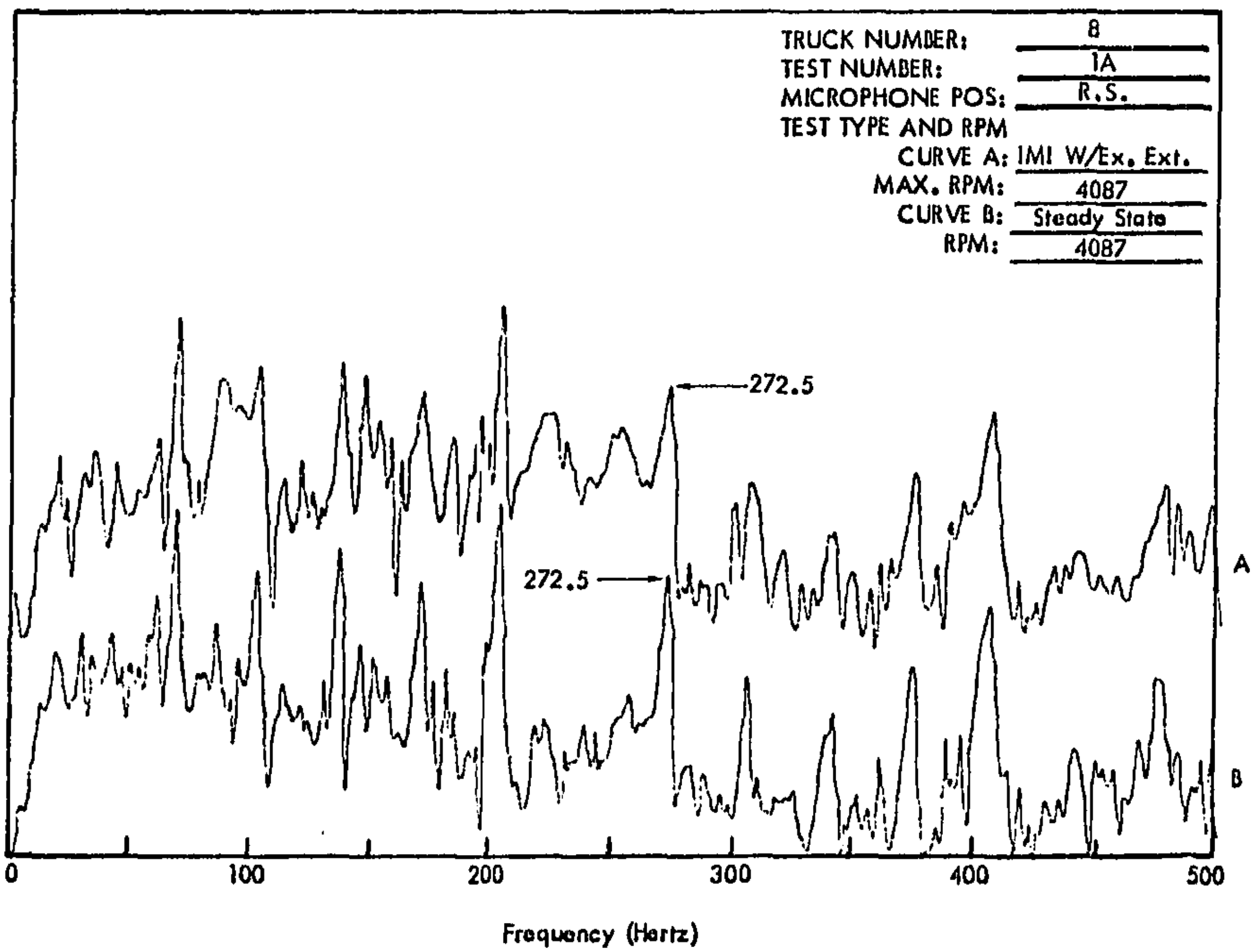

Figure C27. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

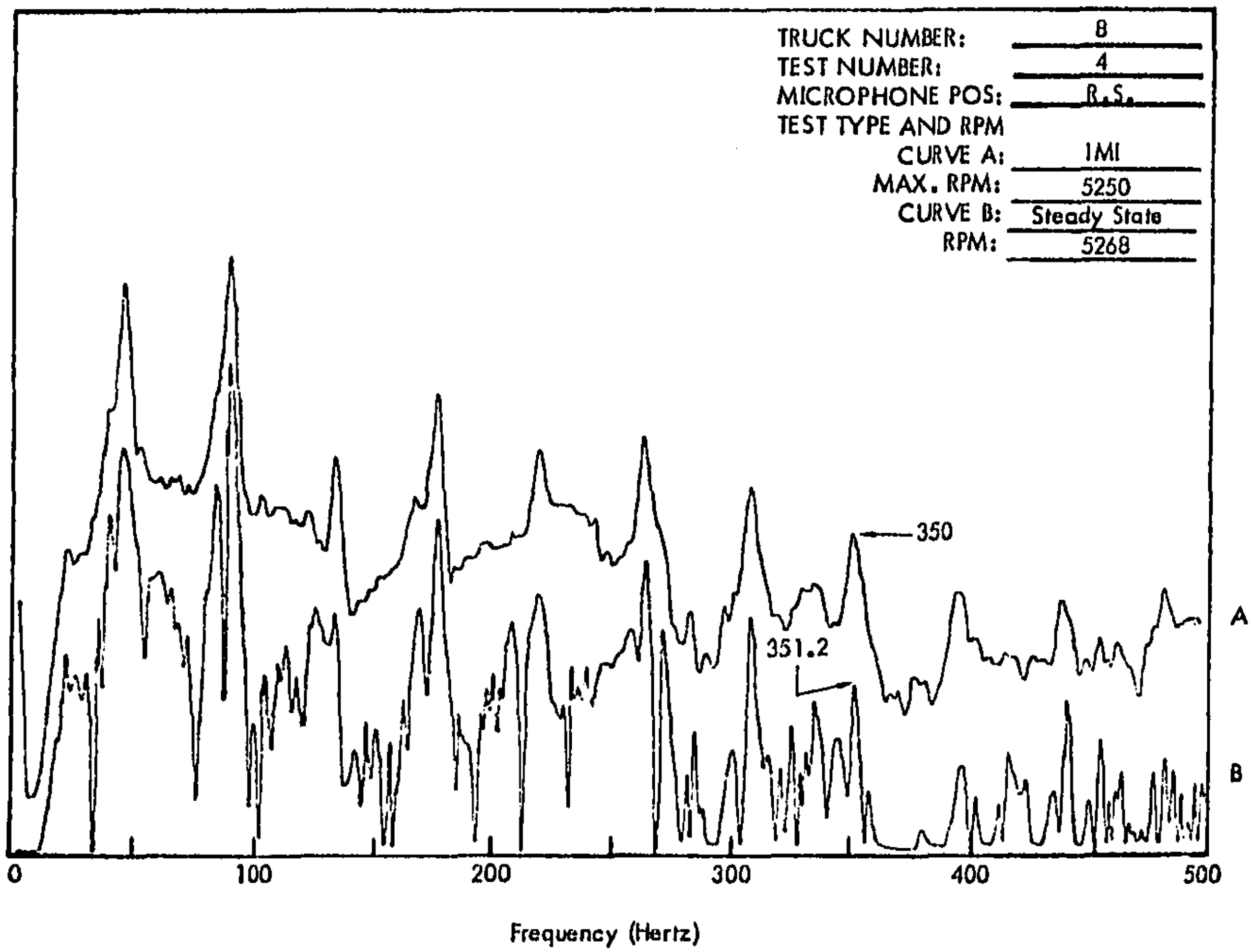

Figure C28. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

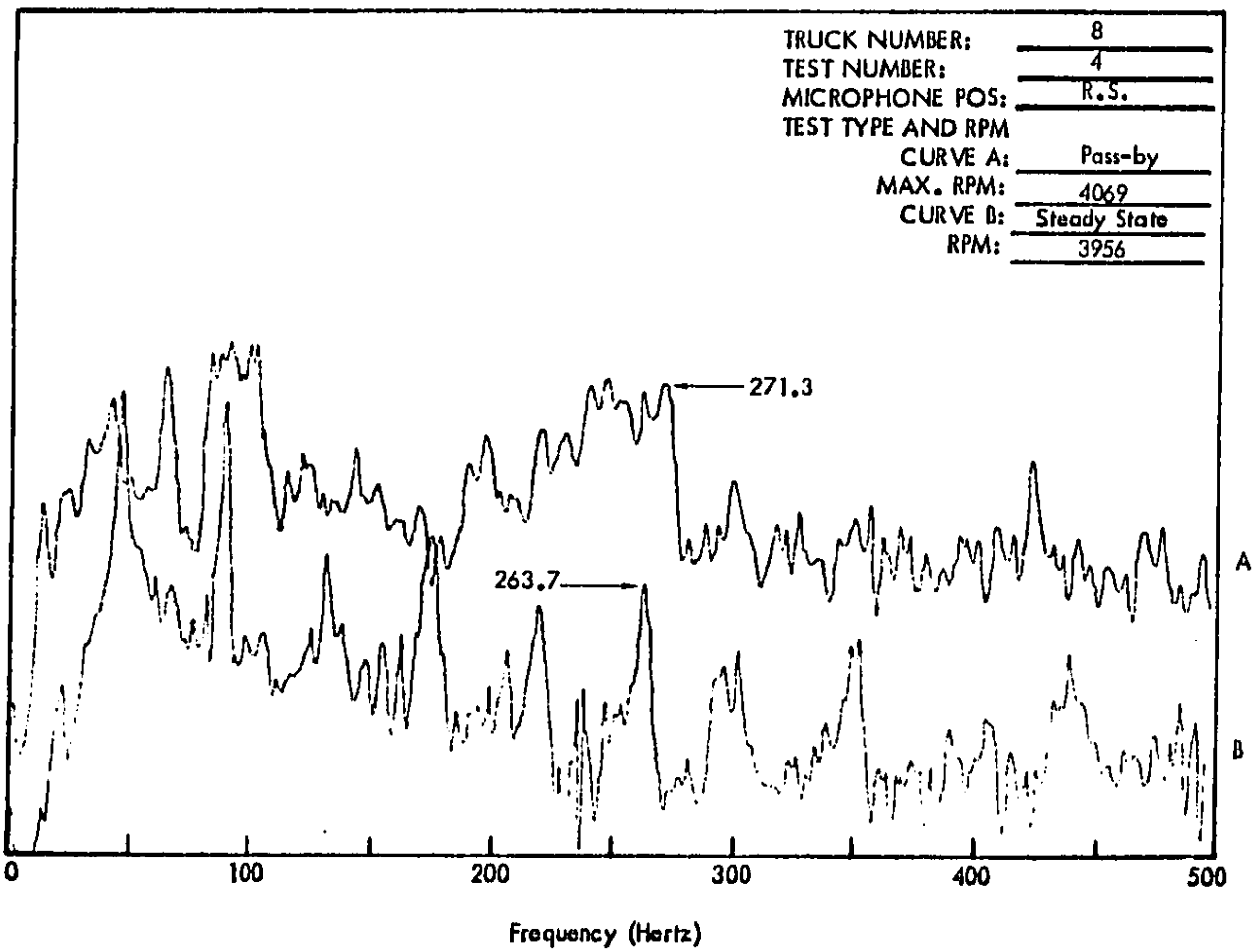

Figure C29. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

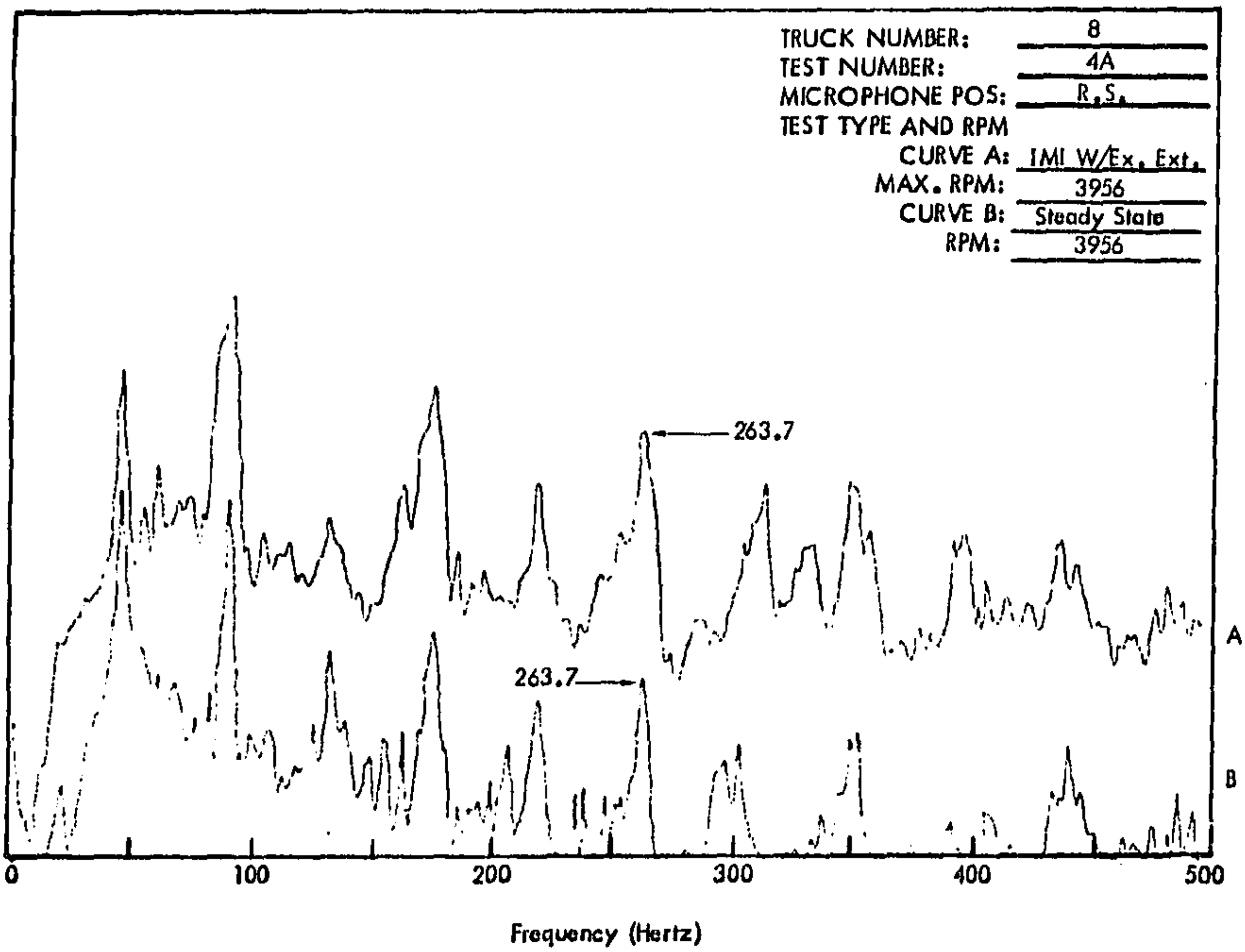

Figure C30. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

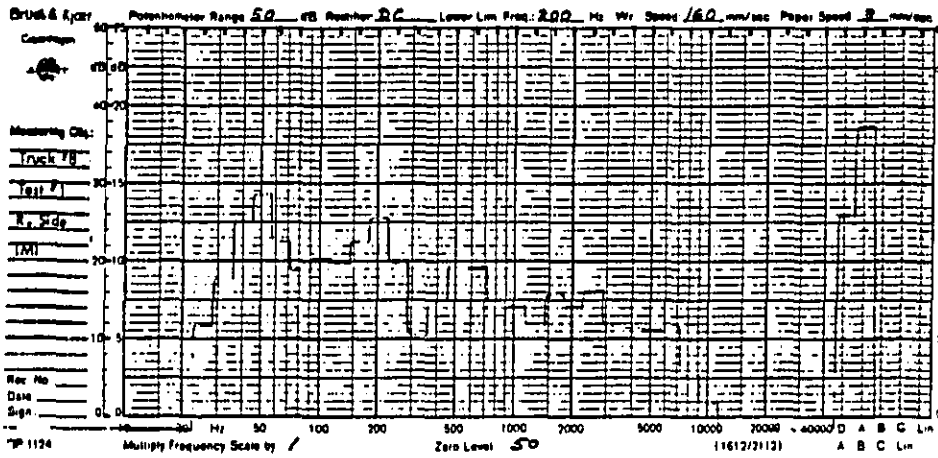

Figure C31. One-Third Octave Spectrum
Truck Number 8 Test Number 1

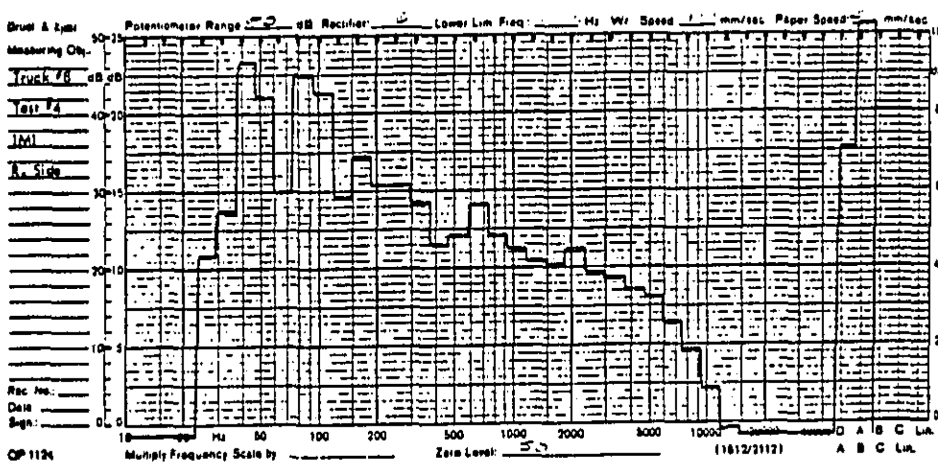

Figure C32. One-Third Octave Spectrum
Truck Number 8 Test Number 4

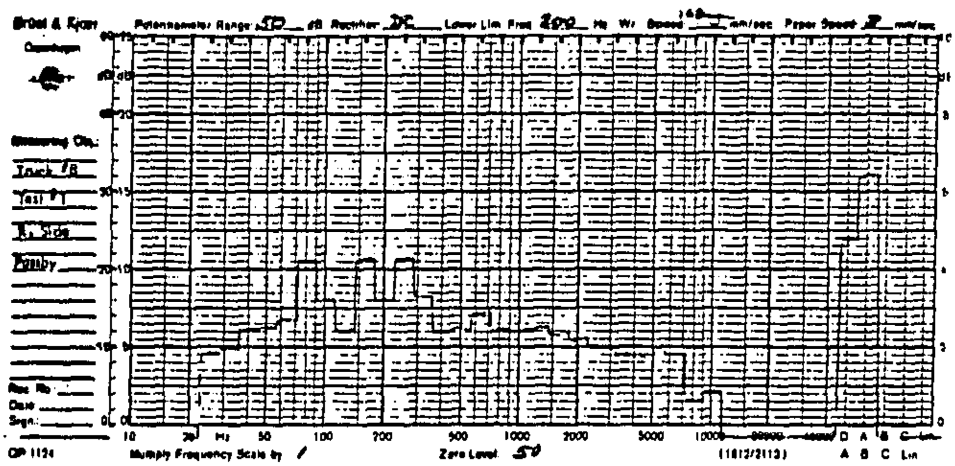

Figure C33. One-Third Octave Spectrum
Truck Number 8 Test Number 1

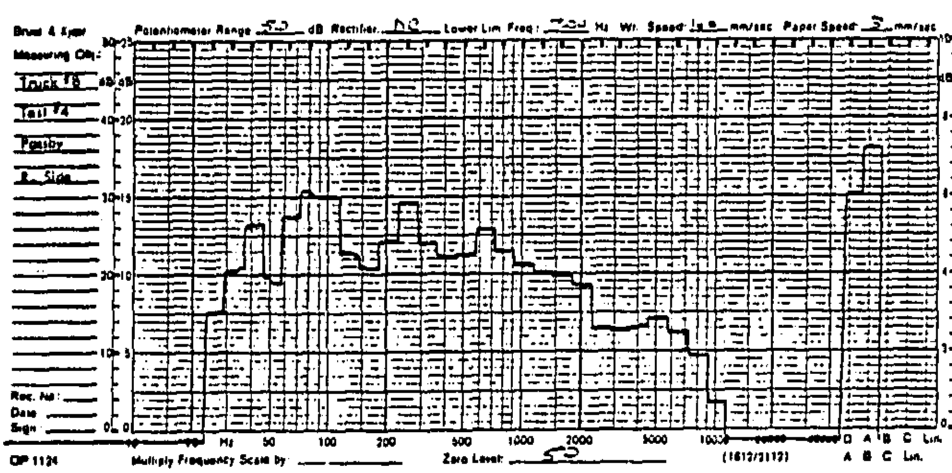

Figure C34. One-Third Octave Spectrum
Truck Number 8 Test Number 4

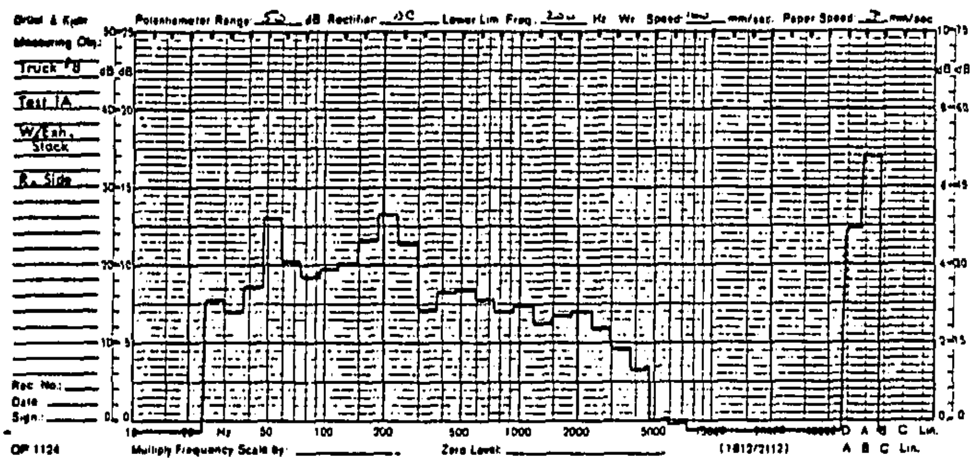

Figure C35. One-Third Octave Spectrum
Truck Number 8 Test Number 1

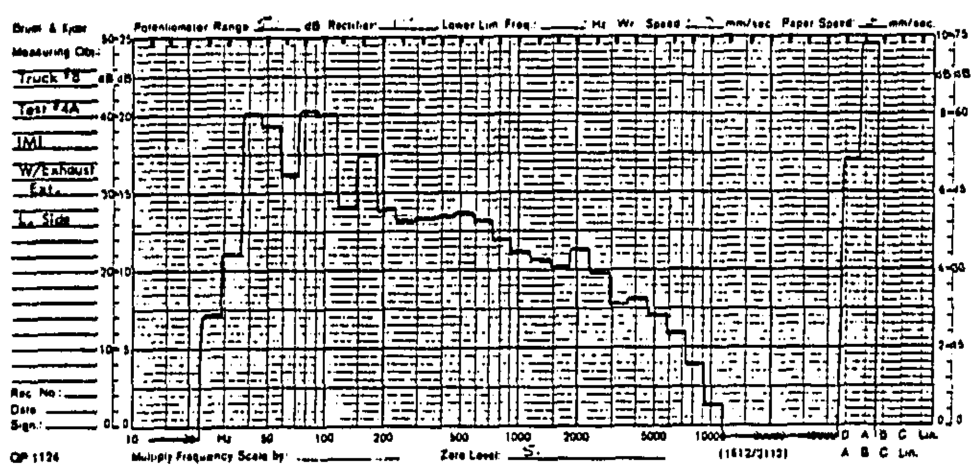

Figure C36. One-Third Octave Spectrum
Truck Number 8 Test Number 4

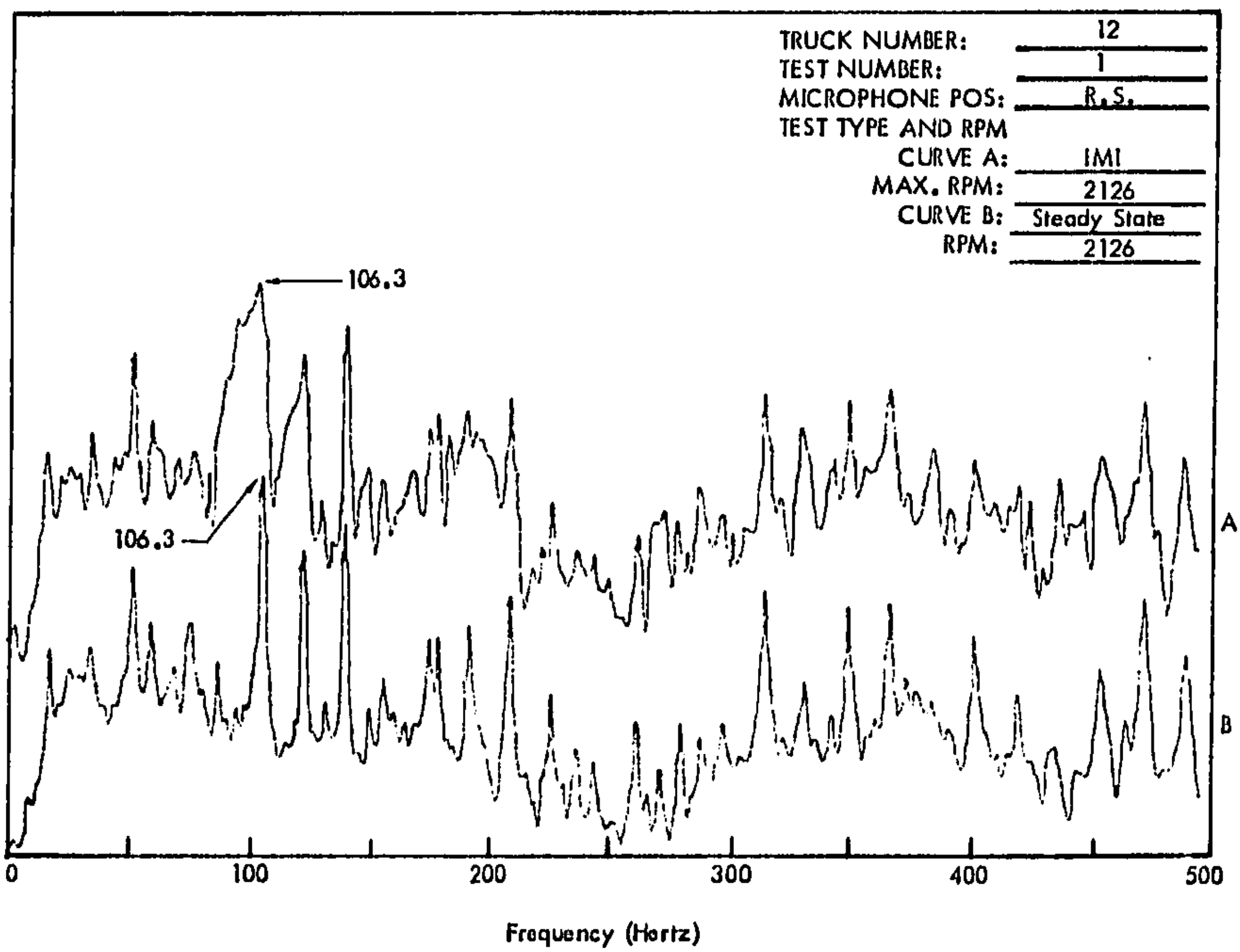

Figure C37. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

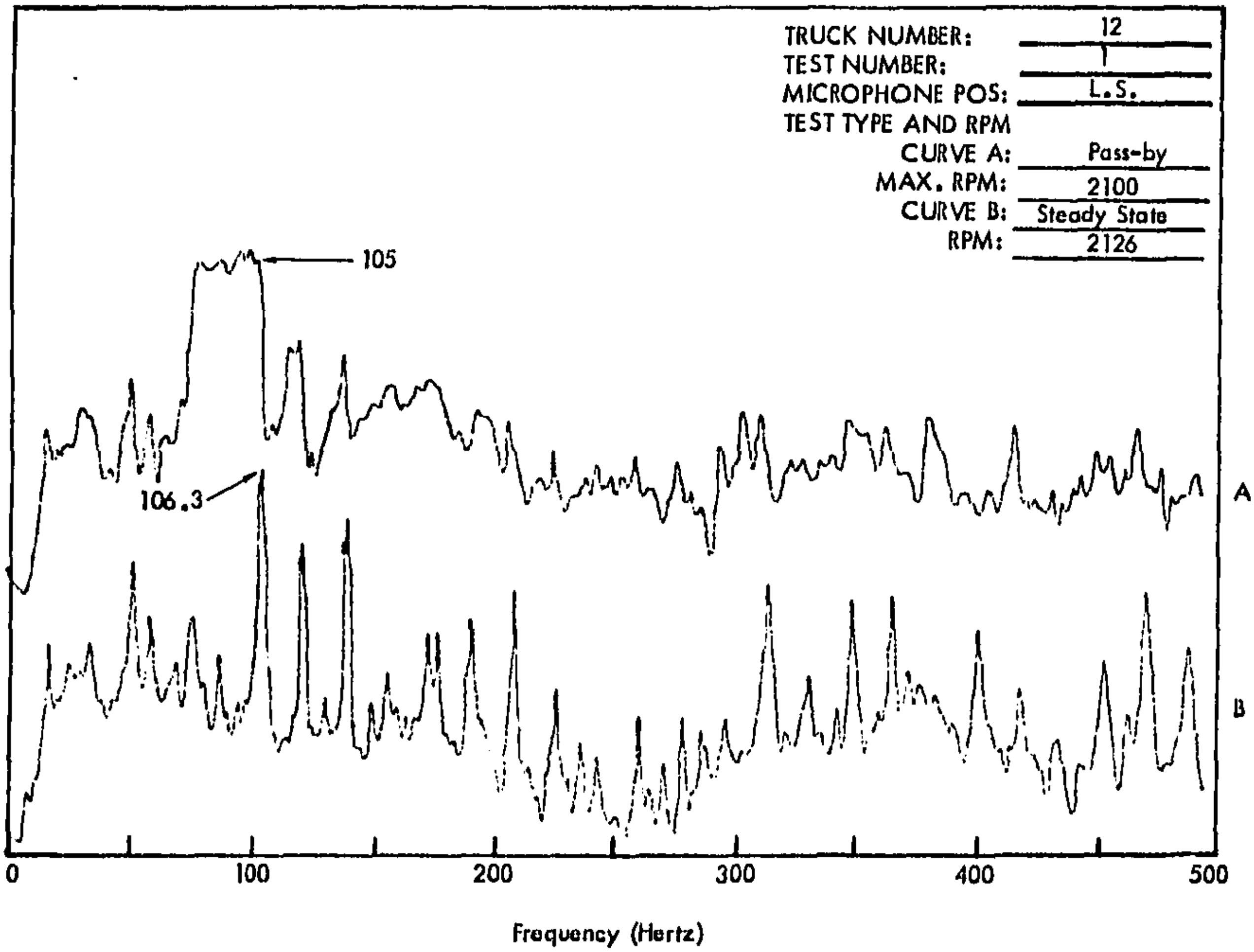

Figure C38. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

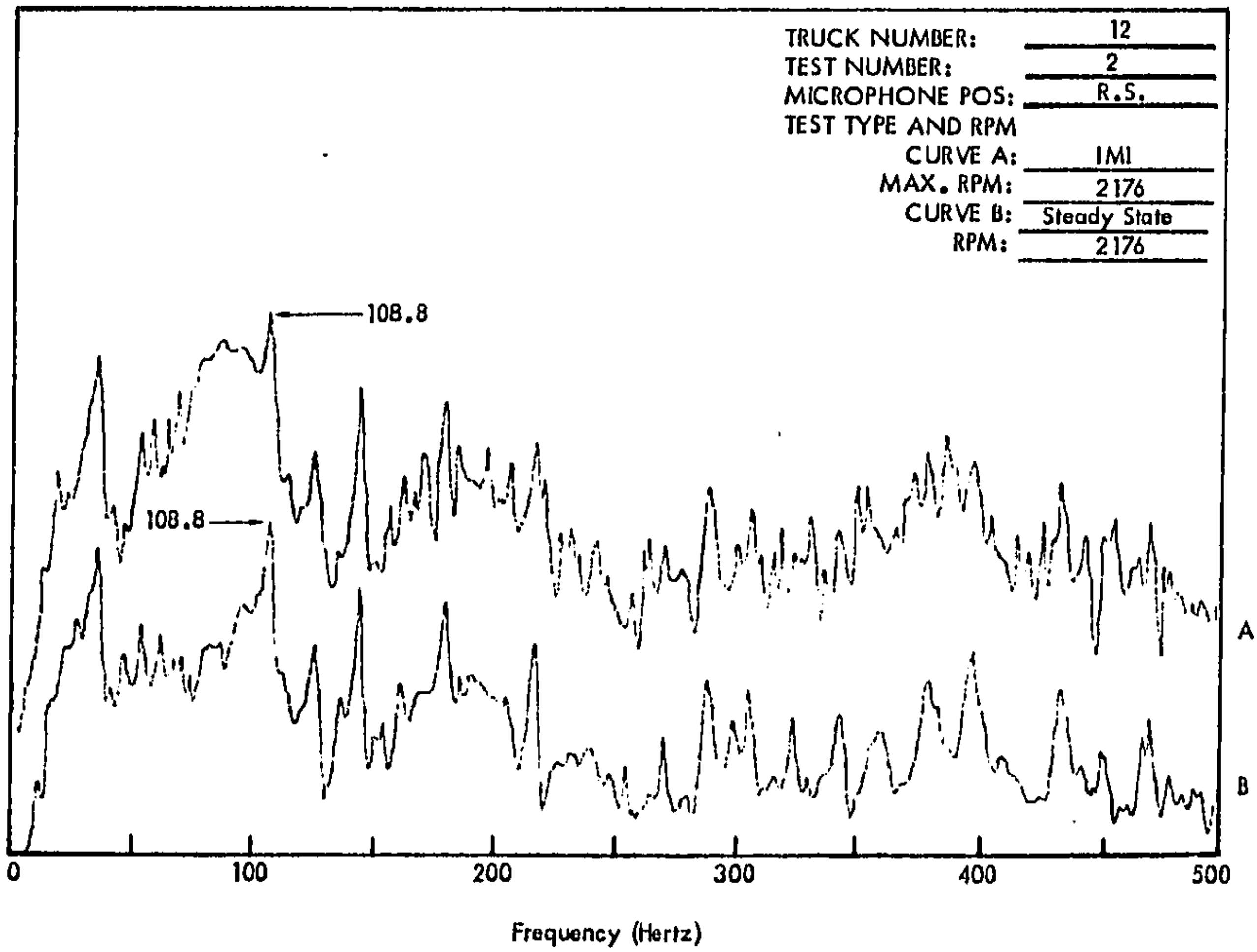

Figure C39. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

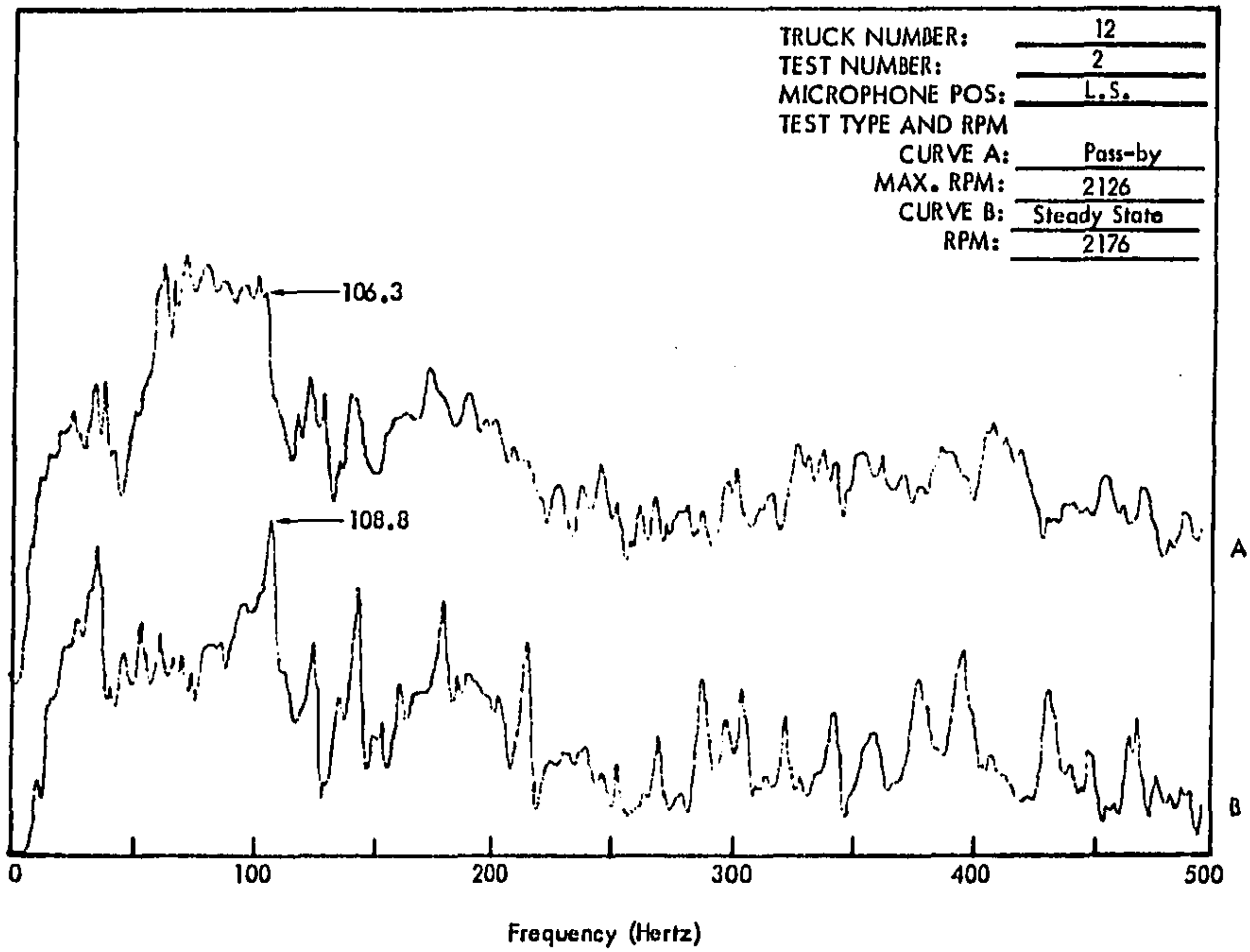

Figure C40. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

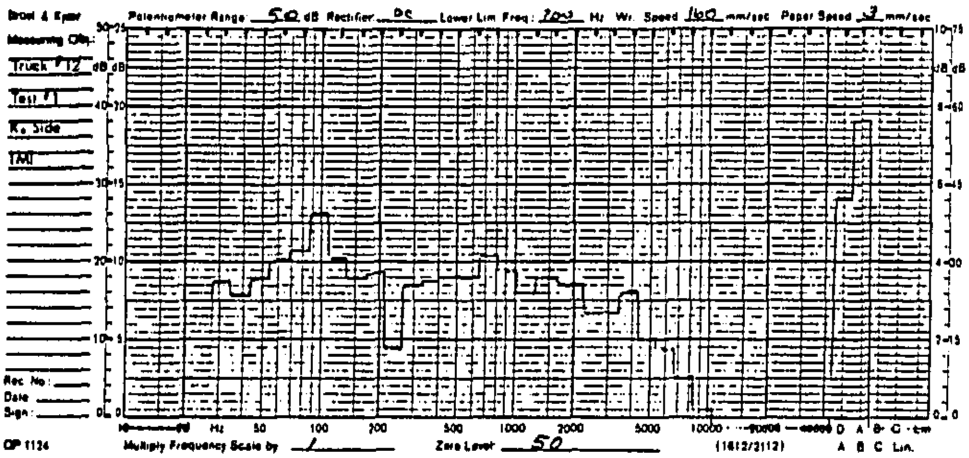

Figure C41. One-Third Octave Spectrum
Truck Number 12 Test Number 1

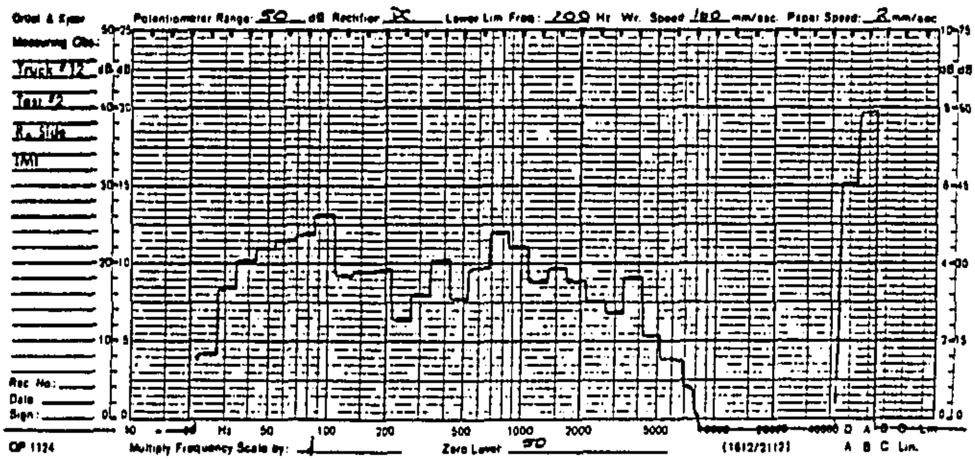

Figure C42. One-Third Octave Spectrum
Truck Number 12 Test Number 2

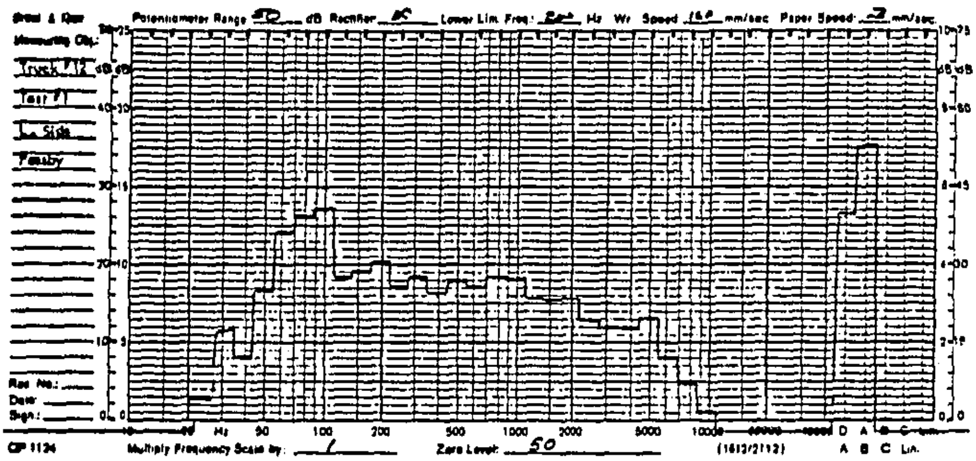

Figure C43. One-Third Octave Spectrum
Truck Number 12 Test Number 1

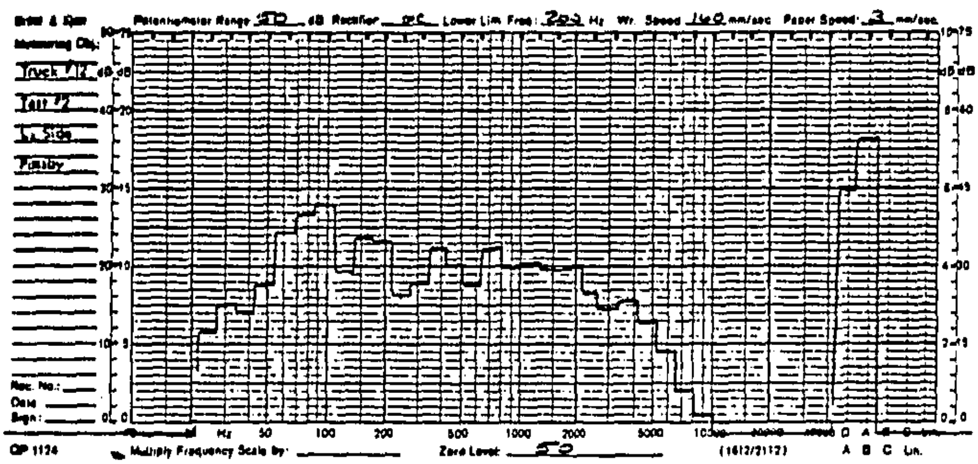

Figure C44. One-Third Octave Spectrum
Truck Number 12 Test Number 2

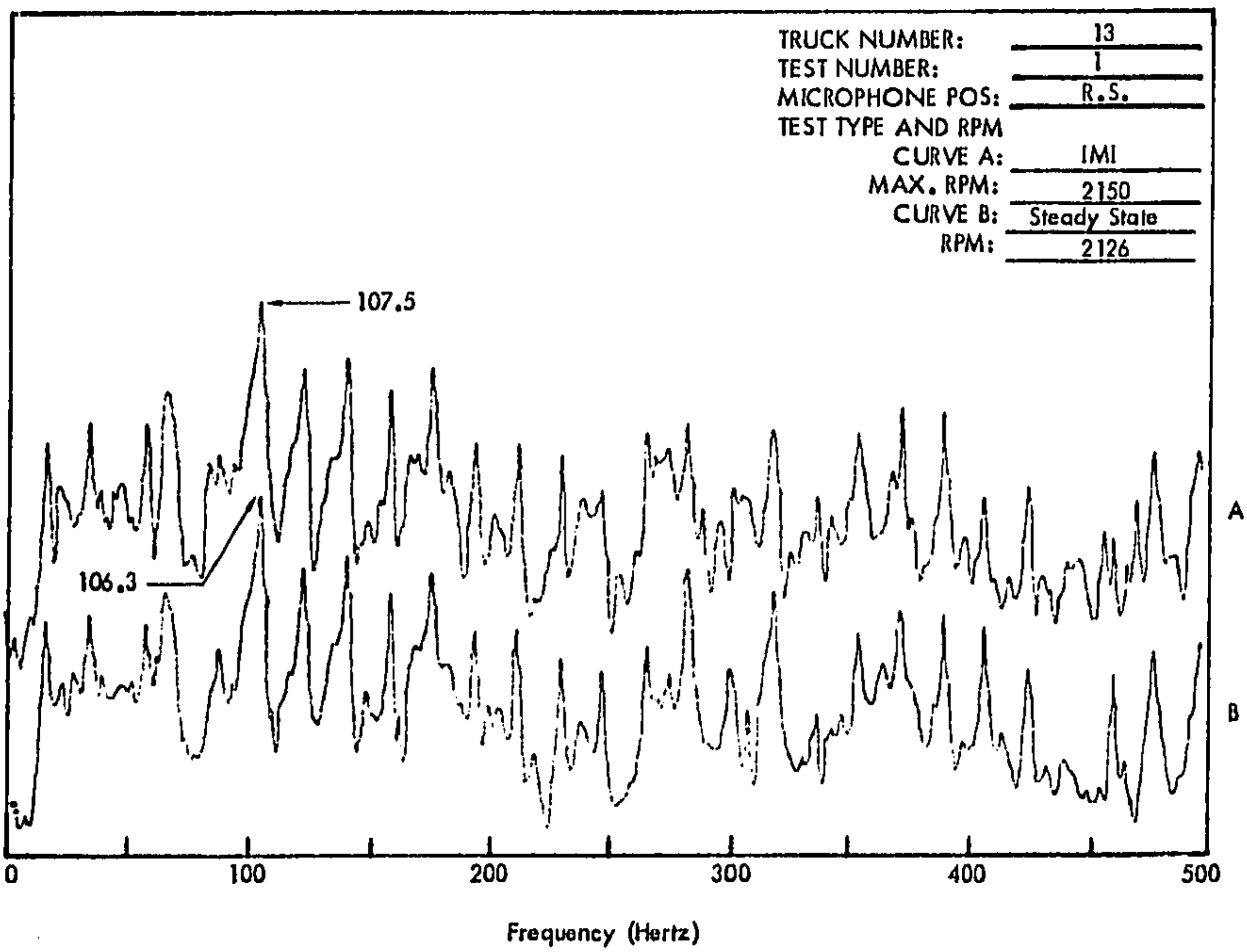

Figure C45. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

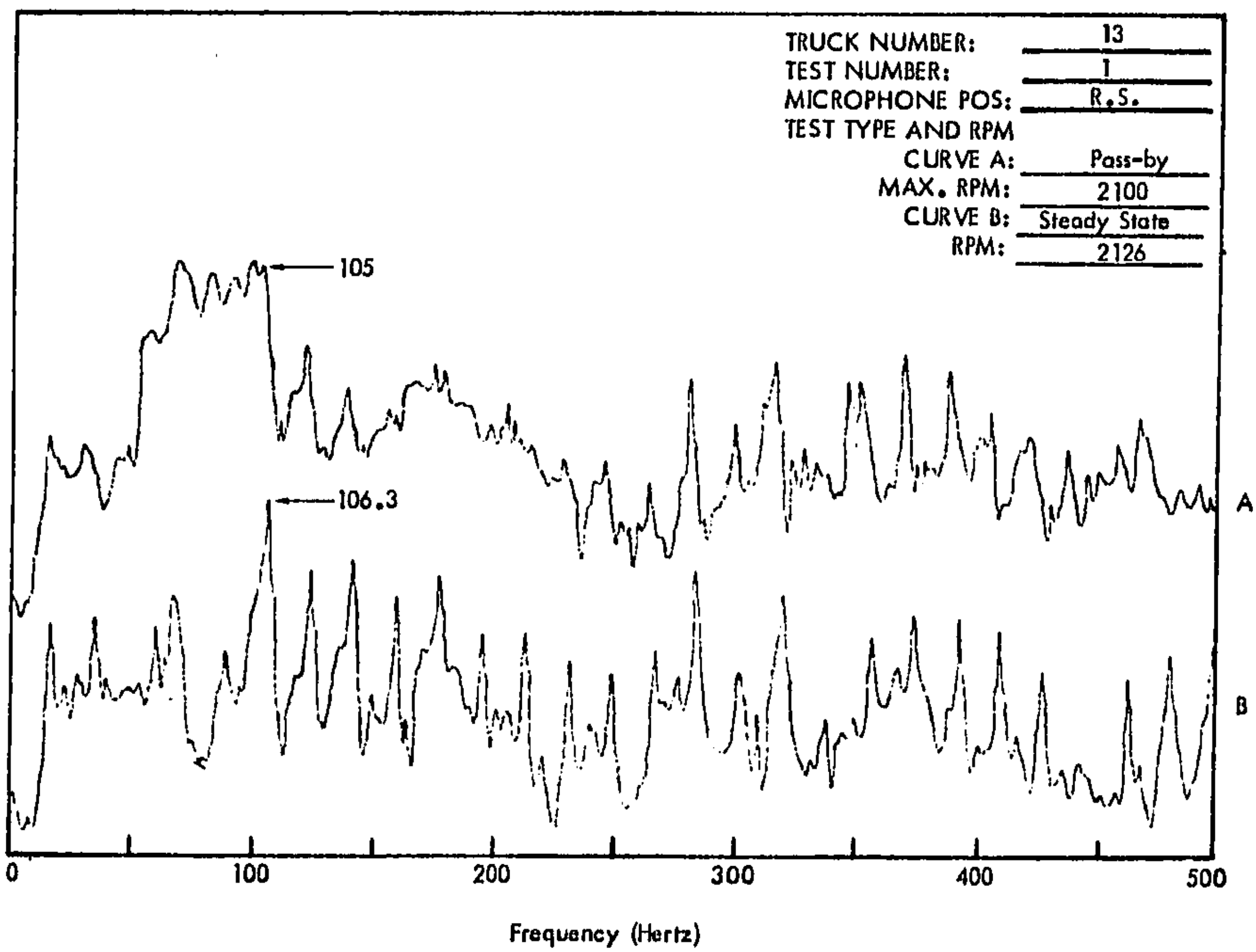

Figure C46. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

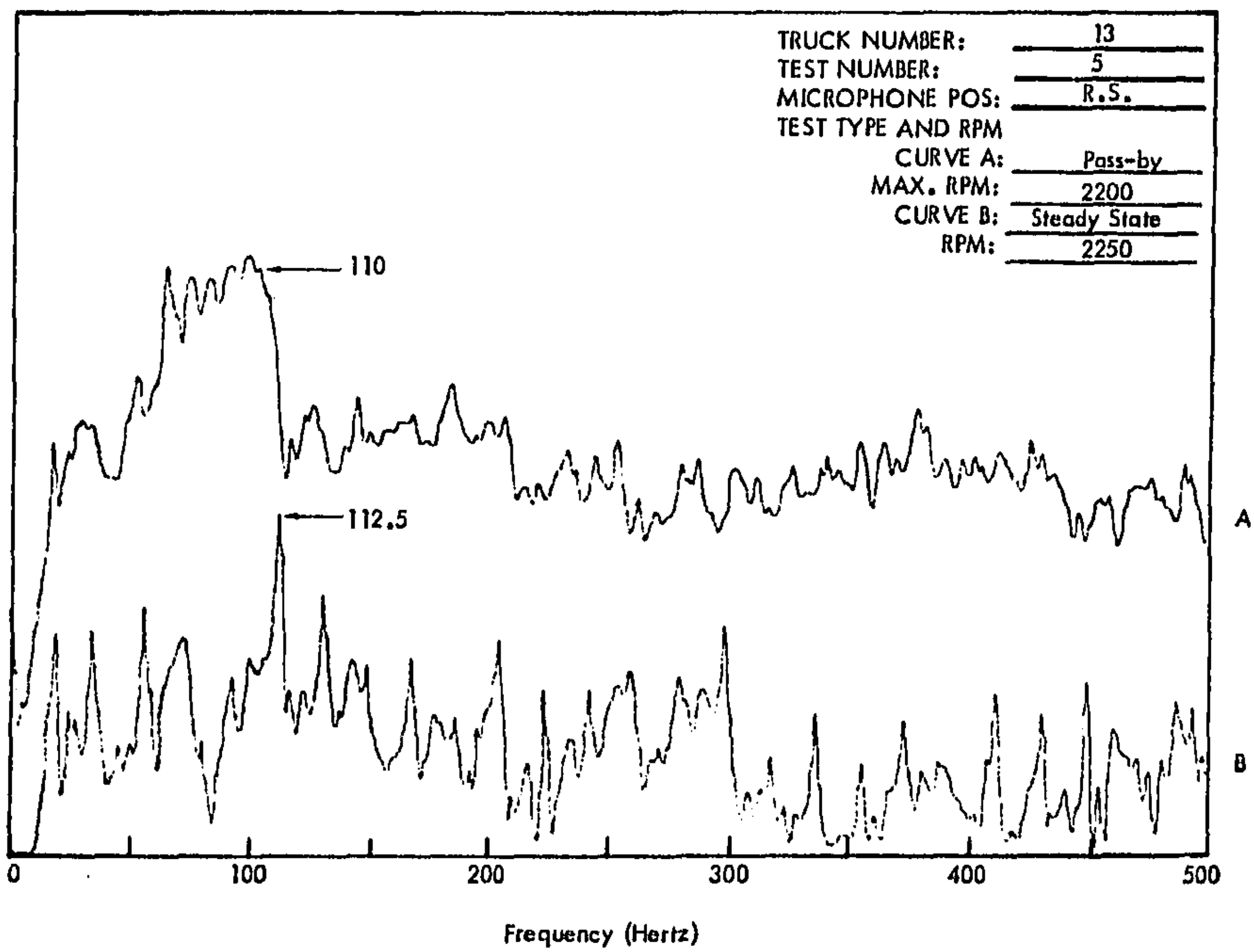

Figure C47. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

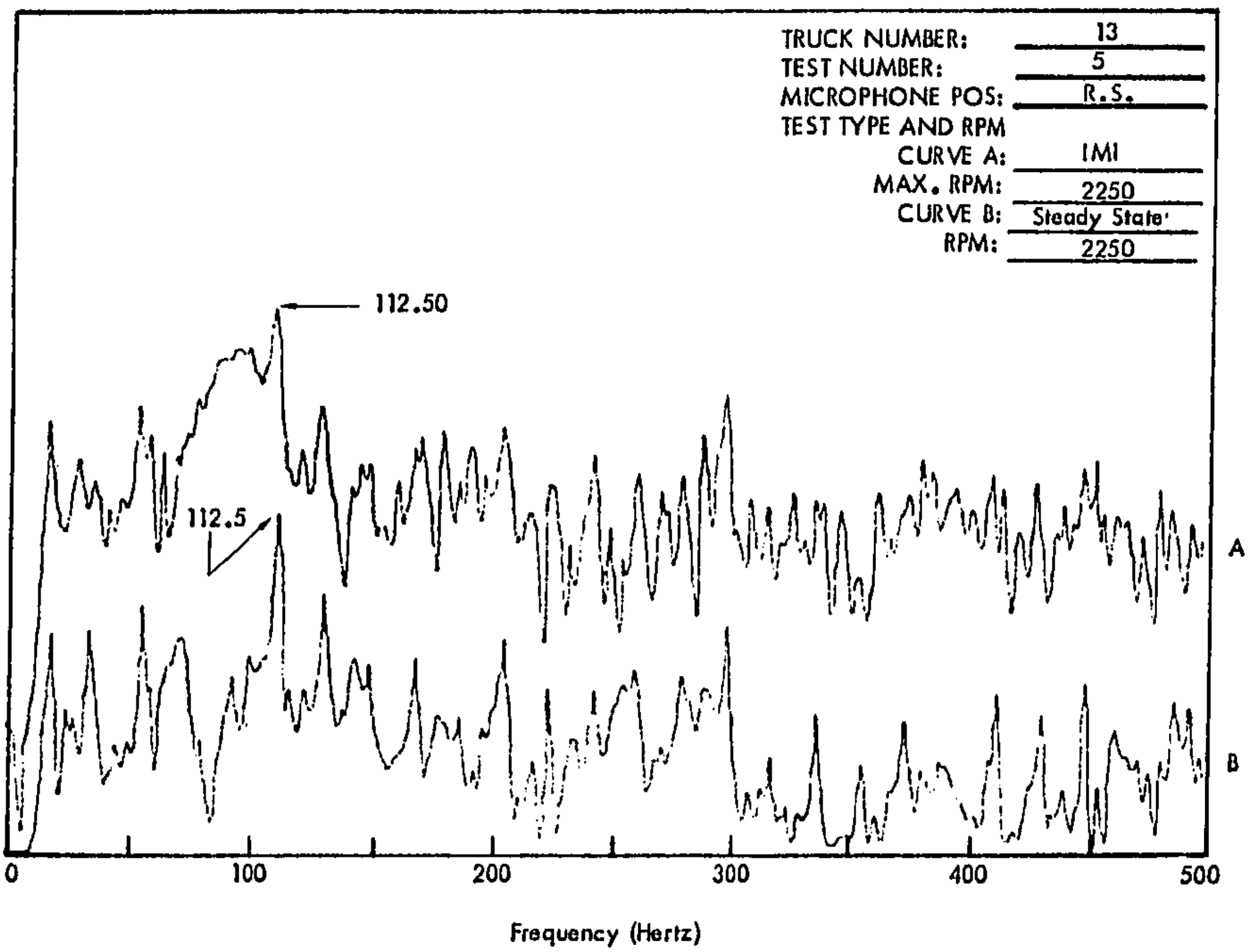

Figure C48. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

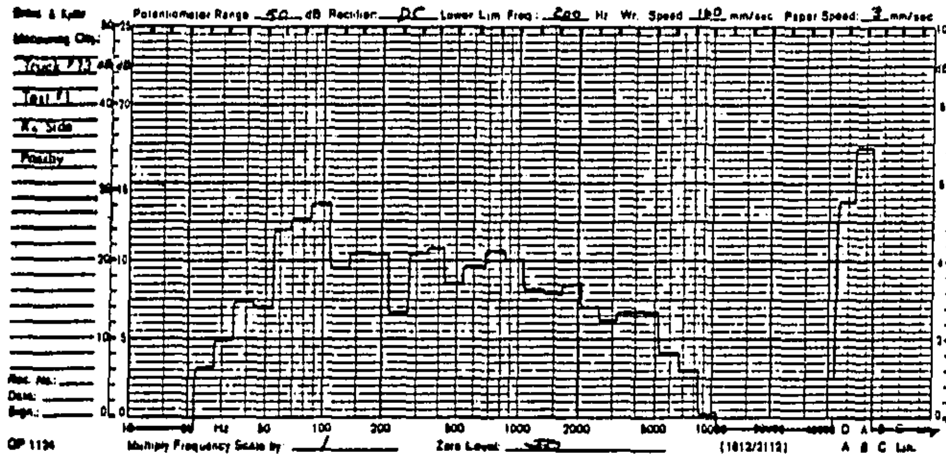

Figure C49. One-Third Octave Spectrum
Truck Number 13 Test Number 1

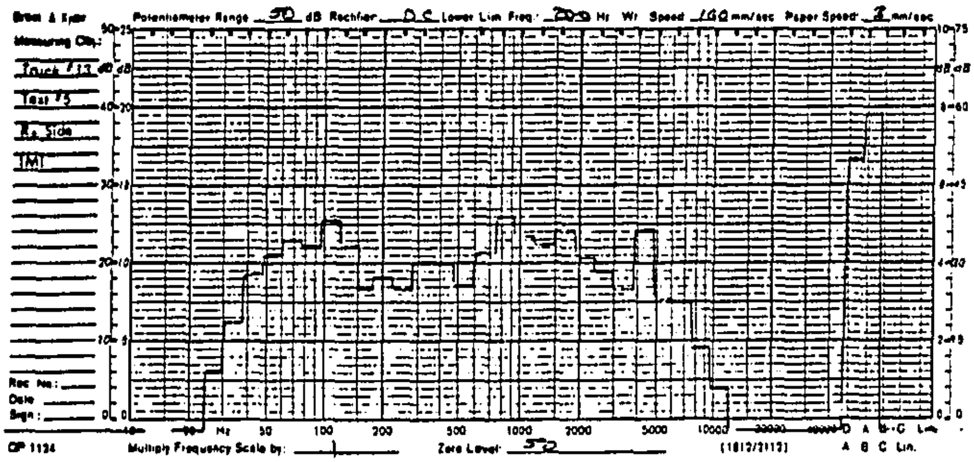

Figure C50. One-Third Octave Spectrum
Truck Number 13 Test Number 5

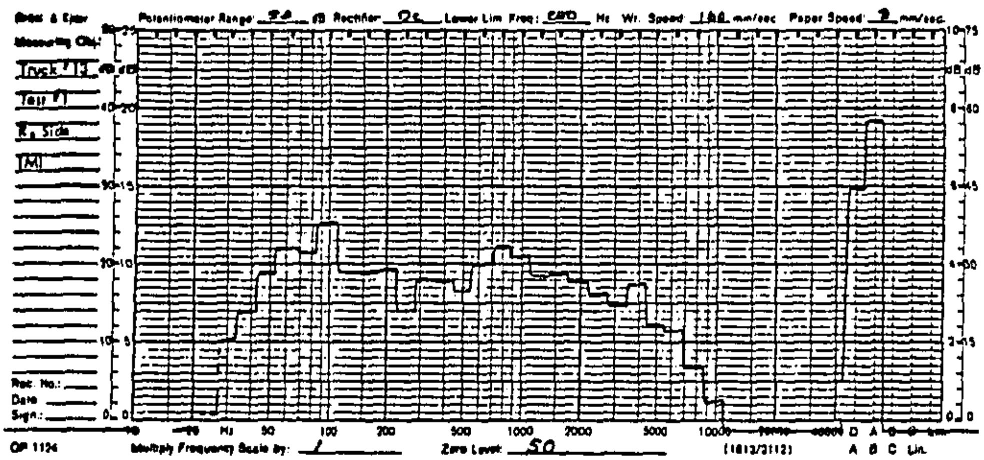

Figure C51. One-Third Octave Spectrum
Truck Number 13 Test Number 1

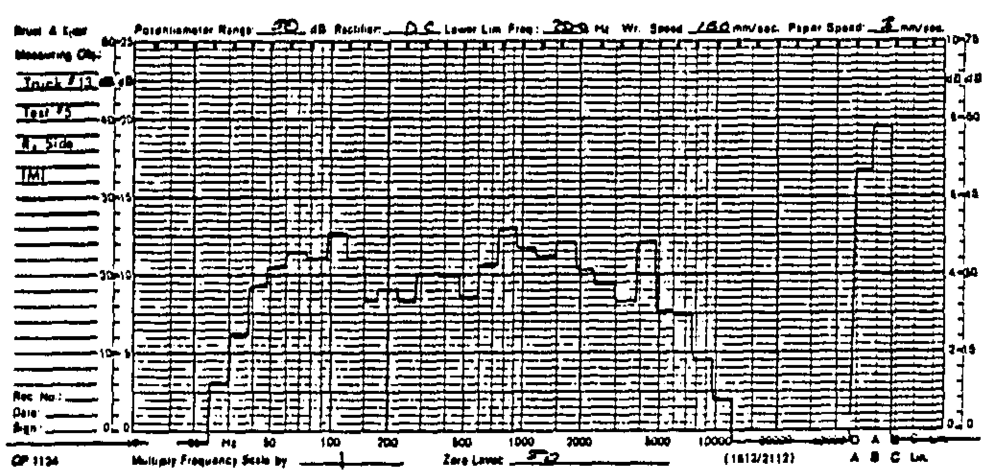

Figure C52. One-Third Octave Spectrum
Truck Number 13 Test Number 5

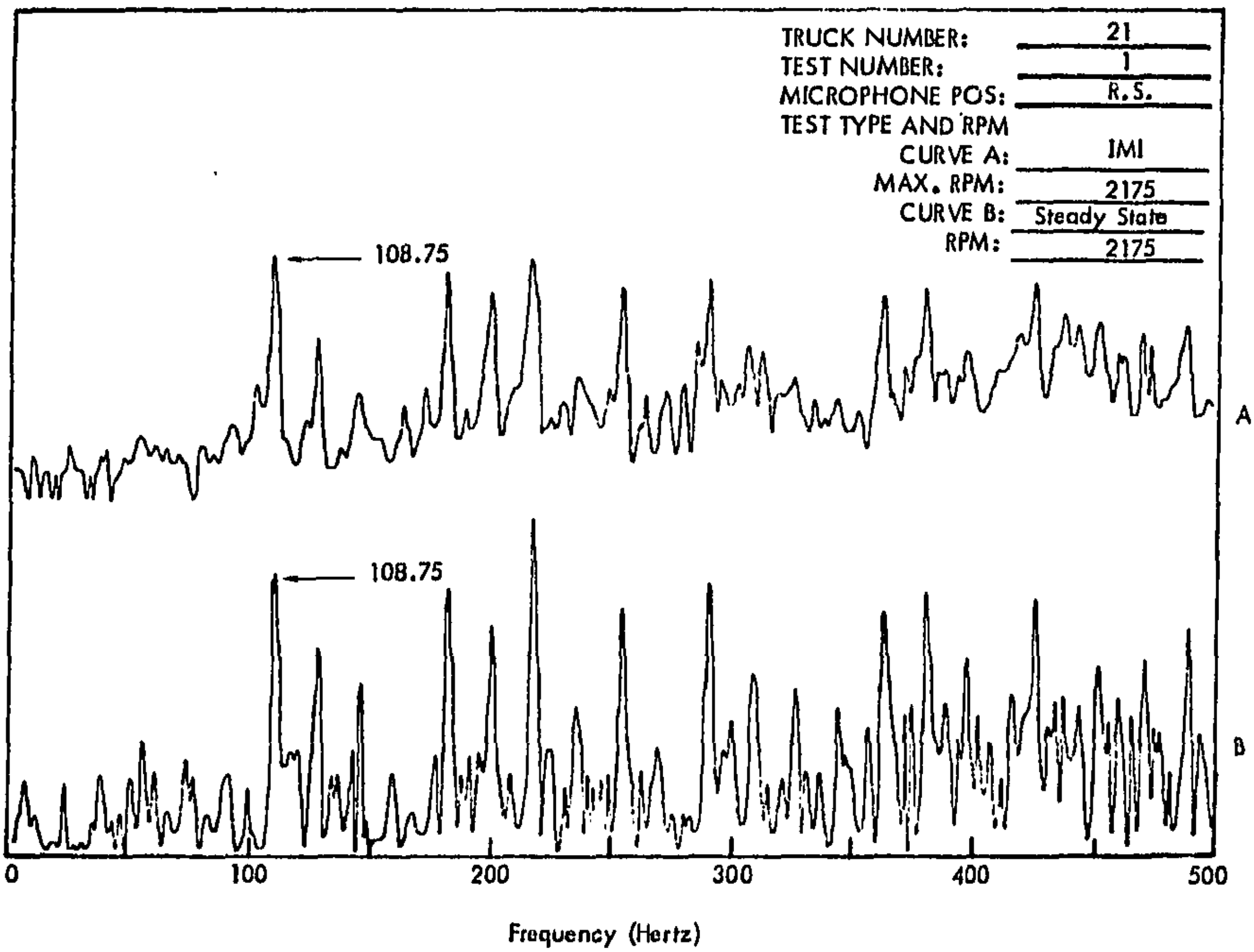

Figure C53. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

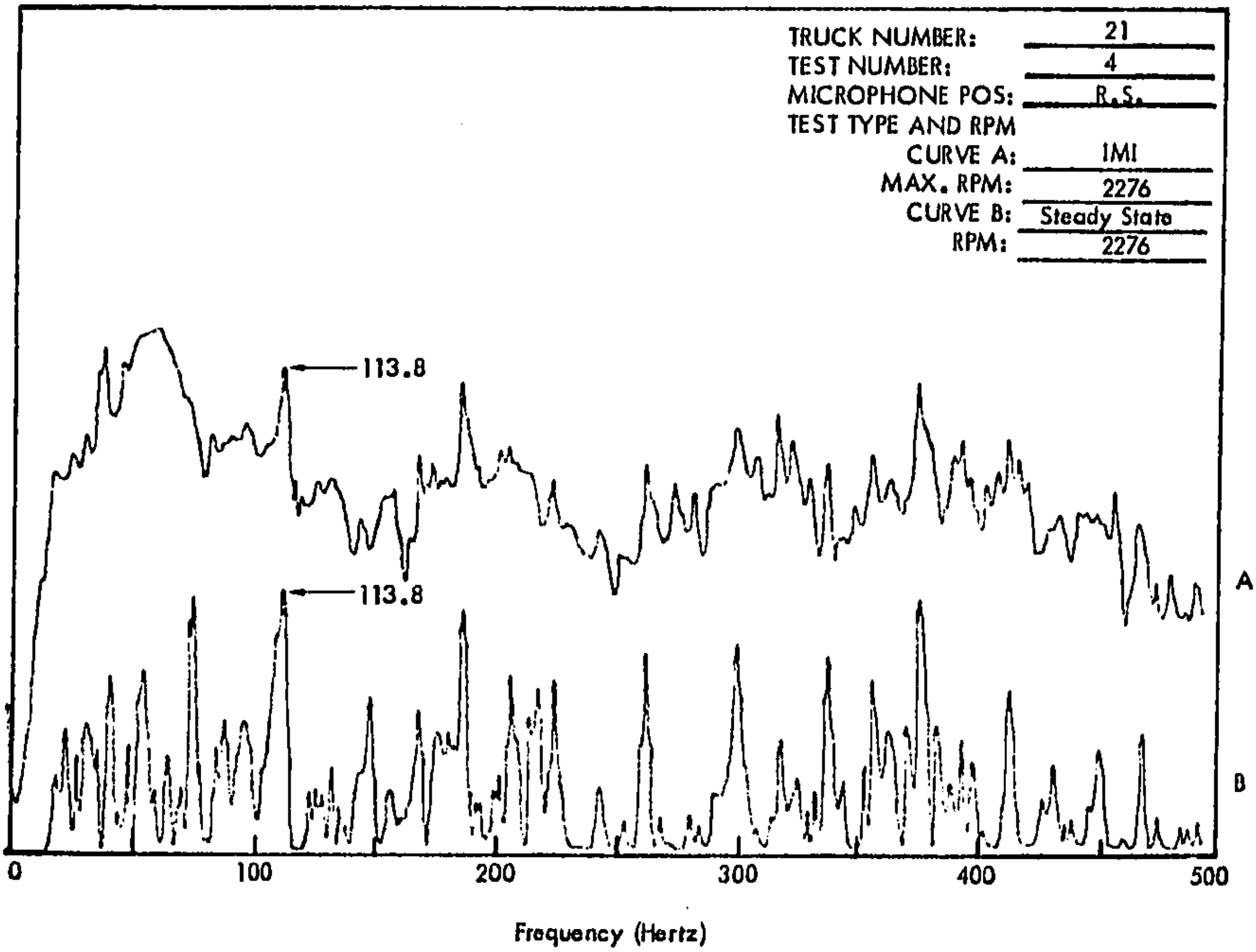

Figure C54. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

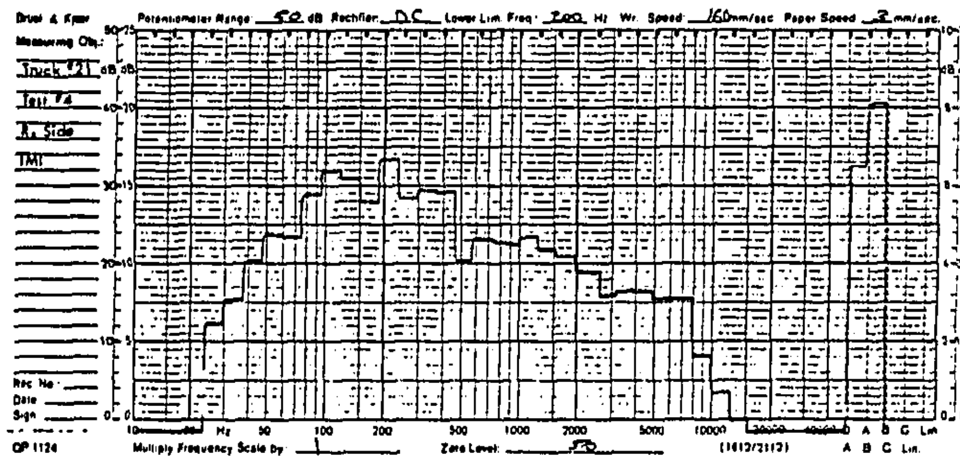

Figure C55. One-Third Octave Spectrum
Truck Number 21 Test Number 4

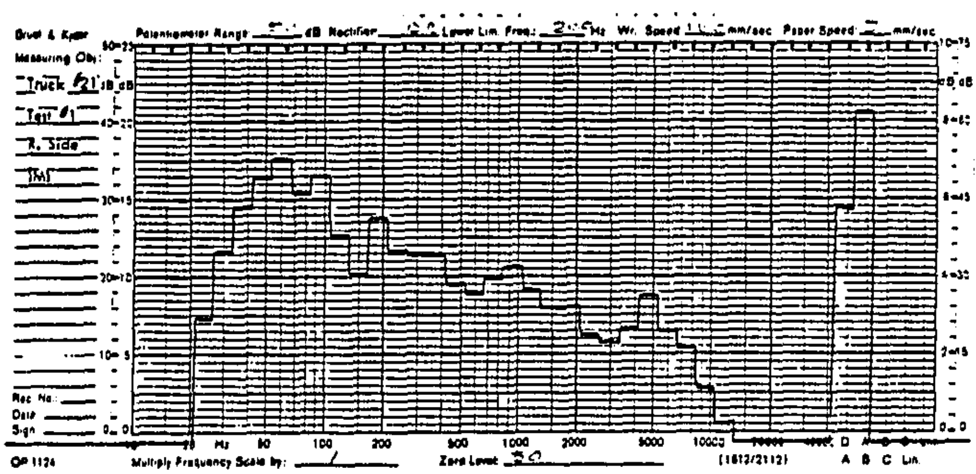

Figure C56. One-Third Octave Spectrum
Truck Number 21 Test Number 1

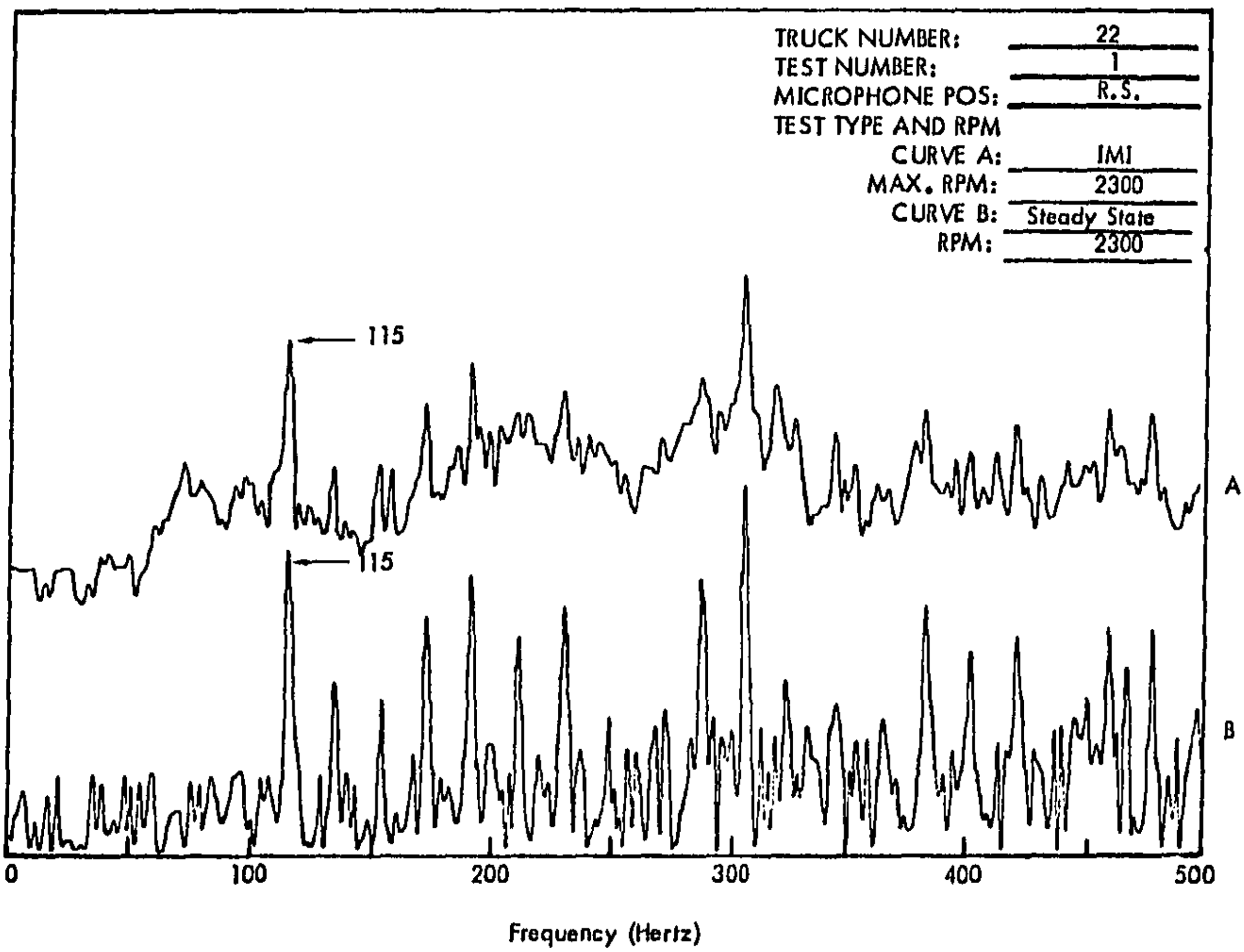

Figure C57. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

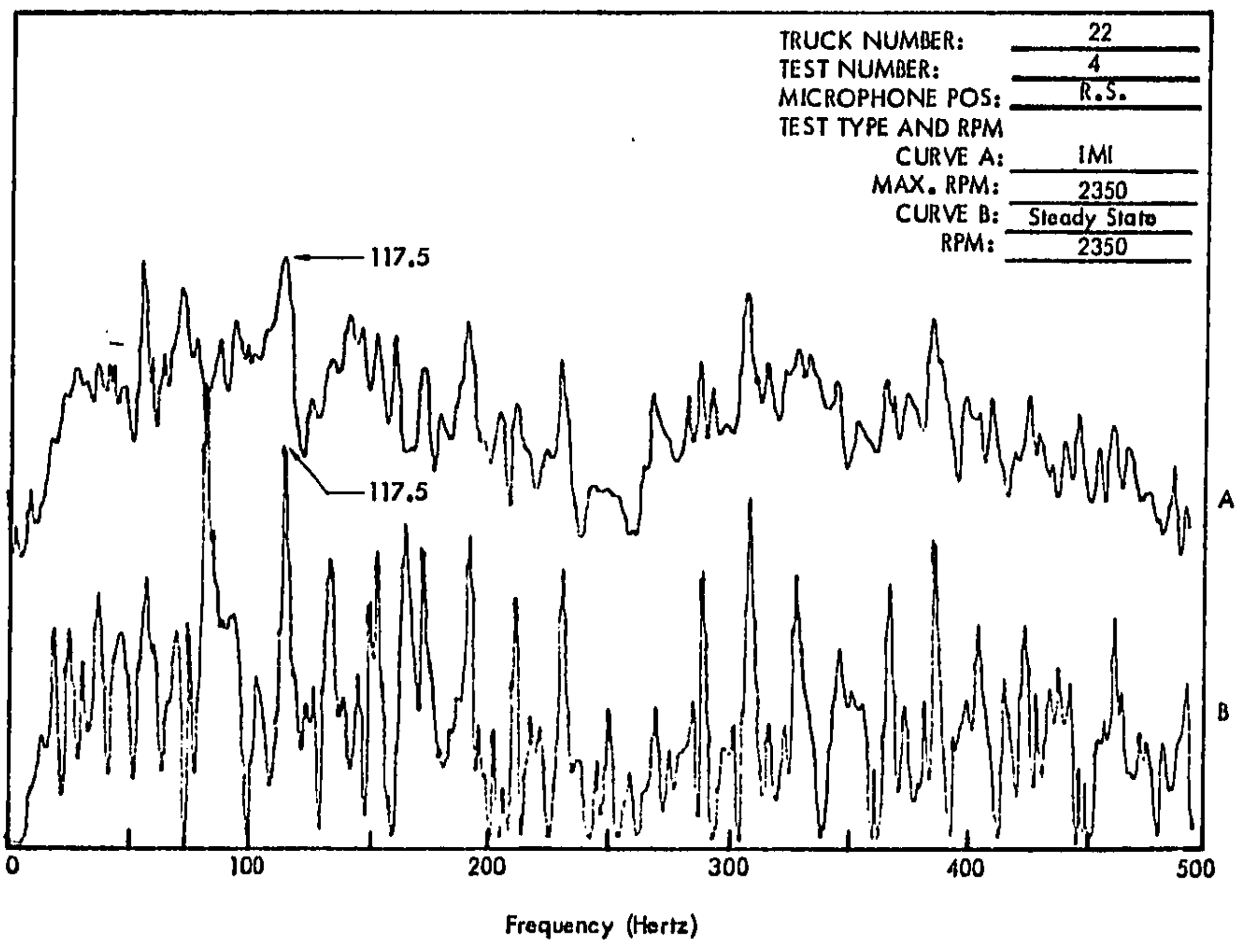

Figure C58. Truck Exterior Noise Spectra (Narrow Band Analysis 1-1/4 Hertz) Measured at 50 Feet. The Spectra Are Used For Determining Engine RPM.

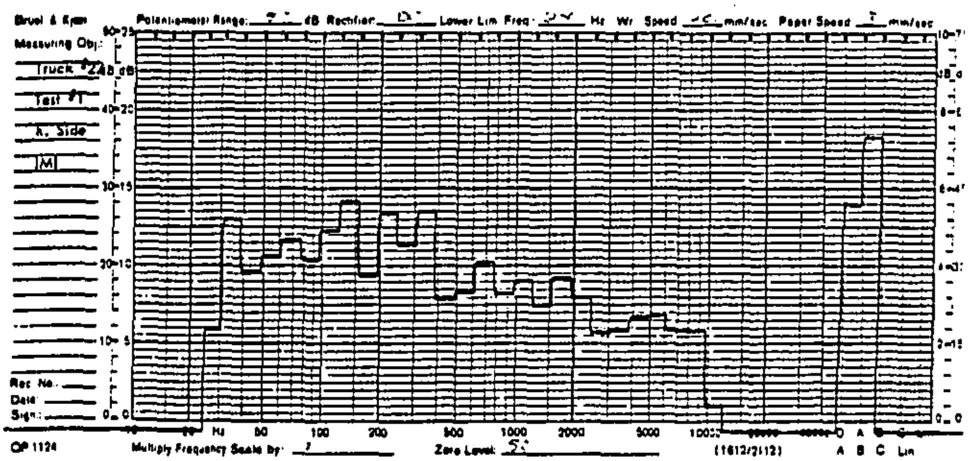

Figure C59. One-Third Octave Spectrum
Truck Number 22 Test Number 1

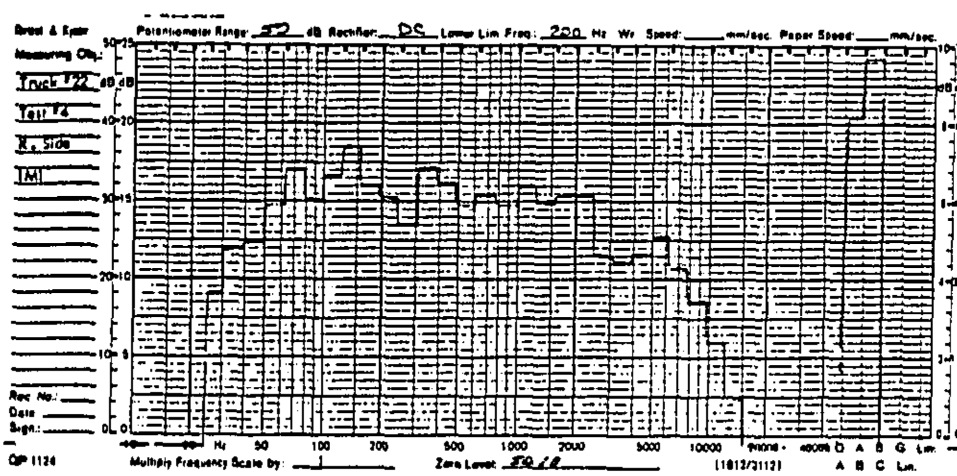

Figure C60. One-Third Octave Spectrum
Truck Number 22 Test Number 4