REFERENCE USE ONLY

REPORT NO. DOT-TSC-OST-76-21

TRUCK NOISE XI
EVALUATION AND REDUCTION OF HEAVY-DUTY TRUCK NOISE

V. Alan Werner
William Boyce

PACCAR Inc.
Truck R&D Center
790 Garden Avenue North
Renton WA 98055

SEPTEMBER 1976
FINAL REPORT

DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
OFFICE OF THE SECRETARY
Office of the Assistant Secretary
for Systems Development and Technology
Office of Noise Abatement
Washington DC 20590

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Technical Report Documentation Page

1. Report No. DOT-TSC-OST-76-21	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle TRUCK NOISE XI EVALUATION AND REDUCTION OF HEAVY-DUTY TRUCK NOISE		5. Report Date September 1976
		6. Performing Organization Code
7. Author(s) V. Alan Werner, Willam Boyce		8. Performing Organization Report No. DOT-TSC-OST-76-21
9. Performing Organization Name and Address PACCAR Inc.* Truck R&D Center 790 Garden Avenue North Renton WA 98055		10. Work Unit No. (TRAIS) OS607/R6513
		11. Contract or Grant No. DOT-TSC-708
12. Sponsoring Agency Name and Address U.S. Department of Transportation Office of the Secretary Office of the Asst. Sec. for Sys. Dev. and Tech. Office of Noise Abatement Washington DC 20590		13. Type of Report and Period Covered Final Report December 1973 - May 1975
		14. Sponsoring Agency Code

15. Supplementary Notes

Under contract to: U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

16. Abstract

This report describes the work performed to examine the noise sources on two common truck configurations manufactured by this company, and to evaluate the noise reduction effectiveness of retrofit hardware. The two trucks selected were Cab-Over-Engine (COE) models with engines most often ordered with these models. One was a Kenworth K-123 with a Cummins NTC-350 engine, the other a Peterbilt 352A with a Detroit Diesel 8V-71T engine.

The major noise source on both trucks was the cooling fan which led to modifications involving fan changes and fan speed decreases which resulted in decreased overall noise levels. The Kenworth's interior and exterior levels were reduced from 92 dB(A) to 89 dB(A) and from 91 dB(A) to 86.5 dB(A), respectively. The Peterbilt interior noise level was reduced from 95 dB(A) to 88.5 dB(A) and from 89 dB(A) to 84.5 dB(A) for the exterior.

Further reduction of noise levels from these trucks would require additional cooling fan changes and some form of engine treatment, the engine being the second major noise source.

17. Key Words Noise, Motor Vehicle Noise, Truck Noise, Exhaust Noise, Mufflers, Engine Noise	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	192	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

In preparing this document, the authors have received extensive assistance from the Peterbilt Motor Company and Kenworth Truck Company, divisions of PACCAR Inc. The staffs of the following manufacturers and distributors were also of valuable service:

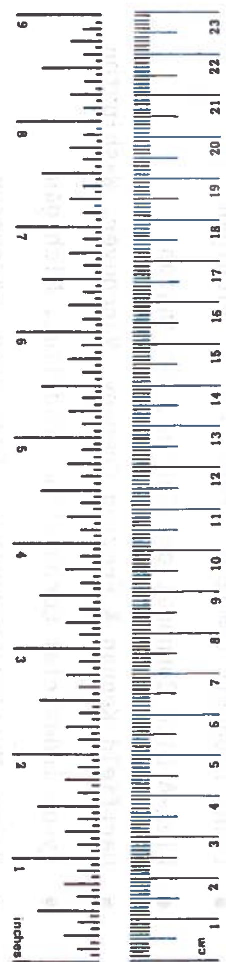
- H. L. Blackford, Inc., Orange, California
- Cummins Engine Company, Columbus, Indiana
- Donaldson Company, Inc., Minneapolis, Minnesota
- Evans Products Company, Grand Rapids, Michigan
- Flex-A-Lite Corporation, Tacoma, Washington
- Hartfield Kennan & Freytag Company, Vancouver, Washington
- Kysor Industrial Corporation, Cadillac, Michigan
- Nelson Muffler Corporation, Stoughton, Wisconson
- Air Flow Systems, Inc., Portland, Oregon
- Specialty Composites Corporation, Newark, Delaware
- Stemco Manufacturing Company, Inc., Longview, Texas

We also are grateful for the many practical comments and suggestions as to format and contents of this document that were received from the technical monitor of this contract, Mr. Robert L. Mason.

METRIC CONVERSION FACTORS

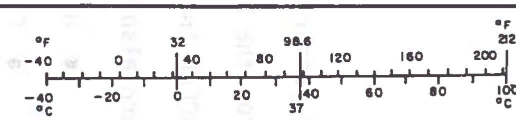
Approximate Conversions to Metric Measures

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



Approximate Conversions from Metric Measures

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



CONTENTS

CONTENTS (CONCL'D)

ILLUSTRATIONS

Figure | Page

ILLUSTRATIONS (CONCL'D)

TABLES

1. INTRODUCTION

The program described in this report was started in December, 1973, at PACCAR Truck R&D to test and retrofit two common truck configurations manufactured by the Company to reduce their noise levels. Both trucks were Cab-Over-Engine (COE) models featuring engines most often ordered with these models; one was a Kenworth K-123 with a Cummins NTC-350 engine and a 145-inch wheelbase, the other was a Peterbilt 352A with a Detroit Diesel 8V-71T engine and a 240-inch wheelbase.

The DOT Noise Program, as this contract was named, began by collecting Unmodified Baseline sound levels using SAE J366 procedure for exterior data and SAE J336 for interior data. Following the baseline series, various modifications were evaluated and tested on the trucks to reduce as much as possible the exterior and interior sound levels. A Sound Source Definition test series was conducted on each truck to determine the contributed sound levels of each major system of the truck. Finally, a set of components was specified to make up a Modified Vehicle package which was tested and evaluated for noise abatement effectiveness. For both trucks, the only modifications specified were fan and fan speed ratio changes; all other systems were left as produced by the factories.

The exterior sound level of the Kenworth was reduced from a maximum of 91.0 dB(A) to 86.5 dB(A). The Peterbilt exterior sound level was reduced from 89.0 dB(A) to 84.5 dB(A). Interior noise was reduced from 92.0 dB(A) to 89.0 dB(A) on the Kenworth and from 95.0 dB(A) to 88.5 dB(A) on the Peterbilt. Both these maximum interior and exterior levels were recorded in J366 acceleration tests.

During the Unmodified Baseline series, the whole picture of truck noise was surveyed by taking data from 24 different tests in both the bobtail and loaded conditions. The number of tests was reduced to 6 after the analysis of the results showed insignificant differences between many of the test conditions.

The Sound Source Definition testing established the cooling fans as the predominant sound sources on both trucks. In descending order, the remaining systems were the engine, exhaust, transmission, intake, and chassis. The Peterbilt's driveline was a surprising sound source ranking below the exhaust system in order.

The testing and evaluation of noise reduction systems or components was centered on cooling tests to qualify fans and system modifications for subsequent sound testing. Several mufflers and peripheral components were tested on both trucks. Additionally, a system of sound curtains (rudimentary enclosures), sound liners, interior shutters, and fan clutches were tested and evaluated for contributions to sound level reductions.

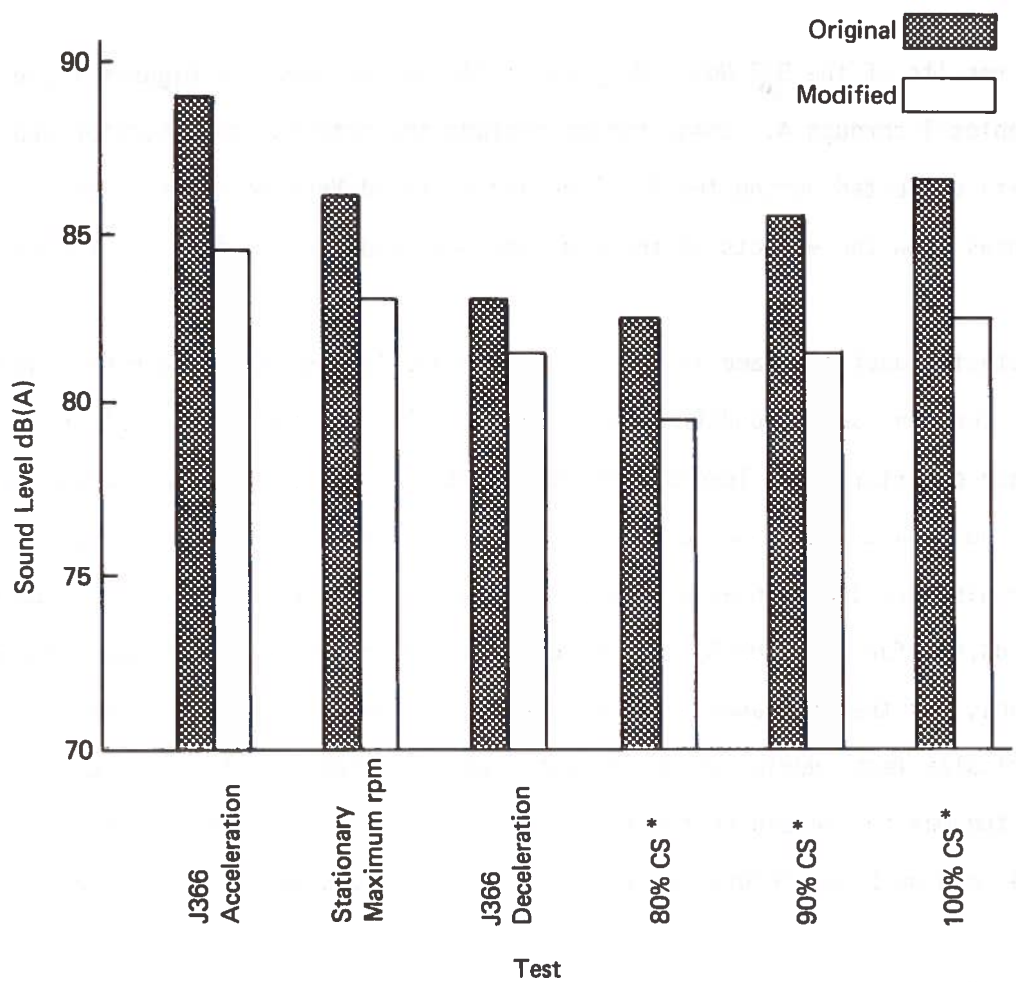
A computer system was used to analyze the sound information for spectral content. This was a fast fourier transform analyzer coupled to a computer central processor and peripheral equipment programmed to process acoustical data digitally with 20 Hertz resolution in a 1/12 octave-band format. The programming allowed gap-free analyzing of transient information with exponential averaging modeled from ANSI S1.4 standard for type 1 fast response sound level meters. In the field, the sound data were recorded on a precision 1/4-inch magnetic tape recorder as well as monitored on a D-C stripchart recorder calibrated to respond as a Sound Level Meter.

2. SUMMARY OF RESULTS

Overall results of the DOT Noise Program at PACCAR are shown in Figures 1 and 2 and Tables 1 through 4. These tables include the exterior and interior sound level data collected during the Baseline and Modified Vehicle tests. The differences show the effects of the modifications made to the two test trucks.

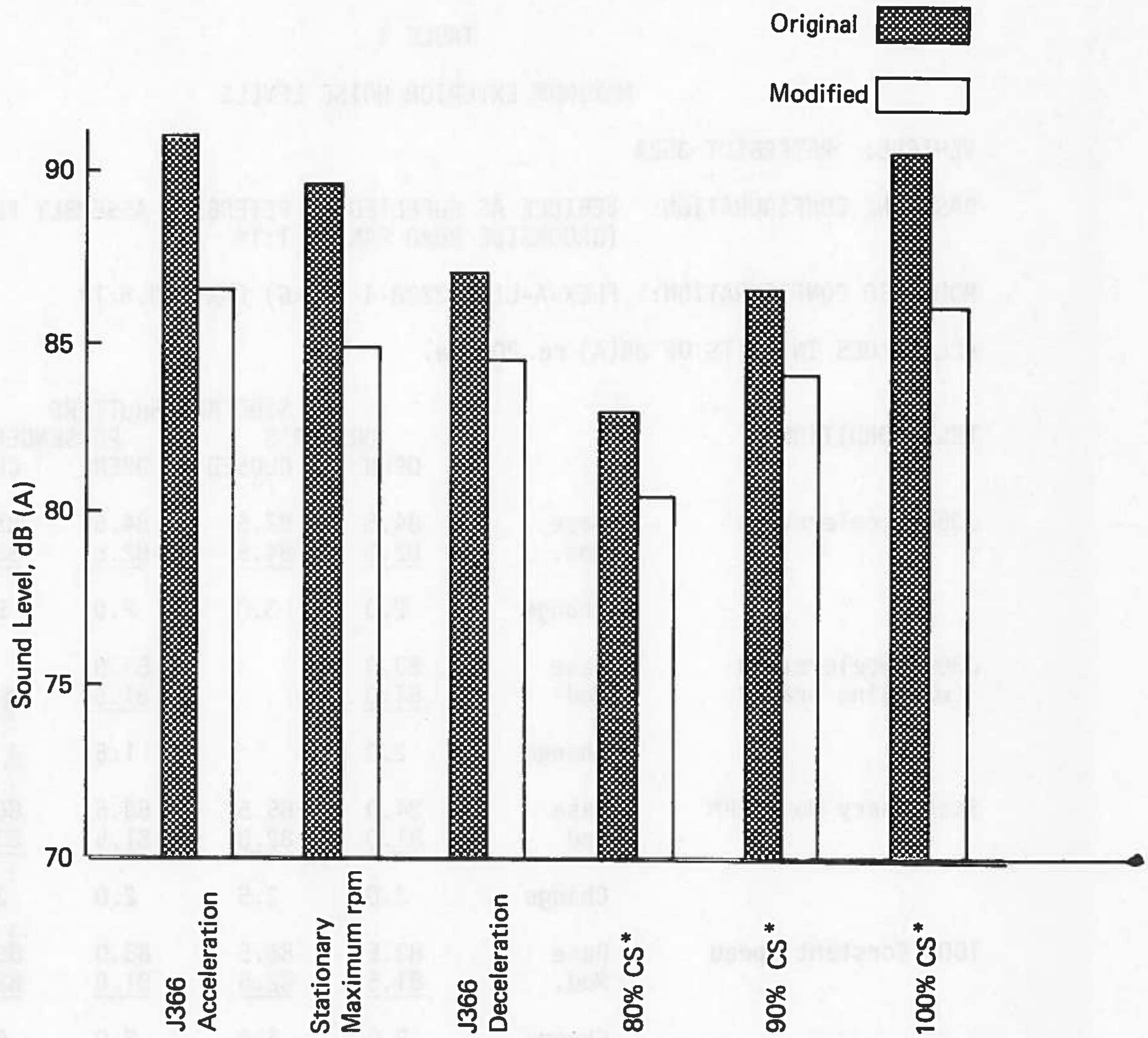
The greatest reductions came in the interior sound levels of the Peterbilt where the 100% constant speed condition had an 8.0 dB(A) reduction. The vehicle's worst case exterior sound levels also were good, showing a 5.5 dB(A) reduction in one condition of the J366 acceleration. The maximum sound level for the Kenworth was also the J366 acceleration exterior; it was reduced from 91.0 dB(A) to 86.5 dB(A), for a 4.5 dB(A) reduction. Not all of the configurations showed reductions, but the increases obtained are not considered as significant. In the particular tests during which increases were recorded, either the levels are not the maximum levels or the test conduct itself (as in the case of the Peterbilt engine brake interiors) is suspected to be out of specifications.

Greater reductions were available with the Peterbilt than the Kenworth because of the source making the greatest contribution. A characteristic of both trucks was that the fan was the single noisiest component. In the case of the Kenworth, the lack of spacing between the block and the radiator core necessitated using smaller pitch width fans. These were not as efficient in cooling. Using less efficient fans forced higher tip speeds and allowed fan stall to occur more rapidly than with the Peterbilt, which had larger radiator/block spacing. Fans "stall" when they reach their maximum pressure gain. This occurs when a vacuum is created with shutters closed or with discharge restrictions. Fan stall was one of the worst cases for vehicle noise.



*Constant speed drive-by levels and percent of governed engine speed.
Vehicle speed less than 35 mph

Figure 1. Original and Modified Maximum Sound Levels, Peterbilt Model 352A



*Constant Speed Drive-by levels and percent of governed engine speed.
Vehicle speed less than 35 mph

Figure 2. Original and Modified Maximum Sound Levels, Kenworth Model K-123

TABLE 1

MAXIMUM EXTERIOR NOISE LEVELS

VEHICLE: PETERBILT 352A

BASELINE CONFIGURATION: VEHICLE AS SUPPLIED BY PETERBILT ASSEMBLY PLANT WITH (BROOKSIDE 28x8 FAN) @ 1:1*

MODIFIED CONFIGURATION: FLEX-A-LITE 3228-4 (28x6) FAN @ 0.8:1*

ALL VALUES IN UNITS OF dB(A) re. 20 μPa.

TEST CONDITION		SIDE AND SHUTTERS: DRIVER'S OPEN	DRIVER'S CLOSED	PASSENGER'S OPEN	PASSENGER'S CLOSED
J366 Acceleration	Base	84.5	87.5	84.5	89.0
	Mod.	82.5	84.5	82.5	83.5
	Change	2.0	3.0	2.0	5.5
J366 Deceleration (w/engine brake)	Base	83.0		83.0	
	Mod	81.0		81.5	
	Change	2.0		1.5	
Stationary Max. RPM	Base	84.0	85.5	83.5	86.0
	Mod.	81.0	82.0	81.5	83.0
	Change	3.0	2.5	2.0	3.0
100% Constant Speed	Base	83.5	86.5	83.0	86.5
	Mod.	81.5	82.5	81.0	82.5
	Change	2.0	4.0	2.0	4.0
90% Constant Speed	Base	82.0	84.0	82.0	85.5
	Mod.	80.5	81.5	81.0	81.5
	Change	1.5	2.5	1.0	4.0
80% Constant Speed	Base	80.5	81.5	81.0	82.5
	Mod.	79.5	79.5	79.5	79.5
	Change	1.0	2.0	1.5	3.0

*Ratio of fan speed to engine speed

TABLE 2

MAXIMUM INTERIOR NOISE LEVELS

VEHICLE: PETERBILT 352A

BASELINE CONFIGURATION: VEHICLE AS SUPPLIED BY PETERBILT ASSEMBLY PLANT WITH (BROOKSIDE 28x8 FAN) @ 1:1*

MODIFIED CONFIGURATION: FLEX-A-LITE 3228-4 (28x6) FAN @ 0.8:1*

ALL VALUES IN UNITS OF dB(A) re. 20μ Pa.

TEST CONDITION		SHUTTERS OPEN	SHUTTERS CLOSED
J366 Acceleration	Base	89.0	95.0
	Mod.	87.0	88.5
	Change	2.0	6.5
Stationary Max. RPM	Base	88.0	94.0
	Mod.	86.0	86.5
	Change	2.0	7.5
J366 Deceleration (w/engine brake)	Base	83.0	86.0
	Mod.	86.5	87.0
	Change	-2.5	-1.0
100% Constant Speed	Base	89.0	93.5
	Mod.	84.5	85.5
	Change	4.5	8.0
90% Constant Speed	Base	86.0	89.5
	Mod.	83.5	85.0
	Change	2.5	4.5
80% Constant Speed	Base	83.5	87.0
	Mod.	84.5	83.0
	Change	-1.0	4.0

*Ratio of fan speed to engine speed

TABLE 3

MAXIMUM EXTERIOR NOISE LEVELS

VEHICLE: KENWORTH K-123

BASELINE CONFIGURATION: VEHICLE AS SUPPLIED BY KENWORTH ASSEMBLY PLANT WITH (BROOKSIDE 28x6 FAN) @ 1.2:1*

MODIFIED CONFIGURATION: FLEX-A-LITE 3528 (28x8) FAN @ 1:1*

ALL VALUES IN UNITS OF dB(A) re. 20μPa.

		SIDE AND SHUTTERS			
		DRIVER'S		PASSENGER'S	
TEST CONDITION		OPEN	CLOSED	OPEN	CLOSED
J366 Acceleration	Base	86.5	91.0	86.5	90.5
	Mod.	84.0	86.5	84.0	86.0
	Change	2.5	4.5	2.5	4.5
J366 Deceleration (w/engine brake)	Base	85.5	86.5	86.5	87.0
	Mod.	83.5	84.5	83.0	83.5
	Change	2.0	2.0	3.5	3.5
Stationary Max. RPM	Base	87.0	88.0	86.5	89.5
	Mod.	82.0	85.0	81.0	83.5
	Change	5.0	3.0	5.5	6.0
100% Constant Speed	Base	85.5	90.5	86.0	88.5
	Mod.	81.5	86.0	82.0	85.0
	Change	4.0	4.5	4.0	3.5
90% Constant Speed	Base	85.0	85.0	84.5	86.5
	Mod.	80.0	84.0	80.5	83.0
	Change	5.0	1.0	4.0	3.5
80% Constant Speed	Base	82.0	81.5	81.5	83.0
	Mod.	78.5	80.5	78.0	80.5
	Change	3.5	1.0	3.5	2.5

* Ratio of fan speed to engine speed

TABLE 4

MAXIMUM INTERIOR NOISE LEVELS

VEHICLE: KENWORTH K-123

BASELINE CONFIGURATION: VEHICLE AS SUPPLIED BY KENWORTH ASSEMBLY PLANT WITH (BROOKSIDE 28x6 FAN) @ 1.2:1*

MODIFIED CONFIGURATION: FLEX-A-LITE 3528 (28x8) FAN @ 1:1*

ALL VALUES IN UNITS OF dB(A) re.20 μ Pa.

TEST CONDITION		SHUTTERS OPEN	SHUTTERS CLOSED
J366 Acceleration	Base	88.0	92.0
	Mod.	87.0	89.0
	Change	1.0	3.0
J366 Deceleration (w/engine brake)	Base	86.0	87.5
	Mod.	85.5	87.5
	Change	0.5	0.0
Stationary Max.RPM	Base	87.0	91.0
	Mod.	85.5	88.0
	Change	1.5	2.5
100% Constant Speed	Base	87.5	91.5
	Mod.	85.0	88.0
	Change	2.5	2.5
90% Constant Speed	Base	85.5	89.0
	Mod.	84.0	86.5
	Change	1.5	2.5
80% Constant Speed	Base	84.0	83.0
	Mod.	82.0	85.0
	Change	2.0	-2.0

* Ratio of fan speed to engine speed

Both trucks showed that altering systems other than the cooling fan and its system had little or no effect on the overall sound level. The original equipment mufflers and intake systems were found to be optimum equipment in terms of sound levels within the scope of changes to be made to the trucks. Other alterations such as acoustical barriers around the engine compartment or acoustical sound absorbers in the engine compartment had some positive effect on noise reduction, but the effects were small. The cost/benefit ratio was not significant; therefore, the results are only reported and discussed; the changes are not recommended. These and other sound reduction methods are covered in this report in later sections.

3. TEST ITEM DESCRIPTION

3.1 TEST VEHICLES

The two primary test vehicles of the DOT Noise Program were both Cab-Over-Engine (COE), heavy-duty, Class 8 highway tractors typical of those produced by the two manufacturing divisions of PACCAR Inc. The cab styles, engines, transmissions, and other features of the trucks were specified to conform to items most often bought by the truck users. The Kenworth was specified with a short wheelbase similar to the trucks used in the eastern part of the country. The Peterbilt was a long wheelbase truck similar to those used in the western states.

Both trucks are shown in Figure 3, and the particular descriptions are listed in Table 5.

3.2 TEST-SITE DESCRIPTION

3.2.1 Sand Point Naval Support Activity

Sand Point Naval Support Activity was the major site used for truck noise evaluation because of its nearly ideal testing conditions. It is a surplus naval air station located in northeast Seattle about 25 miles from the company location, and features a 5,400-foot runway and spacious apron, both with hard, sealed asphalt surfaces. The test course was situated on the apron parallel to the runway in roughly a north/south direction. There was plentiful room to maneuver the trucks for the runs, and absolutely no obstructions in any direction for a minimum of 400 yards. The hard asphalt surface consistently produced the maximum sound levels among the different noise testing sites used, thereby creating a "worst case" situation.

Two photos of Sand Point are Figures 4 and 5.

Figure 3. Front View of the Primary Test Trucks

TABLE 5

TRUCK SPECIFICATIONS--AS RECEIVED FROM MANUFACTURER

	KENWORTH	PETERBILT
Model	K 123	352 A
Wheelbase	145"	240"
Cab Style	COE	COE
Engine	Cummins NTC 350	Detroit Diesel 8V-71T
Transmission	Fuller 12513	Fuller 9513
Rated Horsepower	350 @ 2100 RPM	350 @ 2100 RPM
Max. Governed RPM	2250	2250
Radiator Area	1200 sq. in.	1020 sq. in.
Radiator Fan	Brookside 28x6	Brookside 28x8
Fan Speed Ratio	1.2:1	1:1
Exhaust System	Dual vertical 5 in.	Dual vertical 5 in.
Mufflers	Donaldson MPM09-0161	Donaldson MPM09-0161
Stacks	36 in. square cut	36 in. diagonal cut
Suspension, rear	4 - spring	air leaf
Tires, front	11.00-24.5 tubeless	10.00-22 tubeless
	T-1 (Firestone)	Super-milers (Goodyear)
Tires, rear	11.00-24.5 tubeless	10.00-22 tubeless
	Powerdrives (Firestone)	Powerdrives (Firestone)
Air Cleaner	Donaldson EBA15-0072	Donaldson EBA15-0006
Serial Number	235192	64736
Build Date	11/05/73	11/30/75

Figure 4. Peterbilt on Sand Point Noise Course

Figure 5. General View of Sand Point Noise Course

3.2.2 Military Test Track

The Military Test Track is a test site constructed by a division of the company for testing and demonstrating military vehicles. It features an asphalt track, 25 feet wide, forming a right angle triangle of about one mile in length. The longest leg of the track is about 1,400 feet. The noise pad was constructed approximately in the middle of this leg. The area to the side of the track was leveled and filled with large, crushed aggregate and the instrumentation placed according to J366 specifications. There were no obstructions or reflecting surfaces for a minimum of 150 feet from the microphone or vehicle centerline.

A sketch and photo of the Military Test Track are Figures 6 and 7.

3.2.3 Backlot

The Backlot site shown in Figure 8 was used to evaluate components for the retrofit selection process. Located directly behind the laboratory, it was sufficient to allow a 100-foot clear zone around the microphone and truck location. The site was small and allowed only a static runup test condition, but the convenience of the shop and instrumentation location permitted rapid and expedient comparison of different components. When the computer was brought on line, a direct, real-time analysis procedure was started allowing immediate spectral analyses of the noise signatures.

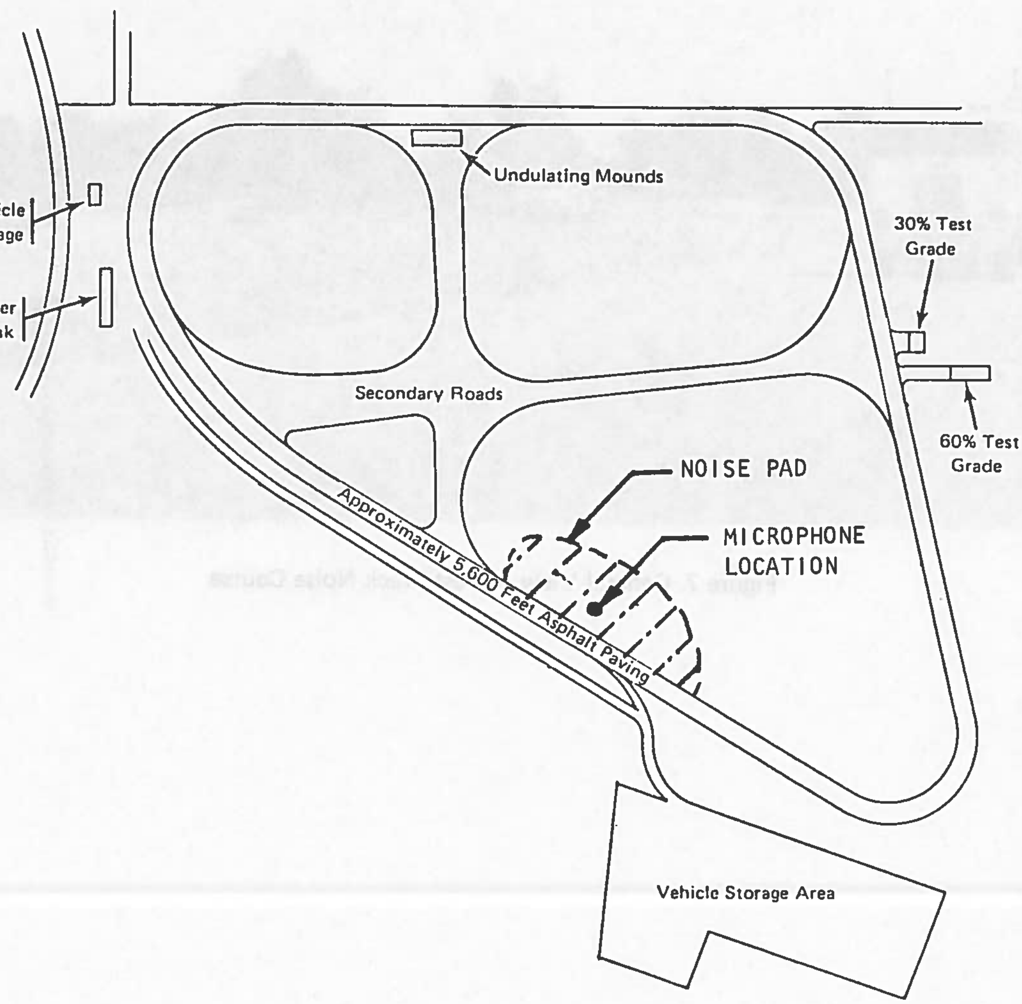


Figure 6. Test Track Noise-Testing Location

Figure 7. General View of Test-Track Noise Course

Figure 8. Backlot Test Location

3.3 TEST INSTRUMENTATION

The instrumentation used in the DOT Noise Program [illegible] following:

Microphones SN363359, 363266 SN259, 497	B&K 1/2-inch condenser microphon[illegible] mounted on 1/2-inch General Radio preamplifi[illegible] 50-P42.
Tape Recorder SN 2623	Nagra Model IV-SJ direct record magnetic tape recorder, using 1/4-inch tape, with two data channels and a third FM voice track, multiple speeds, manual input attenuators, built-in weighing filters for A, B, C, and D weights.
Calibrator SN 321632	B&K pistonphone, type 4220, mechanically driven, battery-powered, producing a tone of 124 dB @ 250 Hz.
Sound-Level Meter SN 328762	B&K type 2204/s Impulse Precision Sound Level Meter, battery-powered, with "fast" and "slow" meter responses and "record" to AC and DC outputs, built-in weighting filters for A, B, C, and D weights.
Log Converter SN 188	B&K Model 215 RMS Voltmeter Log Converter used to convert AC SLM outputs to DC signals for the stripchart.
Stripchart SN 243228	General Radio type 1522 DC stripchart, single-channel, 6" wide paper using permanent ink marker, side event marker, multiple slewing and paper feed speeds.

Frequency Meter SN 784	Hewlett-Packard Frequency Meter, Model 500 B, AC-powered vacuum tube frequency meter calibrated to monitor RPM telemetry signals.
RPM Telemetry	In-house-built transmitter and receiver coupled to a Sun Pulse generator tied to the tachometer drive.
Power Supply	In-house-built battery power supply to feed microphones with 22.5 vdc and switch monitor channel between two channels.
Photocells	Four photocells used to mark truck position on the course by a light mounted to the truck bumper; signals fed to a multiplexer and demodulator system coupled to the tape recorder and stripchart.
Noise-Analysis Computer	Hewlett-Packard 5451B Fourier Analyzer programmed to plot the exponentially averaged spectrum of the maximum (A) weighted sound level recorded for a particular test run. The Analyzer and program are described in detail in Appendix D.
Communications	Citizens Band Radio
Instrumentation Vehicle	Dodge 3/4 ton van equipped with 12/110 volt inverter.

The majority of the instruments are shown installed in the instrument van in Figure 9. Diagrams of the instrumentation set-ups are illustrated in Figure 10 for exterior noise and Figure 11 for interior noise. The Fourier Analyzer is pictured in Figures 12 and 13. The computer-driven digital plotter is shown in Figure 14.

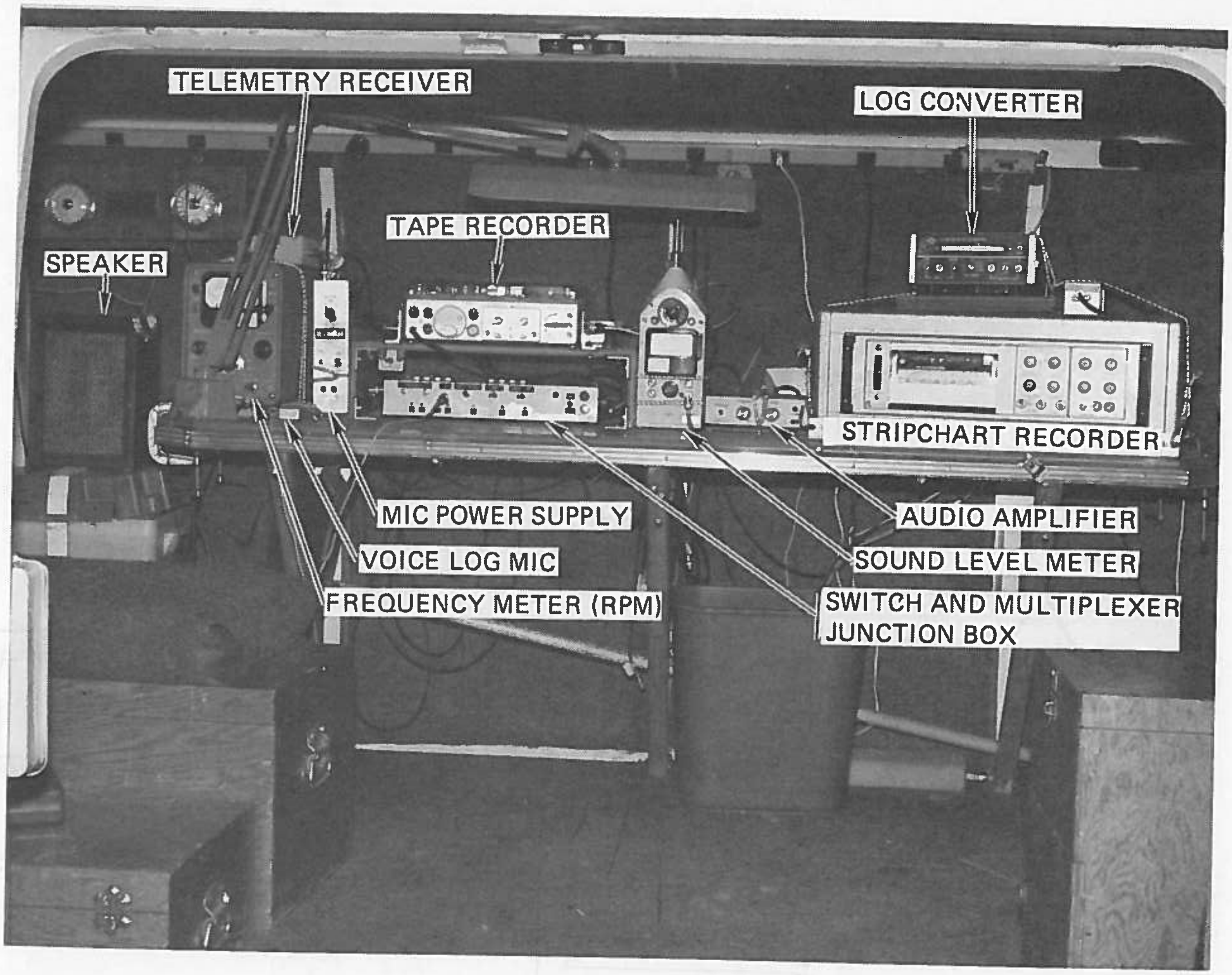


Figure 9. Instrument Van Setup for Field-Data Acquisition

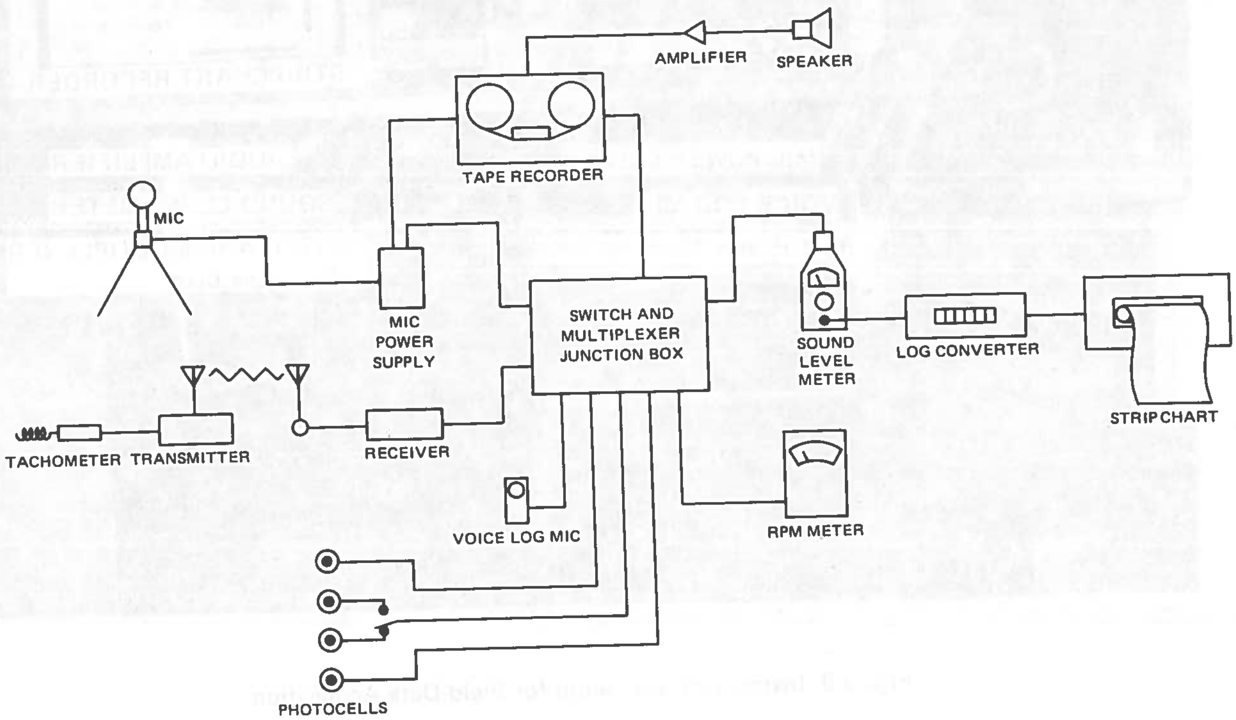


Figure 10. Exterior Noise Measurement System Equipment Schematic

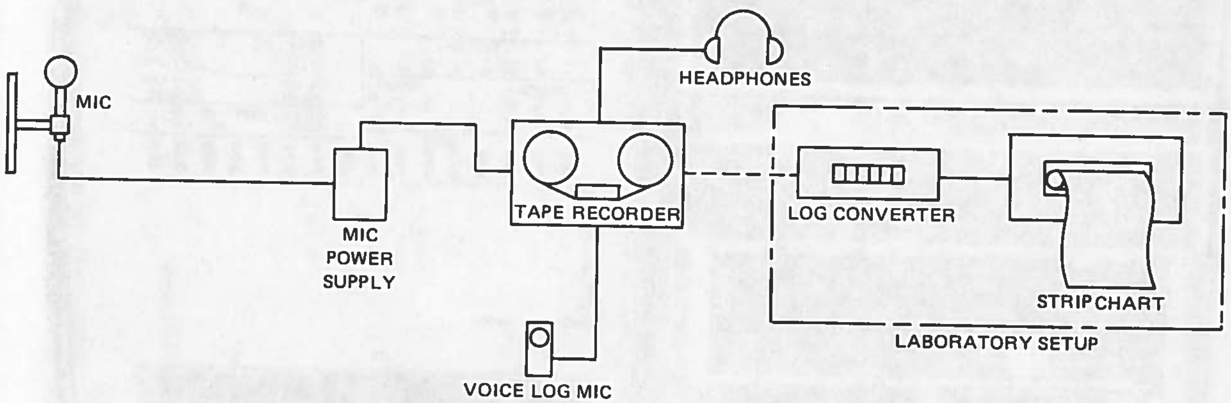


Figure 11. Interior Noise Measurement System Equipment Schematic

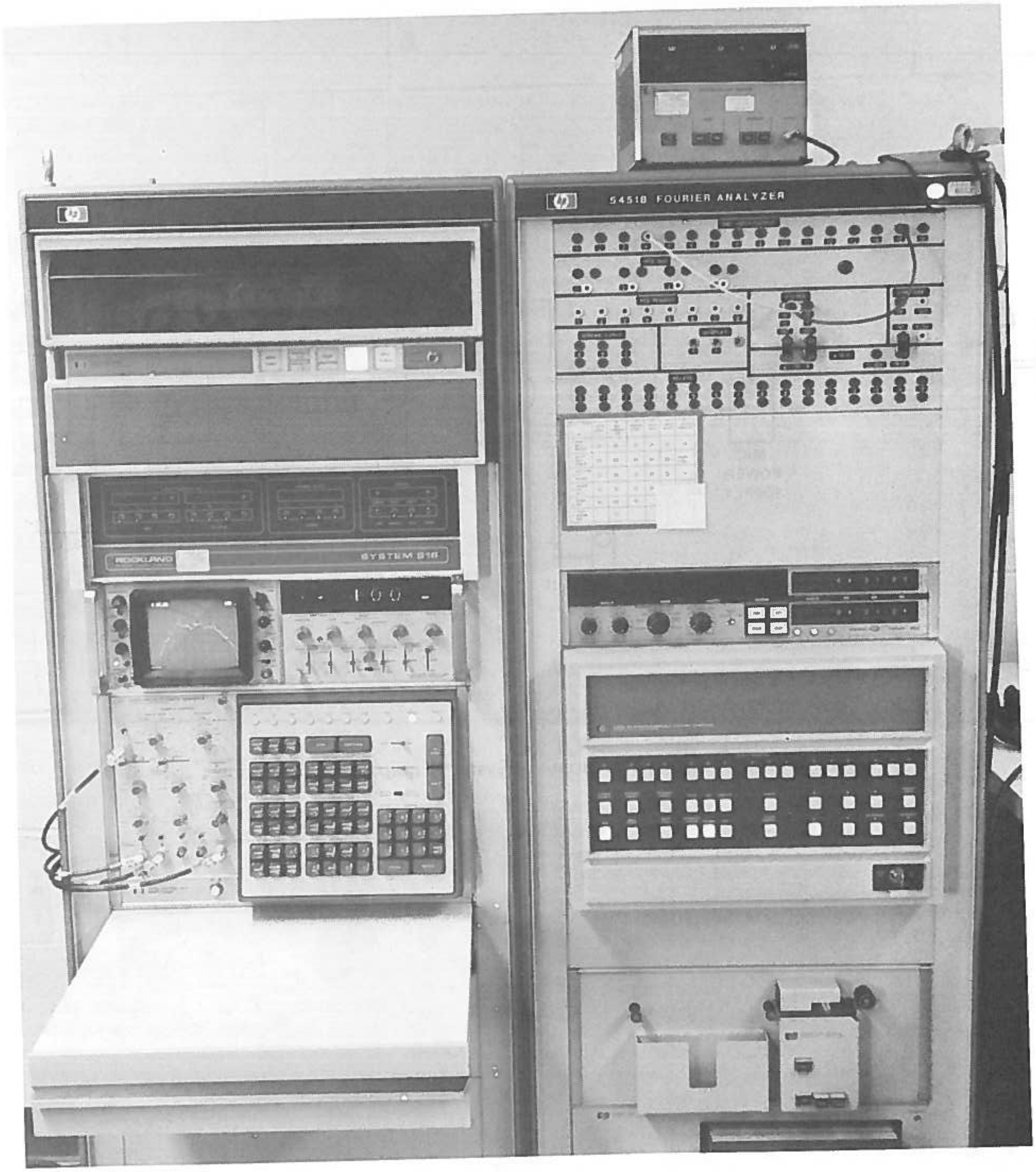


Figure 12. Hewlett-Packard Fourier Analyzer

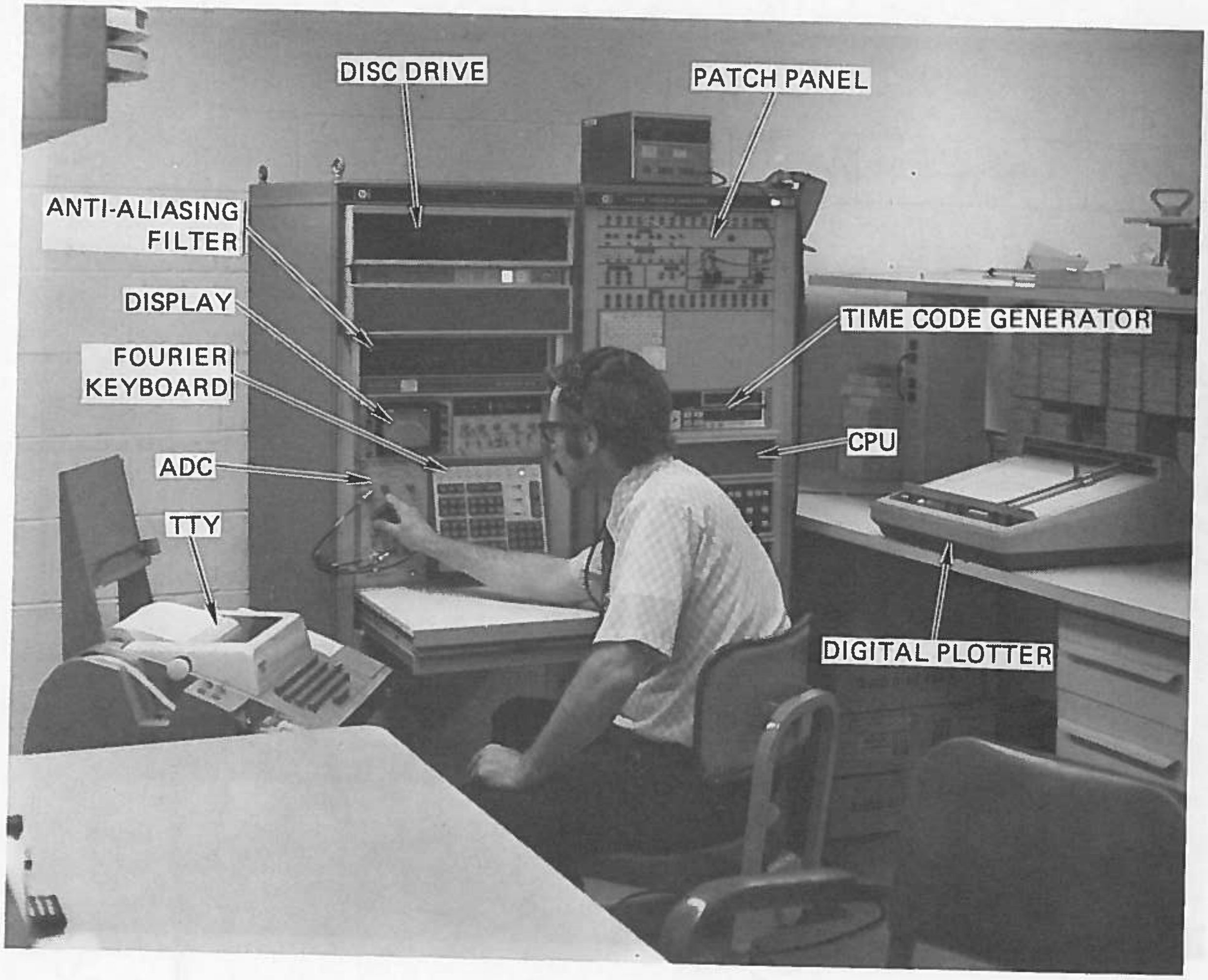


Figure 13. General View of Spectrum-analyzing Instrumentation

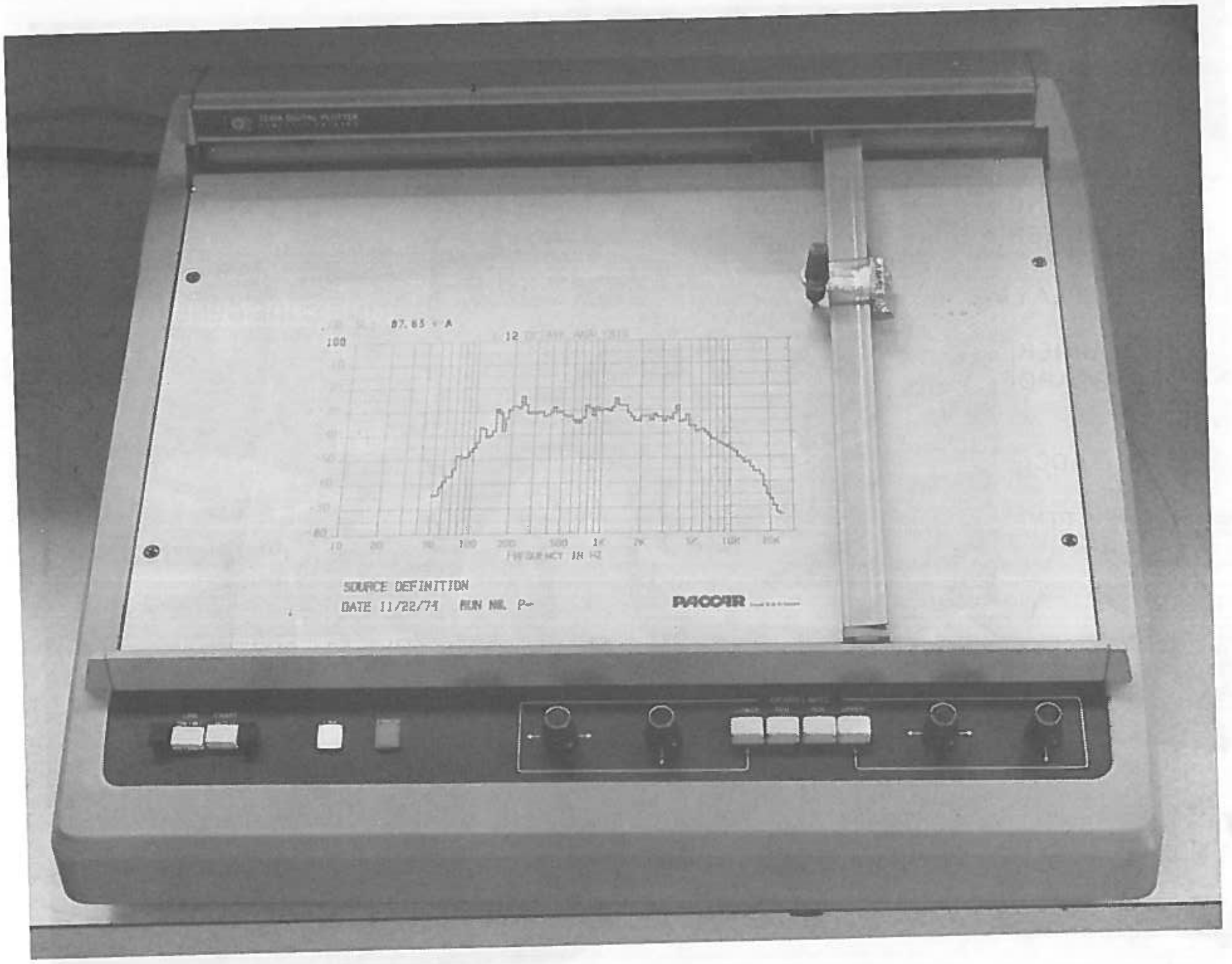


Figure 14. Spectrum-Analysis Plot on Computer Plotter

4. TEST RESULTS

4.1 BASELINE TESTS

4.1.1 Exterior-Sound Levels

The Baseline Tests were run in two locations and two time frames. The first series of tests was performed at the Military Test Track as soon as the trucks and instrumentation were ready for testing. During this series, 28 test configurations were run to survey the whole field of noise testing on heavy-duty trucks. The results of that testing are cataloged in Table 6 and Table 7 for the respective trucks.

Following the initial series of tests, the results were analyzed and reduced to 6 test types for the bobtail truck alone. The rationale for this reduction is discussed in the Analysis section. A better location for noise testing was found in the Sand Point course where all of the subsequent testing was performed. The Baseline Tests were repeated at this location using only the 6 test types decided upon.

The results of the second set of Baseline Tests are included in Tables 1 and 3 where the Modified Vehicle Test results are also tabulated and the changes in sound level are calculated. The overall results of the program are summarized in these two tables.

4.1.2 Interior-Sound Levels

Interior sound levels were recorded for all of the 28 run conditions used for the exterior sound levels. Using the rationale presented in the Analyses section, only the results of the six most significant conditions are presented in the Summary or Results section, Tables 2 and 4.

TABLE 6

BASELINE NOISE TESTS--PETERBILT

LOCATION: TEST TRACK

VEHICLE: PETERBILT 352 A

TEST CONDITION: J366 TEST COURSE

	SIDE AND SHUTTERS			
	DRIVER'S		PASSENGER'S	
	OPEN	CLOSED	OPEN	CLOSED
Bobtail				
J366 Acceleration	82.5	87.5	85.5	87.5
Stationary, Max. RPM	81.0	86.0	82.0	85.5
" , Idle	61.5	63.5	63.0	63.0
" , Max. Torque	76.0	79.5	75.5	74.5
Constant Speed, 80% Max. RPM	79.0	80.5	78.0	79.5
" , 90% Max. RPM	82.5	81.5	80.5	85.0
" , 100% Max. RPM	82.0	86.5	82.0	86.5
" , Max. Torque	78.0	79.5	77.0	78.5
J366 Deceleration	80.5	80.5	79.0	79.0
Coastby (30 MPH)	66.0	65.5	68.5	66.5
Loaded (with 40' trailer)				
J366 Acceleration	83.5	88.0	84.0	87.0
Stationary, Max. RPM	81.5	85.0	82.5	85.0
" , Idle	63.0	62.5	62.5	63.5
" , Max. Torque	76.0	78.0	76.5	77.0
Constant Speed, 80% Max. RPM	81.0	81.0	79.5	80.5
" , 90% Max. RPM	83.0	83.0	82.0	84.5
" , 100% Max. RPM	82.5	87.0	83.0	86.5
" , Max. Torque	79.5	80.5	79.0	79.0
Constant Speed, 80% Max. RPM w/brakes	82.5	84.0	82.5	83.0
" , 90% Max. RPM w/brakes	84.5	85.0	85.0	87.5
" , 100% Max. RPM w/brakes	84.0	87.0	84.0	86.0
" , Max. Torque w/brakes	82.5	83.5	83.0	86.0
J366 Deceleration	81.0	82.5	83.0	83.0
Coastby (30 MPH)	72.5	72.5	75.5	74.5

TABLE 7

BASELINE NOISE TESTS--KENWORTH

LOCATION: TEST TRACK

VEHICLE: KENWORTH K-123

TEST CONDITION: J366 TEST COURSE

	SIDE AND SHUTTERS			
	DRIVER'S		PASSENGER'S	
	OPEN	CLOSED	OPEN	CLOSED
Bobtail				
J366 Acceleration	85.5	84.5	85.5	85.0
Stationary, Max. RPM	84.0	85.5	82.5	84.0
" , Idle	64.5	65.5	66.0	66.0
" , Max. Torque	74.0	75.5	76.0	75.5
Constant Speed, 80% Max. RPM	79.5	81.5	79.5	79.5
" , 90% Max. RPM	82.5	83.0	82.5	83.0
" , 100% Max. RPM	84.0	86.0	85.5	86.5
" , Max. Torque	76.5	77.5	77.0	78.5
J366 Deceleration	83.5	82.5	85.0	83.5
Coastby (30 MPH)	71.0	71.5	71.5	71.0
Loaded (with 40' trailer)				
J366 Acceleration	85.0	86.0	85.5	85.5
Stationary, Max. RPM	83.5	86.0	-	84.5
" , Idle	66.0	66.5	-	67.0
" , Max. Torque	75.0	76.5	-	76.5
Constant Speed, 80% Max. RPM	81.0	81.5	81.0	81.5
" , 90% Max. RPM	83.0	83.0	83.0	82.5
" , 100% Max. RPM	84.5	86.0	85.0	86.5
" , Max. Torque	79.0	79.5	79.5	79.0
Constant Speed, 80% Max. RPM w/brakes	-	-	-	-
" , 90% Max. RPM w/brakes	-	-	-	-
" , 100% Max. RPM w/brakes	85.0	86.5	-	86.0
" , Max. Torque w/brakes	-	-	-	-
J366 Deceleration	86.0	86.0	-	86.0
Coastby (30 MPH)	67.5	67.5	68.0	68.0

The pattern of the interior sound levels followed the exterior sound level readings. The conditions that produced the maximum noise for the exterior also were the loudest in the interiors. The difference between run conditions did not precisely follow in incremental amounts, nor did the spectral analyses (not included in this report) match for interior versus exterior, but the solutions applied to the exterior sound were able to affect and reduce the interior sound.

4.1.3 Test Procedures

The noise tests performed in the program are lumped into five distinct groups that differ only in the details of truck operation. The most important group is the J366 procedure conforming to the SAE J366 test procedure, Exterior Sound Level for Heavy Trucks and Buses. This is the fundamental test procedure used by the industry to measure sound levels of heavy-duty trucks. This procedure consistently gave the maximum sound level readings, particularly in the acceleration mode.

The following is a summary of the six baseline test procedures:

J366 acceleration and deceleration: Performed according to the SAE J366, Exterior Sound Levels for Heavy Trucks and Buses. The acceleration test is performed in a gear (4th for bobtail) selected to accelerate the vehicle from 2/3 governed RPM to full governed RPM while in the sound course. During the deceleration test, the truck enters the course at full governed RPM in the same gear (4th) and decelerates upon reaching a mark near the mid-point in the noise course (40 feet into the course).

Stationary, Max RPM: With the vehicle parked so the exhaust stacks were on line with and the truck centerline 50 feet from the microphone, the engine was run steadily at full governed RPM for the data acquisition with the transmission in neutral.

Constant Speed: The vehicle was driven through the sound course at a steady speed close to 30 MPH in the appropriate gear for the chosen engine speed. The speeds used were 80, 90, 100 percent of full governed RPM and the RPM of maximum torque (1,500 RPM for both trucks).

Constant Speed with Brakes: This test simulated a truck climbing a hill of some grade by approximating the load induced. The trucks were driven through the course with wide open throttle while the trailer brakes were used to pull the truck down to the chosen RPM. The appropriate gear was used to allow the chosen engine speed to give about 30 MPH.

Coast-by: The coast-by was an engine off, clutch disengaged coast-through to measure the residual sounds of the truck tire, chassis, and incidental rattles. This was performed at both 20 and 30 MPH.

4.1.4 Analyses

The series of tests performed in the initial Baseline Tests was informative about all the types of conditions that a truck would be subjected to and about noise emitted. This was a lengthy test series that required more equipment and time than normally available. The results showed that the majority of the tests did not produce the noisiest conditions, and others were duplications of conditions run in configurations more readily measured. Such was the case of all of the loaded runs where no significant information not learned from the bobtail configurations was gained. In the case of the Kenworth, the loaded

J366 acceleration was louder than the bobtail J366 acceleration by as much as 1.5 dB(A); the difference with the Peterbilt was only 0.5 dB(A). In terms of relative information regarding reductions of sound level, the judgment was that bobtail configurations would be fully suitable.

Examination of the remaining tests in the bobtail configuration allowed elimination of some of the tests because they were insignificant compared to the rest. The idle and maximum torque stationary, maximum torque constant speed drive-by and the coast-by consistently produced sound levels much lower than the other tests. They were therefore eliminated from the testing schedule although the coast-by was retained for background levels in some cases.

The results of this analysis reduced the noise runs to six configurations: J366 acceleration, J366 deceleration, 80% constant speed, 90% constant speed, 100% constant speed, and stationary maximum RPM. The constant speed runs were used to illustrate the effects of pass-by noise if the RPM of the engine were reduced either by driver discretion or by alternation to the mechanical governing. The J366 acceleration aand deceleration runs were the primary standards of noise measurement. The stationary maximum RPM tests were consistently lower than the other tests, but they produced results which eliminated the effects of load and drive train from the sound signature. This was particularly helpful during spectrum analyses.

4.2 SOUND-SOURCE DEFINITION

Sound Source Definition is one of the most important portions of a noise program as it defines the singular sound levels of each system on the truck.

From this information, coupled with a comprehensive spectrum analysis, individual component noise contributions can be identified and reduced. This leads to reduction in sound level of the overall truck.

4.2.1 Masking

Complete masking or elimination of sources is the key to a Sound Source Definition test program. As much of the sound on the truck as possible either has to be eliminated by removing components or by wrapping the components to block the transmission path of the sound. This was the procedure used in the Sound Source Definition test plan for the Peterbilt and Kenworth trucks.

The first step in the masking was to clean up and maintain the trucks so there would be as little trouble as possible during the testing. Any unneeded components were then removed, such as the Freon compressor on the Kenworth's Cummins engine. The fan and fan belts were removed from the engine to silence that system. The truck was then ready for wrapping.

The surfaces of the engine that were known to be hot were wrapped with a combination of asbestos cloth and lead sheet (1.0 lb/sq ft). These surfaces included the exhaust manifolds, the turbocharger, and the exhaust pipes. The entire engine was then wrapped in household glass fiber insulation, three and one-half inches thick and foil backed. This was followed by a layer of acoustical barrier known as Baryfol 20M, the equivalent of lead of 2.0 lb/sq ft. Both the insulation and the barrier material were sealed as much as possible with two-inch-wide duct tape. The transmission was wrapped in the same manner except that it was made separate from the engine. To support the materials on the bottom of the engine and the transmission, ropes were slung under the truck and tied to parts of the frame rails.

The exhaust system was routed from a convenient junction point to an industrial muffler by flexible pipe. The muffler was a Burgess BEO-5 rated at about 55 dB(A) through the frequency scale. The muffler was tied to the frame rails behind the cab. A tail pipe pointing the gas-borne sound upwards was then installed. The flexible piping was triple-wrapped in asbestos, insulation, and acoustical barrier. Lead sheeting was used in some areas as additional acoustical insulation.

The intake system used the standard air cleaner on the trucks as the primary silencing mechanism. This and all of the ducting from the intake tube to the engine were wrapped with insulation and barrier material. The rain cap over the mouth of the intake tube was removed so any sound emissions went upward rather than being reflected down. In one case a cardboard box with baffles was placed over the intake opening but was found to be unnecessary.

The wrapping was complete after all of the incidental noises were eliminated. The mud flaps were removed, the fifth wheels either blocked down or removed, and any loose pieces taped to eliminate other rattles. These sources were noticeable when the truck was driven over even moderately rough surfaces after the rest of the truck was quieted.

Figures 15 through 18 show the trucks with various stages of wrapping.

4.2.2 Component-System Sound Levels

The relative contribution of the tested systems on both trucks is shown in Figure 19 and Tables 8, 9, and 10. These tables show the descending order of

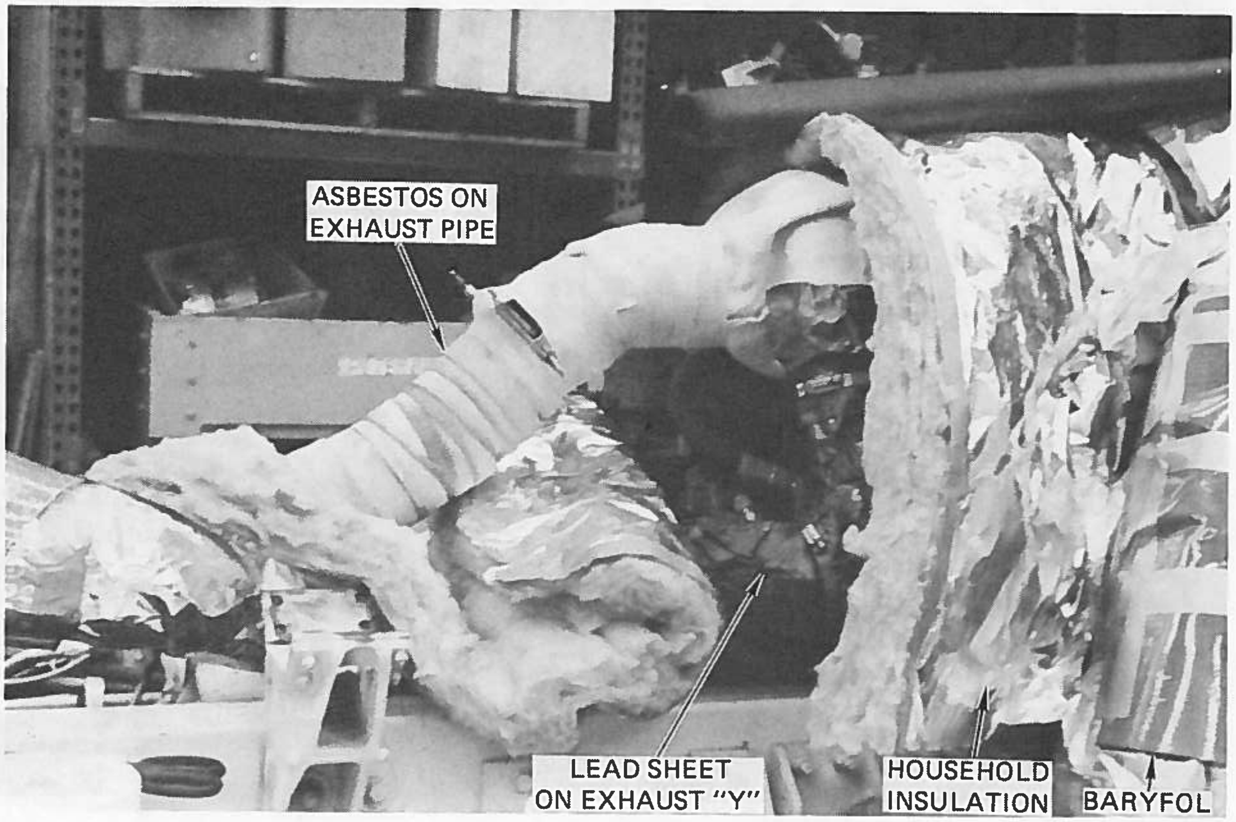


Figure 15. Initial Stages of Peterbilt Wrapping (showing turbocharger and flexible pipe connections)

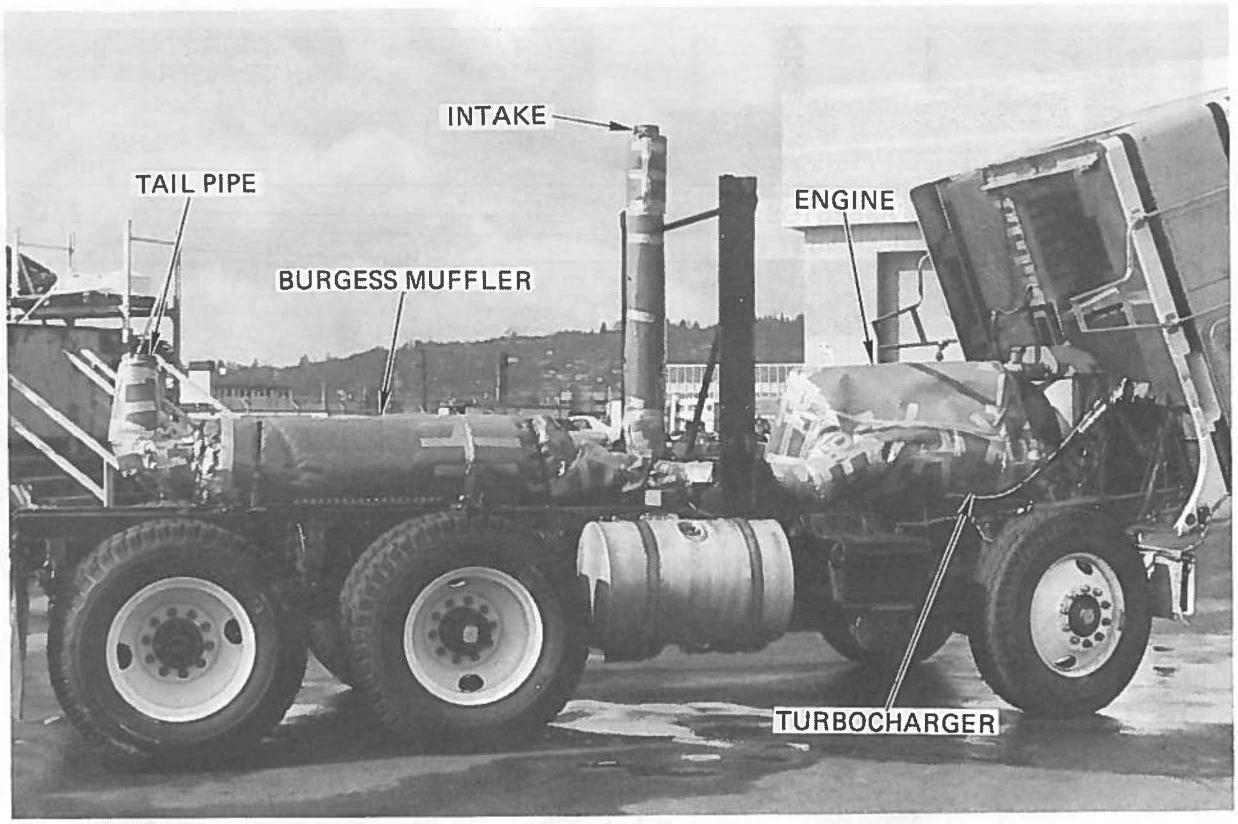


Figure 16. Fully Wrapped Kenworth

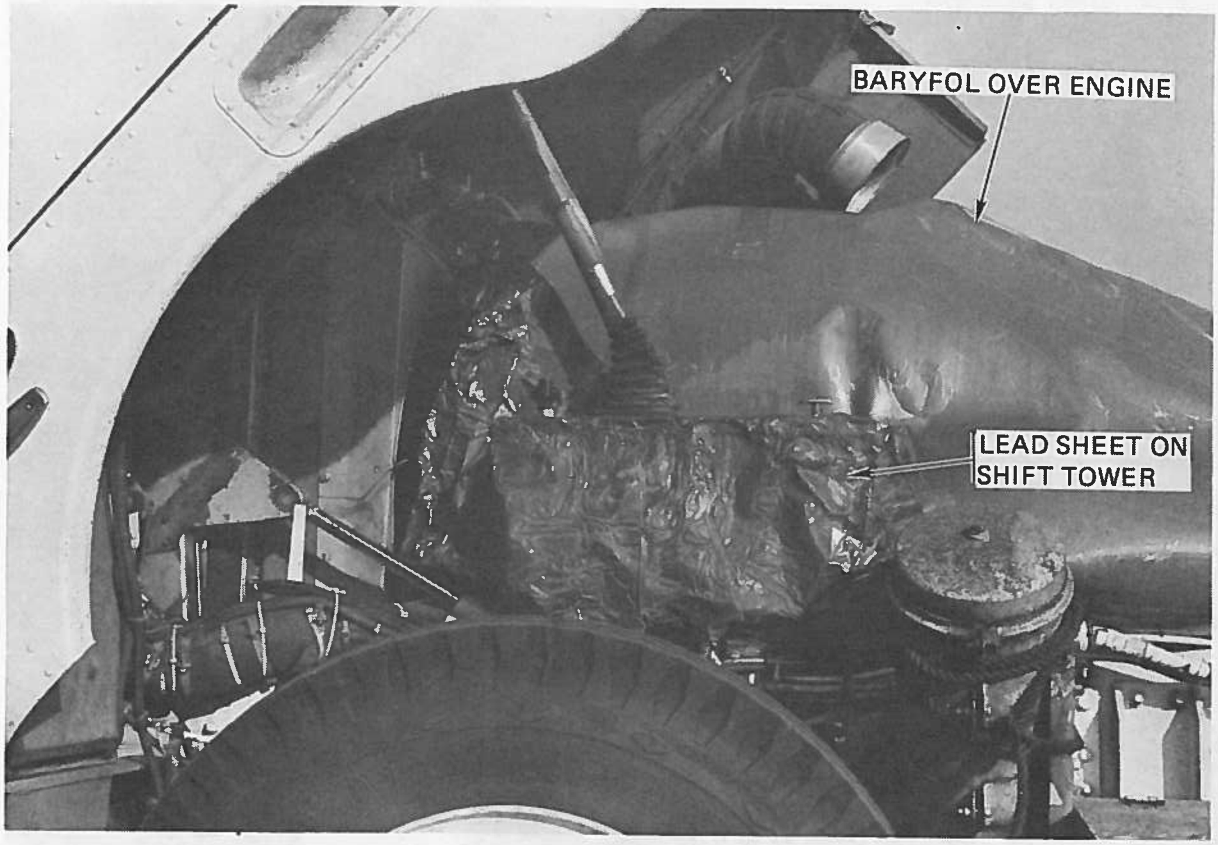


Figure 17. Driver's Side of Peterbilt (detailing engine wrapping)

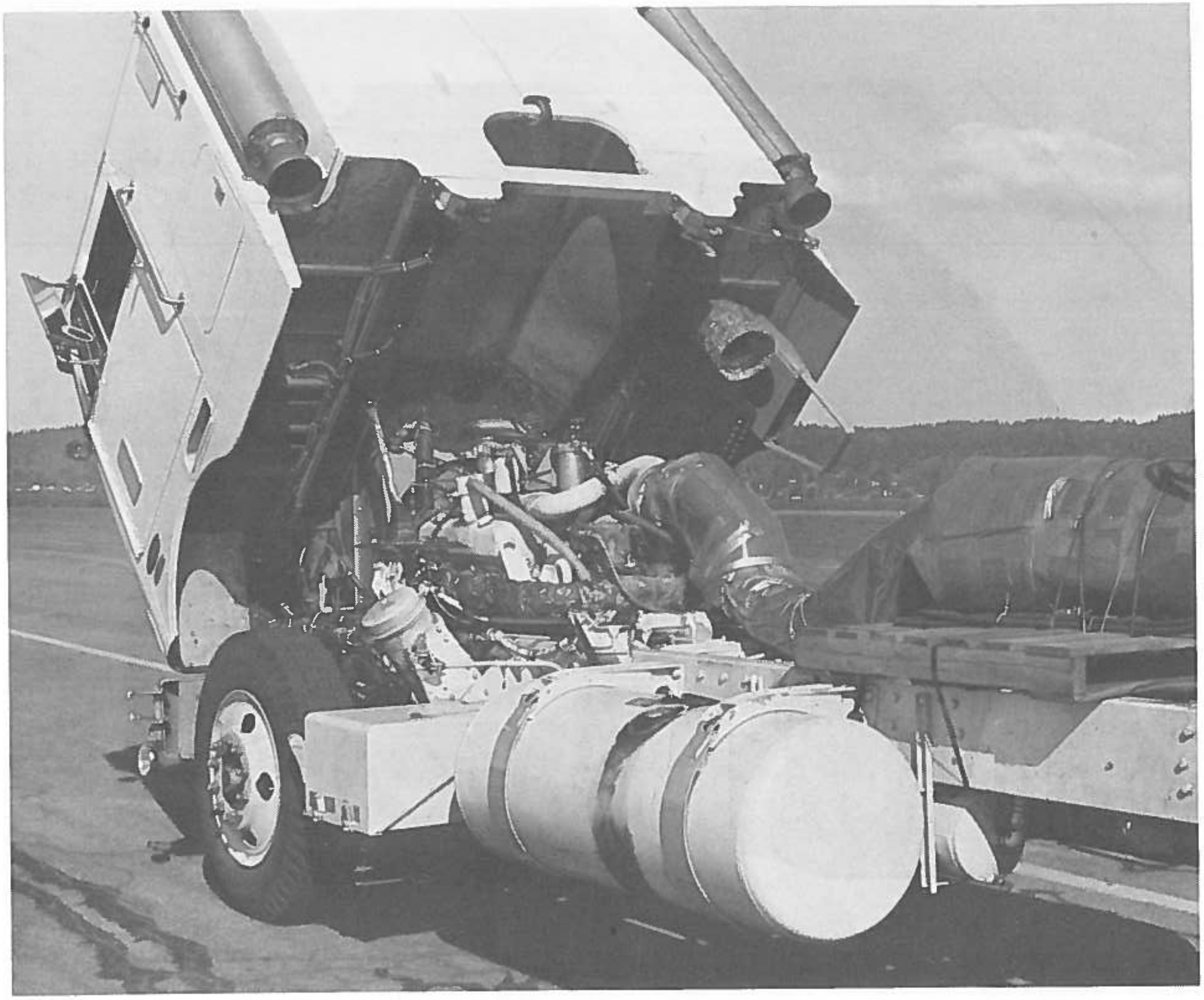


Figure 18. Peterbilt Unwrapped for Engine Sound-Source Definition

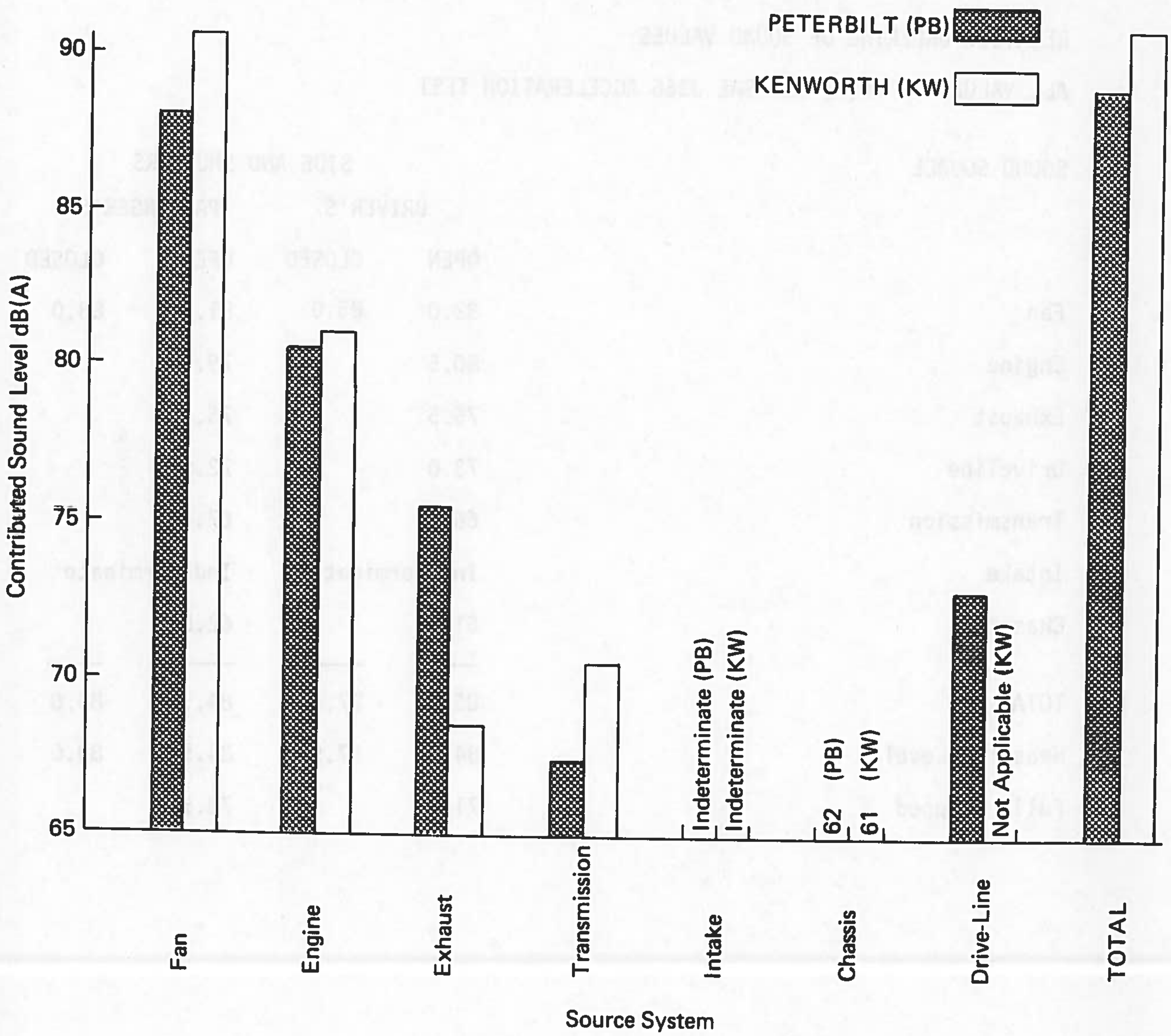


Figure 19. Maximum Sound-Source Values on Original Equipment Trucks - - SAE J366 Procedure

TABLE 8

SOUND-SOURCE LEVELS--PETERBILT 352A

CONFIGURATION: BASELINE (ORIGINAL EQUIPMENT)

RELATIVE ORDERING OF SOUND VALUES

ALL VALUES IN dB(A) FOR SAE J366 ACCELERATION TEST

SOUND SOURCE	SIDE AND SHUTTERS			
	DRIVER'S		PASSENGER'S	
	OPEN	CLOSED	OPEN	CLOSED
Fan	82.0	86.0	81.0	88.0
Engine	80.5		79.5	
Exhaust	75.5		75.5	
Driveline	73.0		72.5	
Transmission	66.5		67.0	
Intake	Indeterminate		Indeterminate	
Chassis	61.5		62.0	
TOTAL	85.0	87.5	84.5	89.0
Measured Level	84.5	87.5	84.5	89.0
Fully Wrapped	71.0		73.5	

TABLE 9

SOUND-SOURCE LEVELS--KENWORTH K-123

CONFIGURATION: BASELINE (ORIGINAL EQUIPMENT) AND MODIFIED VEHICLE

RELATIVE ORDERING OF SOUND VALUES

ALL VALUES IN dB(A) FOR SAE J366 ACCELERATION TEST

SOUND SOURCE	SIDE AND SHUTTERS			
	DRIVER'S		PASSENGER'S	
	OPEN	CLOSED	OPEN	CLOSED
Fan (OEM Brookside 28x6 @ 1.2:1)	85.0	90.5	84.0	90.0
Fan (Modified: Flex-A-Lite 3528 @ 1:1)	80.5	85.0	77.0	83.5
Engine	79.5		81.0	
Exhaust	Indeterminate		68.5	
Transmission	66.0		70.5	
Intake	Indeterminate		Indeterminate	
Driveline	Not Applicable			
Chassis (measured)	61.0	____	60.5	____
Total with OEM Fan	86.0	91.0	86.0	90.5
Measured	86.5	91.0	86.5	90.5
Total with Modified Fan	83.0	86.0	83.0	85.5
Measured	84.0	86.5	84.0	86.0
Fully Wrapped (reference)	76.0		74.5	

TABLE 10

SOUND-SOURCE LEVELS WITH RADIATOR SHUTTERS CLOSED

VEHICLE CONFIGURATION: BASELINE (ORIGINAL EQUIPMENT)

ALL VALUES IN dB(A) FOR SAE J366 ACCELERATION TEST

SOUND SOURCE	PETERBILT (352A)		KENWORTH (K-123)	
	DRIVER'S	PASSENGER'S	DRIVER'S	PASSENGER'S
Fan	86.0	88.0	90.5	90.0
Engine	80.5	79.5	79.5	81.0
Exhaust	75.5	75.5	Indt.	63.5
Driveline	73.0	72.5	-	-
Transmission	66.5	67.0	66.0	70.5
Intake	Indt.	Indt.	Indt.	Indt.
Chassis	61.5	62.0	61.0	60.5
TOTAL	87.5	89.0	91.0	90.5

importance of the systems as well as the contributed sound levels. The item labeled as "driveline" for the Peterbilt is not compatible with the Kenworth as the shortness of the Kenworth does not permit a driveline long enough to be a significant sound source. The Kenworth driveline is a very short connecting shaft with universal joints and spline fittings effectively damping any resonant sounds.

The term "indeterminate" indicates that the sound levels recorded for that system were at the same level or lower than the fully wrapped or baseline levels. In the logarithmic subtraction, subtracting baseline from system sound levels, the result was zero, or indeterminate with regard to a logarithmic figure. In other cases, the difference between the two sound levels was small. This cast substantial doubt on the actual contributed sound level. As shown in Figure 20, the smaller the difference the greater the range of uncertainty in the result. All of the recorded data have tolerances of ± 0.5 dB(A) which means that the tabulated values will have ranges of uncertainty as indicated. The values tabulated are the values calculated. In those instances of small differences, as with the Kenworth exhaust system, the component-contributed sound level could range from a high 5 dB(A) below the baseline to as little as no contribution at all.

The contributed levels for both trucks were combined and compared to actual measurements of the unwrapped conditions. The results for the modified and unmodified conditions are given in Table 11.

4.2.3 Procedure

The testing procedure during Sound Source Definition was to proceed from a fully wrapped truck to an unwrapped truck measuring the sound level of each

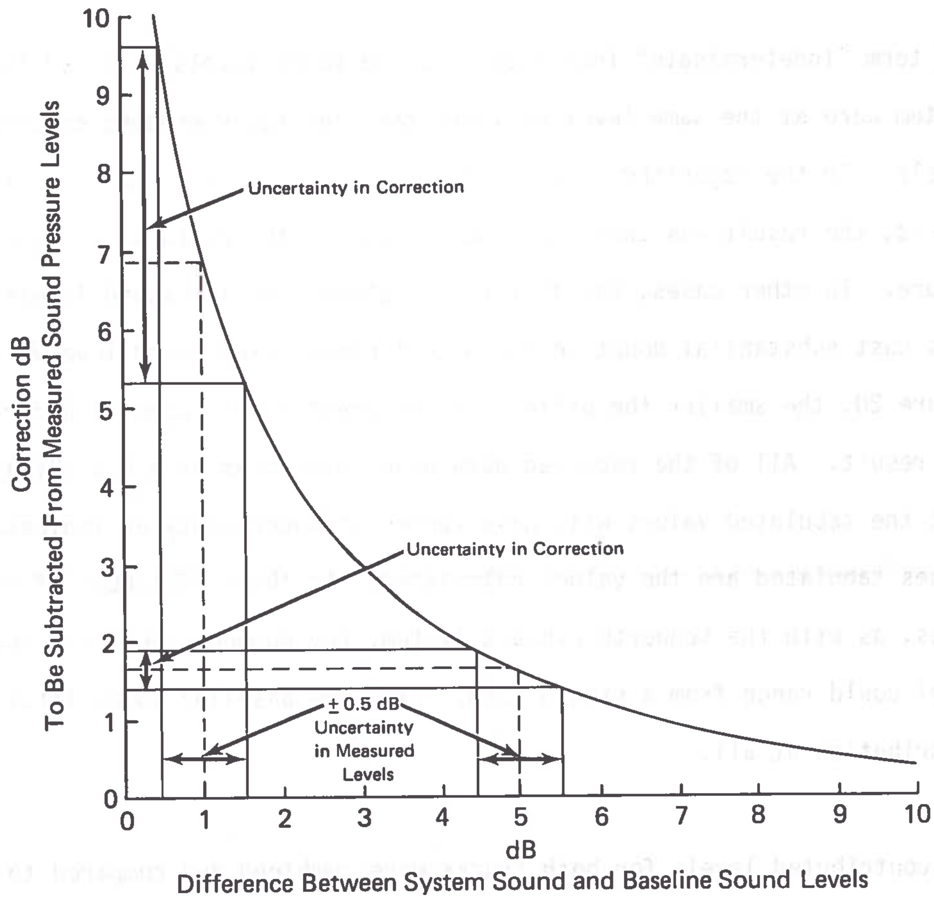


Figure 20. Contributed Noise Correction Plot - showing increase in the uncertainty of correction as the difference between system and baseline sound diminishes

TABLE 11

COMPARISON OF MODIFIED AND UNMODIFIED VEHICLE NOISE

LEVELS AS MEASURED AND CALCULATED FROM

INDIVIDUAL SOURCE MEASUREMENTS

TEST: SAE J366b

		SIDE AND SHUTTERS			
		DRIVER'S		PASSENGER'S	
		OPEN	CLOSED	OPEN	CLOSED
Peterbilt		dB(A)	dB(A)	dB(A)	dB(A)
Original Equipment					
	Measured	84.5	87.5	84.5	89.0
	Calculated	85.0	87.5	84.5	89.0
	Difference	+0.5	0.0	0.0	0.0
Modified Vehicle Equipment					
	Measured	82.5	84.5	82.5	83.5
	Calculated	83.5	85.0	82.0	83.5
	Difference	+1.0	+0.5	-0.5	0.0
Kenworth					
Original Equipment					
	Measured	86.5	91.0	86.5	90.5
	Calculated	86.0	91.0	86.0	90.5
	Difference	-0.5	0.0	-0.5	0.0
Modified Vehicle Equipment					
	Measured	84.0	86.5	84.0	86.0
	Calculated	83.0	86.0	83.0	85.5
	Difference	-1.0	-0.5	-1.0	-0.5

system individually in the process. The systems were rewrapped as necessary to measure the next system.

The Sound Source work was done on the Peterbilt first. Experience gained was then applied to modify the procedure for the Kenworth series of tests. The first test on each truck was of the fully wrapped configuration to establish a baseline for the remaining tests. As this is a foundation for most calculations, great importance was attached to this test to insure it was correct and the sound level was as low as possible. Several attempts were made before a final configuration of the fully wrapped trucks was achieved. The trucks in the fully wrapped configuration were tested using J366 acceleration, stationary maximum RPM, and deceleration. The radiator shutters were open during acceleration and deceleration to allow some cooling by ram air, but during the stationary runs the shutters were both open and closed. Both sides of the trucks were tested.

The easiest system to test after the fully wrapped condition was the intake system. The unwrapped condition for both trucks was obtained by simply removing the insulation and barrier material prior to performing the tests. The J366 acceleration and stationary maximum RPM tests were the only tests performed for the intake system, as they were the only pertinent conditions. The shutters were open for the acceleration runs.

Following the intake system tests, the trucks were rewrapped and tested to confirm the return to baseline levels. Assuming no change, the standard exhaust system was installed. To do this meant attaching the exhaust piping as close to the turbocharger as possible and attaching the mufflers in their normal manner.

The tests included J366 acceleration, deceleration, and stationary maximum RPM where only the stationary runs used shutters closed as one condition. Several mufflers were tried during the exhaust system test of the Peterbilt to firmly establish their contribution to sound level reduction. These mufflers were pre-selected based on manufacturer's information and some testing done previously with the unwrapped truck. The Kenworth was tested using only the original equipment mufflers adding superstacks as a supplemental test condition.

At this point in the Sound Source testing, the procedure and sequence varied greatly for the two trucks. After testing the exhaust system, the Peterbilt was returned to a fully wrapped state and the baseline levels were measured again. The front of the engine was then unwrapped to establish an airflow path for the fan. The remainder of the engine wrapping was left in place to minimize the noise emission from that source. The truck was tested in this configuration, using J366 acceleration and stationary maximum RPM conditions, with the shutters open and closed. This was the initial attempt to establish the fan baseline.

During the Peterbilt sequence, the fan was installed with the hardware required for its proper operation. The J366 acceleration and stationary maximum RPM tests were run again using open and closed shutters throughout. Several fans were tested during this portion of testing as it had been predetermined that the fans were the most significant sound level contributors. In addition to the fans, two different fan ratios were tested according to results of previous testing for sound and cooling. Only the most promising fans, in addition to the original equipment, were tried.

The next system tested was the transmission. In the case of the Peterbilt, this was tested using the fan baseline rather than the fully wrapped baseline, as it was determined that the fan baseline was not much different from the fully wrapped. The test conditions included J366 acceleration, deceleration, and stationary maximum RPM. The shutters were closed for two of the four runs in stationary maximum RPM.

The engine was the next system tested. The transmission was left unwrapped as its contributed level was shown to be at least 10 dB(A) below the expected level of the engine. The wrapping on the engine was removed in stages. First only the insulation and barrier material was removed leaving the lead and asbestos on the manifolds of the Peterbilt. Then the entire engine was uncovered. There was little difference between the two configurations, in terms of sound level. The tests used were J366 acceleration, deceleration, and stationary maximum RPM. The shutters were open except for two runs in the stationary maximum RPM mode.

While the exhaust and intake systems were still wrapped for the Peterbilt, combinations of systems were tried with the engine and fan first. This used the J366 acceleration and stationary maximum RPM tests with shutters open and closed. Several different combinations were tried, then the fan was removed and the exhaust system restored and tested in J366 acceleration, deceleration, and stationary maximum RPM, primarily with open shutters. Finally, all of the systems were restored to original equipment status and tested for J366 acceleration, deceleration, and stationary maximum RPM. These tests established that the truck had returned to the original baseline sound levels.

The contributed levels for the various Peterbilt systems were calculated, combined, and compared to the measured levels for the unwrapped truck. The large differences between measured and calculated levels led to further investigation of the fan-contributed levels. They were found to be low. This was probably due to airflow restrictions and different sound reflective quantities associated with the partially wrapped engine configuration used during the fan level tests.

New fan-contributed levels were obtained using a modification of the previously mentioned procedure. The truck was in the unwrapped stock condition. The Fan Baseline was established by testing without the fan turning. Contributed levels by this procedure, when combined with the other system levels, correlated with actual levels for the unwrapped truck. This series of tests concluded the Sound Source work on the Peterbilt.

The Kenworth exhaust system was not unwrapped following the contributed level testing for that system. The levels of the original equipment mufflers and superstacks were low and were used as the baseline for the next system: the transmission. The same series of tests and procredure as those used for the Peterbilt were used to test for transmission noise. Very little change in levels was recorded, relative to the fully wrapped configuration, and the transmission was left unwrapped.

The fan and fan drive hardware were installed, and the front of the Kenworth engine was unwrapped. Tests were performed, with and without the fan turning, to determine the contributed level. This level was compared to the level obtained from previously recorded data for fan-on, fan-off conditions with the engine completely unwrapped. The partially wrapped engine configuration did not yield correct fan-contributed levels, as was also the case for the Peterbilt. The engine was then completely unwrapped and the engine-related data were obtained for the same run conditions that were chosen for the Peterbilt.

The exhaust superstacks were removed, returning the truck to the OEM configuration. The Fan Baseline levels were measured with the fan belts removed. Several fan and drive ratios, including OEM, were installed and tested according to the Peterbilt procedure. Comparison of the combined contributed levels to the unwrapped truck levels verified the contributed levels. Sound source testing was completed.

4.2.4 Analyses

Spectral analyses of the pertinent runs recorded during the Sound Source Definition testing on both trucks were performed to ascertain the frequency components contributing to the overall sound levels. Additionally, the spectra obtained from the isolated subsystems gave valuable information about the nature of these systems. The Fourier Analyzer operates digitally and was programmed to produce spectral analyses ranging from 20 Hz to 10,000 Hz with 20 Hz resolution (see Appendix). The plots are of the 50-millisecond time span having the maximum overall sound pressure level based on an exponential average from the start of the run.

The progress of the software programming matched that of the analyses themselves. In most of the Peterbilt spectral analyses, the ceiling is +100 dB. The earlier spectral analyses, however, have variable ceiling lines computed by the computer ranging from +70 to +90dB. The plotted information is exactly the same regardless of the plot format.

All sound level plots are contained in the appendixes. The runs included as Sound Source Definition are labeled, as are those for Unmodified Baseline and Modified Vehicle testing.

Each of the spectral plots, generally, shows a predominant peak at a particular frequency, especially for the original systems. This would be a point of interest in the system where measures would be taken to reduce the sound level. A spectral analysis exhibiting a flat curve through the frequency range would either be a difficult case to engineer or a desirable result of quieting measures.

The Baseline Sound Source runs represent both a minimum level for the Sound Source Definition as well as (for the truck as produced) a current best effort of quieting the vehicle albeit not in road-ready condition. Appendix Figures B-1 and B-2 show two such runs for the Peterbilt. The passenger's side run (B-1) shows a noise peak at about 1,400 Hertz that is 13 dB higher than the levels near it. This peak is not fully explained, but one hypothesis is that it is coming from the Burgess industrial muffler used in this test condition.

The intake system runs, Figures B-3 and B-4, are essentially the same as the Fully Wrapped runs, still showing the peak at 1,400 Hertz. The standard exhaust system using the Donaldson MPM09-0161 mufflers shows a different spectral plot, as seen in Figures B-5 and B-6. In these two plots, the peak sound occurred at 450 Hertz with the passenger's side having a secondary peak at 150 Hertz, or near the primary frequency for the eight cylinder, two stroke engine. It is possible that the 450-Hertz spike is the third harmonic of the primary frequency interacting with another sound at the same frequency caused by some other source.

The two plots labeled "driveline" for the Peterbilt are runs taken fully wrapped with the exception of the two propeller shafts, one from the transmission to a center bearing, the second from the bearing to the first differential. The strong characteristic of Figures B-7 and B-8 is the addition of spike at 1,600 Hertz along with the 1,400 Hertz spike seen in the Fully Wrapped runs. It is suspected that the driveline(s) experiences an excitation under torsional loading at a frequency near or at the instantaneous resonant frequency, and emits sound of that tone.

The figures showing the engine, B-9 and B-10, and the four figures for the fan baseline, Figures B-11 through B-14, all show the same characteristic of being broadband, typical of an unwrapped engine. The engine would be expected to be a multiple of sound sources in addition to the primary firing frequency because of its complexity. The differences between an Engine run and a Fan Baseline are slight in terms of sound; the Fan Baseline is the Engine configuration with the standard exhaust and intake systems restored, but with the fan turned off for data acquisiton.

The four plots for the OEM fan (Brookside 28x8) are in Figures B-15 through B-18. The characteristic of these data is the strong peak at 300 Hertz, which is the prime frequency of an eight-bladed fan rotating at the same speed as the engine. In most cases, the peak becomes more dominant when the shutters are closed due to fan stall from a lack of incoming air. The passenger side, shutters open run shown in Figure B-15 illustrates this well in that the 300 Hertz peak is attenuated and has far less effect on the overall level. Figures B-19 and B-20 are 100% Constant Speed drive-by runs recorded for the Unmodified Baseline series mentioned for comparison. Even with reduced power train loading, the single characteristic of the spectral plots is still the 300 Hertz peak caused by the fan.

The four spectral plots for the Modified Vehicle configuration and the Sound Source Definition data are synonymous. Using a Flex-A-Lite 3228-4 operating at 0.8:1 with the engine, the plots are all at lower overall levels and show more broadband information. The strong peak at the fundamental blade frequency, in this case 180 Hertz with the six-bladed fan, is not the overriding peak. Instead, other sound sources become more contributory, especially those causing the spikes at 1,400 and 1,600 Hertz. These plots are Figures B-21 through B-24. Figures B-25 and B-26 are 100% Constant Speed drive-by runs for the Modified Vehicle testing, which again illustrate the reduced contribution by the fan and fan speed modification.

The Kenworth fully wrapped Baseline runs, Figures C-1 and C-2, exhibit a peak near 500 Hertz for both sides of the truck. Efforts to eliminate the peak were not effective, but the importance was decreased as the unwrapping progressed.

The figures showing the intake system unwrapped, C-3 and C-4, show a new peak at 7 KHz; the rest of the two spectra are unchanged from the Fully Wrapped plots.

Very little energy is contained in the 7 KHz peaks, which are 15 dB down from the peaks at 500 Hz, even though the sound of the turbocharger whine is noticeable to the ear.

The standard exhaust system gives two possibilities for spectra with the maximum overall levels. Figures C-5 and C-6 show more energy at frequencies below 500 Hz with peaks at the fundamental and second harmonic of the engine firing frequency. The peak at 500 Hz is attenuated and shifted to a lower frequency, indicating that these maximum levels occurred at a lower RPM than for the fully wrapped runs. The other maximum spectrum duplicated the Baseline runs as shown by Figure C-7. The addition of superstacks decreased the levels at 1 KHz and above, as demonstrated by Figures C-8 through C-10, and are the basis for comparison to the Engine and Transmission runs.

The levels at frequencies above 500 Hz in the Engine and Transmission plots, Figures C-12 and C-13, show increases of about 10 dB. The spectra are broadband in nature and the overall levels are 5 to 8 dB(A) higher.

Figures C-13 through C-16 show the Fan Baseline configuration, which is a complete OEM truck without the fan, to have nearly the same spectra as the Engine and Transmission.

The OEM fan (Brookside 28x6) plots are Figures C-17 through C-20. They are characterized by a peak near 260 Hz and smoothing between peaks at higher frequencies. The 260 Hz peak is the blade passing frequency for the six-bladed fan turning at 1.2 times the engine RPM. The peak is dominant for both sides in the shutters closed conditions due to fan stall. With the shutters open the peak is reduced, especially on the passenger side. The importance of the peak is reflected by the increase in overall levels with the shutters closed.

The Modified Vehicle and Sound Source configurations are identical. The plots showing the benefit gained by the modification, using the Flex-A-Lite 3528 fan operating at the engine speed, are Figures C-21 through C-24. The shutters closed levels are still higher than for the open condition. The peaks at the blade passing frequency, 280 Hz for eight blades at 1:1 speed ratio, are reduced in level from those of the OEM fan.

4.3 SELECTIVE COMPONENT TESTING

In between the Baseline Testing and the Modified Vehicle testing, effort was given to determine the nature of the sound level reduction situation and the exact selection of components to perform the task. This effort attacked many of the systems in the truck to secure a meaningful reduction in overall sound level. The theory was to solve the exterior sound level that would automatically reduce the interior sound level by producing less sound at the source. Because of the timing of the test sequence and other factors, the selective testing was performed using the sound level of the entire truck rather than isolating systems by themselves. The work was performed at several locations; therefore, the results are shown as relative to other truck configurations at a particular location. In these calculations, a negative figure indicates a reduction in sound level, and a positive figure indicates and increase.

4.3.1 Cooling System

One of the first assumptions was that the cooling system was a high contributor to the truck sound level. Therefore, most of the work done was on the cooling system, as discussed in the Selection Procedure and Trade-Off Section. The decision was made that any modifications to the cooling system would first be subjected to a cooling test; if the cooling test met established criteria, then a sound level test would be performed and a selection decision made on the basis of the two sets of information.

A great number of cooling tests were performed on the two test trucks. Tabulations of the cooling tests are contained in Tables 12 and 13. The modifications, primarily fan changes, were then tested for noise based on this pre-selection. Most of the sound level testing was done at the Backlot location using a stationary maximum RPM format, reasoning that a sound level reduction at this location would equate to sound level reduction during a J366 acceleration or other testing format. The results of the Backlot testing for fans is the basis of Table 14.

The modification made to the truck to form the Modified Vehicle make-up was selected using the results of the cooling tests, Backlot results, and other intrinsic factors relating to the installation of the fans or cooling system components.

4.3.2 Mufflers

A muffler modification is a relatively simple change if the restrictions on exhaust back pressure are not exceeded. Several mufflers were tried on the

TABLE 12

COOLING TEST RESULTS--PETERBILT (352A)

MFG.	SIZE	P.W.	DRIVE RATIO*	AIR-TO-WATER	NOTES
Brookside (480293)	28x8	3.23	1:1	90	1,8,9
" "	"	"	1:1	89	1,2,8,9
" "	"	"	0.8:1	99	1,2,8,9
Flex-A-Lite (3228F3)	28x6	3.75	1:1	90	2,8,9
" "	"	"	0.8:1	94	2,8,9
Brookside (460380)	28x6	3.00	1:1	94	2,3,8,9
Switzer (908421)	28x6	3.56	1:1	90	2,8,9
Flex-A-Lite (1728-2A)	28x6	3.50-3.00	1:1	100	2,4,8,9
Flex-A-Lite (XT29D)	28x6	3.00	1:1	94	2,4,8,9
Dual Flow (DF28C)	28x6	2.50	1:1	98	2,5,8,9
"	"	"	1:1	114	2,5,6,8,9
Flex-A-Lite (3428)	28x8	4.00	0.8:1	96	2,8,9
Brookside (480293)	28x8	3.23	1:1	101	1,2,6,8,9
Brookside (X-3472)	29x8	3.50	1:1	94	2,6,8,9
Brookside (X-3472)	29x8	3.50	0.8:1	88	2,7,8,9
Flex-A-Lite (3228-4)	28x6	4.00	0.8:1	88	2,8,9

*RATIO OF FAN SPEED TO ENGINE SPEED

NOTES:

1. Original fan configuration from factory
2. Recirculation shields installed
3. K-123 original fan
4. Molded aerodynamic shape
5. Fiberglass material
6. Without shroud
7. With modified shroud--minimum tip clearance
8. Size, diameter (in.) X number of blades
9. Projected width of fan (P.W.)

TABLE 13

COOLING TEST RESULTS--KENWORTH (K-123)

MFG.	SIZE	P.W.	DRIVE RATIO*	AIR-TO-BOIL	NOTES
Brookside (460380)	28x6	3.00	1.2:1	132	1,7,8
Brookside (460380)	28x6	3.00	1:1	109	7,8
Brookside (480286)	28x8	3.25	1:1	121	7,8,9
Brookside (480286)	28x8	3.25	1:1	122	2,7,8,9
Brookside (480302)	28x8	3.12	1:1	124	7,8,9
Flex-A-Lite (fiberglass)	28x6	2.50	1:1	101	3,7,8
Flex-A-Lite (molded)	28x8	3.50-3.00	1:1	108	4,7,8
Flex-A-Lite (3528)	28x8	3.25	1:1	123	7,8
"	"	"	1:1	117	5,7,8
"	"	"	1:1	125	6,7,8

*RATIO OF FAN SPEED TO ENGINE SPEED

NOTES:

1. Original fan configuration from factory
2. Standard shroud sealed
3. Fiberglass material, flexible
4. Molded aerodynamic shape
5. Modified shroud
6. Modified shroud, second generation
7. Projected width of fan (PW)
8. Size, diameter (in.) x number of blades
9. Projected width of test fan. Nominal P.W. = 3.23

TABLE 14

FAN EVALUATION FOR NOISE REDUCTION

dB(A) (TEST) - dB(A)(BASE) = dB(A)(TABULATED)

	SIDE AND SHUTTERS			
	DRIVER'S		PASSENGER'S	
	OPEN	CLOSED	OPEN	CLOSED
KENWORTH (K-123)				
At Backlot site: Mic @ 25 feet Stationary Maximum RPM				
Brookside 28x8 (480302) @ 1:1	0	0	-	-
Flex-A-Lite 28x8 (3528) @ 1:1	-1	-0.5	-	-
Fan Off	-4.5	-4.5	-	-
At Test Track: Mic @ 50 feet J366 Acceleration				
Brookside 28x6* @ 1.2:1	0	0	0	0
Brookside 28x8 (480302) @ .975:1	-3.5	-1	-2.5	-1.5
PETERBILT (352A)				
At Backlot site: Mic @ 25 feet				
Brookside 28x8* 1:1	0	0	-	-
Flex-A-Lite 28x6 (3228-F3) @ 1:1	-1	-1	-	-
Switzer 28x6 (908421) @ 1:1	-1	0	-	-
Brookside 29x8 (X-3472) @ 0.8:1	-2	-3.5	-	-
Fan Off	-4	-8	-	-

* UNIT SUPPLIED BY VEHICLE MANUFACTURER

two test trucks and measured for sound levels and back pressures. The information on back pressure supplied by the vendors was considered as adequate for the purposes of initial evaluation with the intent to measure the back pressure on the final configuration if some major alterations were made. In addition to the mufflers tested, some peripheral components such as superstacks and resonators were tried to determine if these had any significant contribution to sound level reduction.

The results of the muffler changes are tabulated in Tables 15 and 16. All of the testing on the Peterbilt was done in the Backlot location using the computer for spectral analyses. Some of the Kenworth testing was also done at this location with computer analysis, but some was also done at the Test Track location using both J366 acceleration and stationary maximum RPM at 50 feet.

4.3.3 Acoustical Material

The addition of acoustical material to the truck was considered initially to be a simple and inexpensive method of reducing noise. This method was therefore tried, but not to the scale that was originally intended for two reasons: the application of the material represented a greater task than initially thought, and the results did not show the level of reduction expected.

Two different manufacturers of materials representing two styles of sound absorbing concepts were applied to the engine tunnel facing the engine (called the doghouse). One of the blankets was 1/2 inch open face flexible foam with an adhesive backing obtained from H. L. Blachford; this was put onto the Peterbilt. The other was 1 inch flexible foam with an adhesive backing on one face and an

TABLE 15

MUFFLER EVALUATION FOR NOISE REDUCTION--PETERBILT (352A)

dB(A)(TEST - dB(A)(BASE) = dB(A)(TABULATED)

	SIDE AND SHUTTERS			
	DRIVER'S		PASSENGER'S	
	OPEN	CLOSED	OPEN	CLOSED
At Backlot site: Mic @ 25 feet				
Stationary Max. RPM: Baseline Truck				
Basic Stacks - 36" diagonal cut 5" pipes				
Donaldson MPM09-0161*	0	0	-	-
Nelson T-13981	+1	+1	-	-
Stemco 9354	+1	+0.5	-	-
Nelson T-14150	+2.5	+2.5	-	-
With Donaldson AEM00-1230 Superstacks				
Donaldson MPM09-0161	+0.5	+1.5	-	-
Nelson T-13981	-0.5	+1	-	-
Stemco 9354	0	+0.5	-	-
Nelson T-14150	+1.5	+1.5	-	-
Various Stack Combinations				
Donaldson MPM09-0161 w/48" square cut	+2	+1.5	-	-
Donaldson MPM09-0161 w/36" square cut	0	+1	-	-
Donaldson MPM09-0161 w/o stacks	+0.5	0	-	-

* SUPPLIED AS PART OF BASELINE VEHICLE

TABLE 16

MUFFLER EVALUATION FOR NOISE REDUCTION--KENWORTH (K-123)

db(A)(TEST) - dB(A)(BASE) = db(A)(TABULATED)

	SIDE AND SHUTTERS			
	DRIVER'S		PASSENGER'S	
	OPEN	CLOSED	OPEN	CLOSED
At Test Track: Mic @ 50 feet				
J366 Acceleration: Modified Vehicle *				
Donaldson MPM09-0161 **	0	0	0	0
Donaldson MPM09-0161 w/Donaldson AEM00-1230 Superstacks	0	-0.5	0	-0.5
Donaldson MPM09-0161 w/Donaldson MUM06-0072 Resonators	-1	-0.5	0	0
Donaldson MPM09-0161 w/Donaldson MUM06-0072 Resonators & AEM00-1230 Superstacks	-0.5	-0.5	0	0
Nelson T-13981	+1	-0.5	0	0
At Test Track: Mic @ 50 feet				
Stationary Max. RPM: Modified Vehicle *				
Donaldson MPM09-0161 **	0	0	0	0
Donaldson MPM09-0161 w/Donaldson AEM00-1230 Superstacks	0	-0.5	-0.5	-1
Donaldson MPM09-0161 w/Donaldson MUM06-0072 Resonators	+2	0	0	0
Donaldson MPM09-0161 w/Donaldson MUM06-0072 Resonators & AEM00-1230 Superstacks	-1	0	0	0
Nelson T-13981	+1	0	+1	-0.5
At Backlot site: Mic @ 50 feet				
Stationary Max. RPM: Modified Vehicle *				
Donaldson MPM09-0161 **	0	0	0	0
Donaldson MPM09-0161 w/Donaldson AEM00-1230 Superstacks	+0.5	-2	0	+0.5
Nelson T-13981	+1	+0.5	+1	0
Nelson T-13981 w/Donaldson AEM00-1230 Superstacks	0	0	0	0
At Backlot Site: Mic @ 25 feet				
Stationary Max. RPM: Modified Vehicle * and ***				
Donaldson MPM09-0161 w/Donaldson AEM00-1230 Superstacks	0	0	-	-
Stemco 9354	+2.5	+2.5	-	-
Stemco 9354 w/Donaldson AEM00-1230 Superstacks	+1.5	+2.0	-	-

TABLE 16 Cont.

MUFFLER EVALUATION FOR NOISE REDUCTION--KENWORTH (K-123)

db(A)(TEST) - db(A)(BASE) = db(AL(TABULATED)

	SIDE AND SHUTTERS			
	DRIVER'S		PASSENGER'S	
	OPEN	CLOSED	OPEN	CLOSED
At Backlot Site: Mic @ 25 feet				
Stationary Max. RPM, Fan Off: Modified Vehicle * and ***				
Donaldson MPM09-0161 w/Donaldson AEMOO-1230 Superstacks	0	0	0	0
Stemco 9354 w/Donaldson AEMOO-1230 Superstacks	+0.5	+0.5	-	-
Nelson T-13981	+1.5	+2	-	-
Nelson T-13981 w/Donaldson AEMOO-1230 Superstacks	+0.5	+1	-	-

* BROOKSIDE 28x8 FAN WITH .975:1 RATIO
** SUPPLIED AS PART OF BASELINE VEHICLE
***SOUND LINER (1" S.C. TUFCOTE)

enclosing skin on the other face produced by Specialty Composites. This was put onto the Kenworth in two stages, first to the tunnel area only, and then to the entire cab floor area.

The results of the sound level testing using absorbing materials is shown in Table 17. All of this testing was performed in the Backlot location with the microphone at 25 feet.

4.3.4 Sound Curtains

A second idea for using sound material was to create sound barriers around the engine compartment to block the radiation of sound from the engine, fan, and other components in that area. To do this, curtains were made using a barrier material called Baryfol 10M, manufactured by H.L. Blachford. (This is a lighter form of the material used in wrapping the trucks for Sound Source Definition.) It has an acoustical density equivalent to 1.0 lb/sq ft of lead. These curtains were attached to the corners of the cab meeting the engine tunnel area and allowed to overlap the frame rails to block the direct radiation of sound. The areas around the ducts and pipes were sealed as best they could be and the opening at the rear of the cab covered by taping a piece to the cab itself.

The curtains for the Kenworth were built up in stages. First curtains on the sides only were tried, then curtains around the full area of the engine compartment, and finally a complete enclosure featuring sealing around the exhaust pipe and intake duct. Two of the configurations tested are shown in Figures 21 and 22.

TABLE 17

ACOUSTICAL MATERIAL EVALUATION FOR NOISE REDUCTION

dB(A)(TEST) - dB(A)(BASE) = dB(A)(TABULATED)

	SIDE AND SHUTTERS			
	DRIVER'S		PASSENGER'S	
	OPEN	CLOSED	OPEN	CLOSED
KENWORTH				
At Backlot site: Mic @ 25 feet Staionary Max. RPM				
Without Acoustical Material	0	0	-	-
With 1" Tufcote, tunnel area only	+1	+0.5	-	-
With 1" Tufcote, full coverage	-1	-0.5	-	-
PETERBILT				
At Backlot site: Mic @ 25 feet Stationary Max. RPM				
Without Acoustical Material	0	0	-	-
With ½" Blachford open-faced foam	-0.5	-1.5	-	-

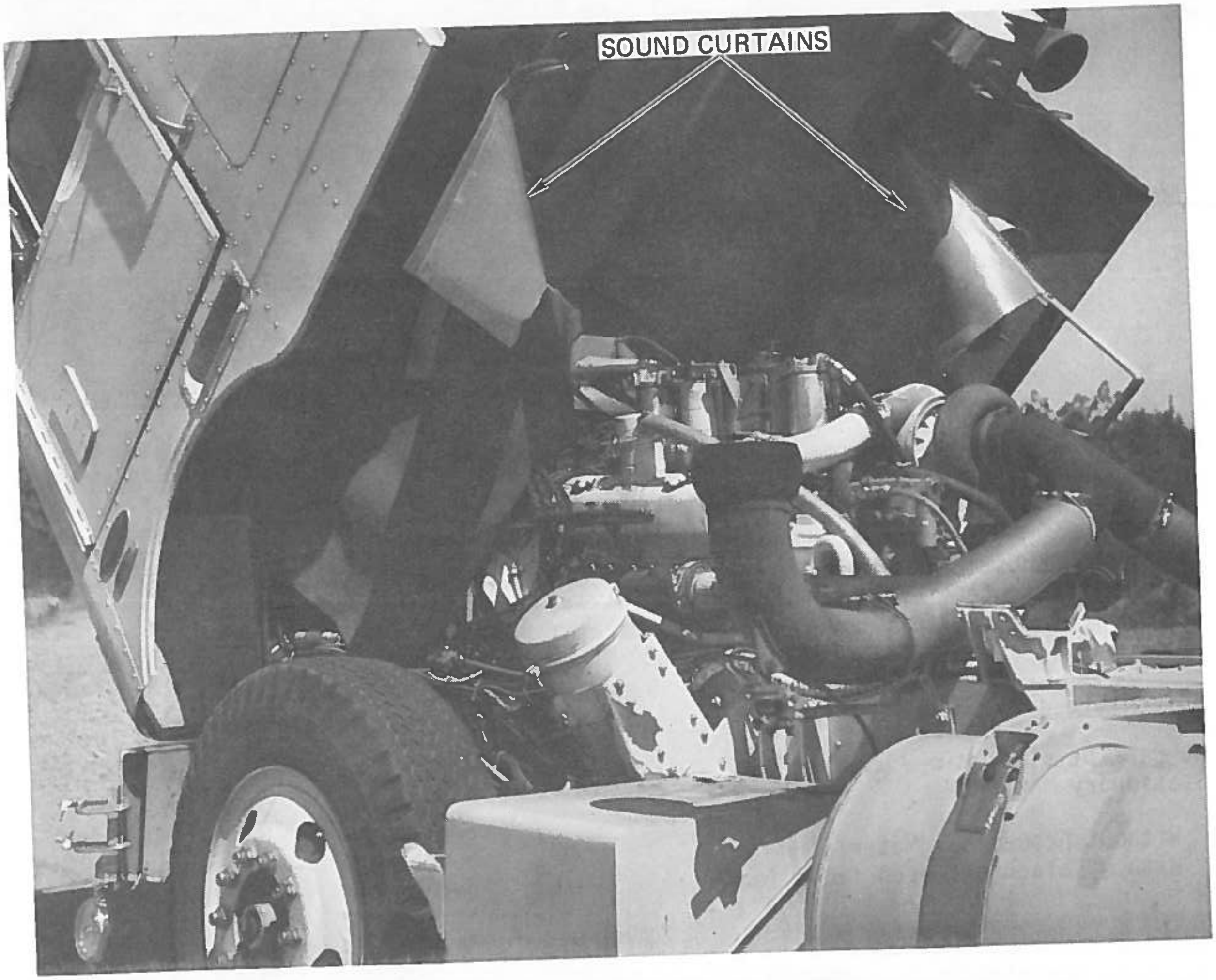


Figure 21. Sound Curtains on the Peterbilt

Figure 22. Rear-opening Curtain on the Kenworth

The results of the sound curtain testing are grouped into Table 18. All of this testing was performed at the Test Track; therefore, only the J366 acceleration information is tabulated.

4.3.5 Interior Shutters

The substitution of interior shutters for the normal exterior mounted shutters was promised by one vendor to increase the cooling capacity of the truck at the same time as reducing the noise level. At least it was thought that if the cooling capacity of the system were increased, a slower fan could be more easily adapted, and this would produce less noise. Two sets of interior shutters were obtained from two different manufacturers and installed on the Kenworth for evaluation in cooling and noise. The noise results are reported in Table 19 for both exterior and interior microphone locations. The interior shutters are compared to the Unmodified Baseline.

4.3.5.1 Kysor Shutters: The interior Kysor shutters are vertical vanes mounted between the radiator core and the fan using special shrouds and mounting brackets. The shutter operation is air-controlled by the use of a "shutter-stat" in the bottom tank of the radiator. The shutters are either open or closed being positioned with an air cylinder. For testing purposes, the normal temperature-controlled operation was by-passed to a manual control.

4.3.5.2 Evans Shutters: The Evans shutters were two sets of horizontal vanes mounted in a special shroud, again between the radiator core and the fan. Their operation was controlled by a vernatherm in the bottom tank of the radiator with positions established by the temperature of the coolant. A screw adjust is

TABLE 18

SOUND-CURTAIN EVALUATION FOR NOISE REDUCTION

dB(A)(TEST) - dB(A)(TABULATED)

	SIDE AND SHUTTERS			
	DRIVER'S		PASSENGER'S	
	OPEN	CLOSED	OPEN	CLOSED
KENWORTH (K-123)				
At Test Track: Mic @ 50 feet				
J366 Acceleration				
Baseline Truck				
Without Curtains	0	0	0	0
With Side Curtains Only	-2.5	+2	-1	+1.5
With Full Curtains	-2.5	+0.5	-1	-1
With Full Curtains and Pan Cover	-3	+0.5	-1	-2.5
With Pan Cover Only	-2	+4	-1	+1.5
Modified Truck *				
Without Curtains	0	0	0	0
With Full Curtains	-0.5	+0.5	-0.5	-1
Modified Truck **				
With Side Curtains Only	0	0	0	0
With Full Curtains	0	-0.5	+1	-1
With Full Revised Curtains	-0.5	-1	+0.5	-0.5
With Full Revised Curtains and Pan Cover	-1.5	-1.5	+0.5	-2
PETERBILT (352A)				
At Test Track: Mic @ 25 feet				
J366 Acceleration: Baseline Truck				
Without Curtains	0	0	0	0
With Side Curtains Only	-1	-1.5	-3	-2.5
With Full Curtains	-1.5	-2.5	-4	-4

* BROOKSIDE 28x8 FAN WITH .975:1 SPEED RATIO

** BROOKSIDE 28x6 FAN WITH 1:1 SPEED RATIO

TABLE 19

RADIATOR SHUTTER EVALUATION FOR NOISE REDUCTION--KENWORTH (K-123)

dB(A)(TEST) - dB(A)(BASE) = dB(A)(TABULATED)

	SIDE AND SHUTTERS			
	DRIVER'S		PASSENGER'S	
	OPEN	CLOSED	OPEN	CLOSED
EXTERIOR LEVELS				
At Test Track: Mic @ 50 feet J366 Acceleration				
Standard Shutters*	0	0	0	0
Kysor	+2.5	+1.5	+1.0	+0.5
Evans	-0.5	+2.5	-1.0	+2.5
Evans, 1/4 open	+5.5		-	
Evans, 1/2 open	+4.5		-	
Evans, 3/4 open	+3.0			

	SHUTTERS	
	OPEN	CLOSED
INTERIOR LEVELS		
Standard Shutters *	0	0
Kysor	+2.0	-1.0
Evans	+4.5	-0.5
Evans, 1/4 open	+5.0	
Evans, 1/2 open	+5.5	
Evans, 3/4 open	+4.0	

*SUPPLIED AS PART OF BASELINE VEHICLE

provided which was used to modulate the amount of shutters opening, thereby allowing full-open, 3/4-open, 1/2-open, 1/4-open, and full-closed. The installation is shown in Figure 23.

4.3.6 Analyses

As the work performed during Selective Component Testing was an interim step in choosing the modifications for the final configuration, no spectral analyses were made. All of the decisions made from this information were made on the basis of the overall dB(A) sound level.

The results of the testing showed that the fans, or other changes to the cooling system, made the greatest difference to the sound level of the overall truck. The changes made to the exhaust system, additions of sound liners, and installations of sound curtains made only small changes that would not stand up to a rigorous cost/benefit computation or might not be practical from a maintenance aspect during the life of a truck.

The results of the Sound Source Definition testing confirmed the conclusions. The cooling fan was by far the most significant sound source in the truck. The Peterbilt has a difference of as much as 8 dB(A) in the worst condition between the fan level and that of the next loudest source. The difference in the Kenworth is 9.5 dB(A). Therefore, by modifying only one system, and that as inexpensively as possible, the greatest cost/benefit ratio was achieved.

4.3.7 Discussion

Discussions of the particular changes made in the systems is as follows:

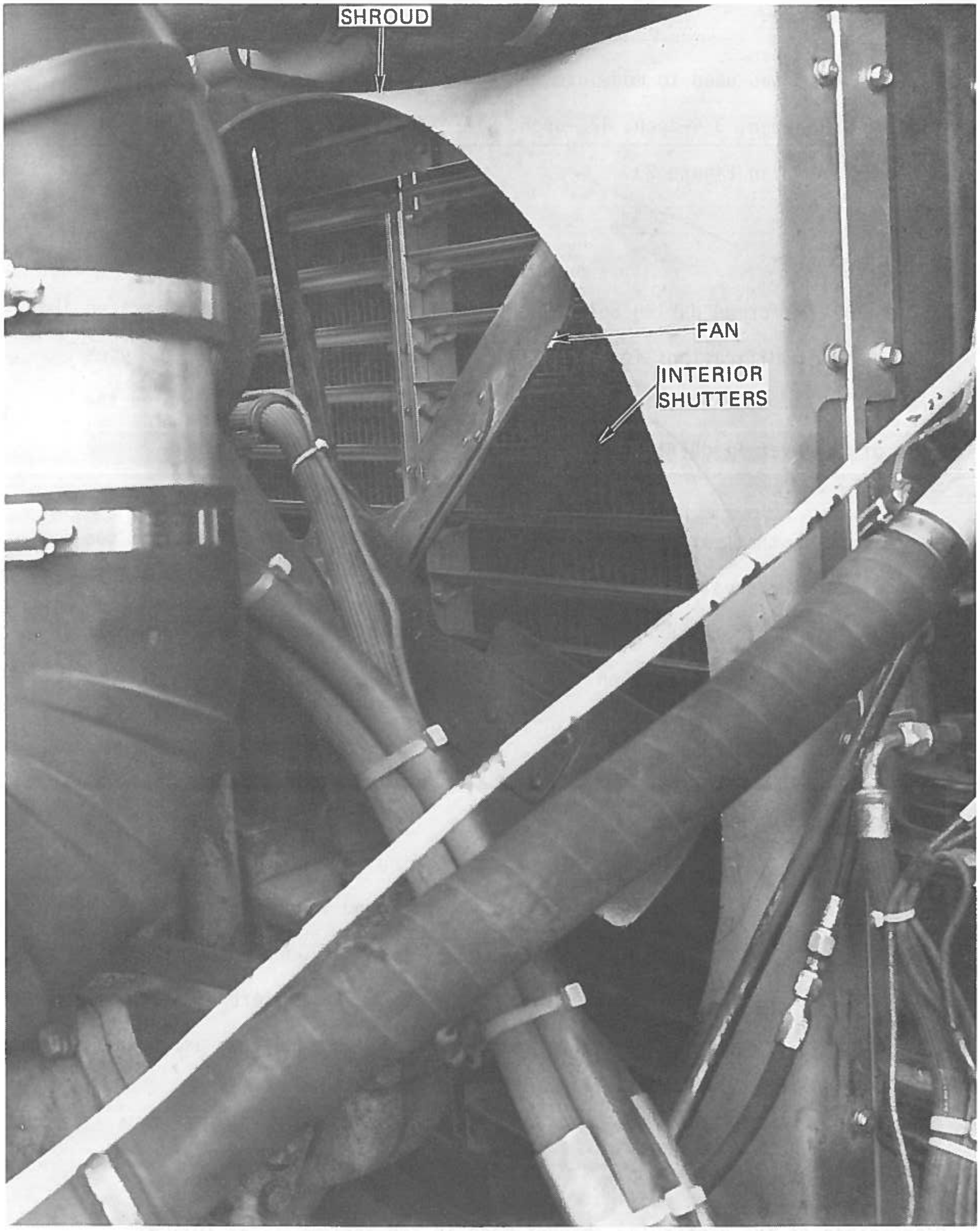


Figure 23. Evans Rear Interior Shutters

4.3.7.1 Cooling System: The greatest improvements in sound level can be made by altering the cooling system. The first task was to select a fan that would both cool to specifications and still be quiet. To this end, the Modified Vehicle contains this change. Reducing the fan speed ratio would make the major difference in noise level, but this requires an extensive testing program to insure that cooling margins are maintained. To some degree this was accomplished on both trucks with the greater improvement on the Peterbilt. Some possibility exists of further reducing the fan speed ratio on the Cummins engine of the Kenworth. Further effort towards reducing noise in the cooling system should be to totally integrate and optimize all the components.

One area only briefly touched in the cooling system work is the interaction of fan clutch and shutter operation. The best means to reduce fan noise is to turn the fan off, which is possible about 95% of operating time according to one study. The worst case of noise, on the other hand, is the combination of a running fan working against closed shutters. One possibility is to phase the shutters with the fan clutch so that when the shutters were closing, the fan would either slow down or turn off, depending on clutch design. A second stage of the system would be to open the shutters while leaving the fan off if the cooling needs were being met simply with ram air. This is now being done on production trucks made by PACCAR.

Another less exotic consideration briefly encountered in the Noise Program is the use of either vertical vane shutters or interior shutters. Some testing to survey the concept of interior shutters was performed using the original equipment trucks. Time did not allow for further evaluation of these components, but literature indicates some benefit might exist using these variations.

Some improvements in sound level would come about if the efficiency of the cooling system were to allow further reductions in the fan speed, as already discussed. Some of the increase in efficiency would be created by improving the contribution of the fan shrouds to channel the airflow through the radiator with less turbulence. Some methods discussed for this are improving the airflow in the fan shroud or reducing the fan tip to shroud clearance to reduce recirculation. A second method of improving efficiency would be to optimize the radiator itself by several recognized means such as increasing tube numbers or increasing surface area while maintaining good airflow. These are being investigated for sound level as well as cooling ability by the manufacturing divisions of PACCAR.

4.3.7.2 Exhaust System: The results of the test work in the area of mufflers and muffler-peripheral devices showed the greatest improvement in sound level to be about 1 dB(A), or about the level of the tolerance of error in data acquisition, while the greatest increase in sound level was about 2.5 dB(A). Because the exhaust system was not the most significant contributor to the overall sound level of the trucks, any improvements to this system would not be reflected in improvements for the whole truck. It was further found that the original equipment mufflers alone did as well as any other devices or combinations of devices in controlling the sound of the exhaust system.

Further improvements to the exhaust system might prove worthy at a time in the future when the overall level of the truck sound is reduced to the point where the exhaust system becomes more contributory. At this point, some investigation of improving the integrity of the system would probably be the best approach.

Products being introduced into the market include improved flexible pipe, improved joint connectors, double-walled pipe to attenuate shell noise, muffler shell additions, and better mufflers. Some work performed during the program showed that there are mufflers available that are better than the original equipment used in the test trucks, but these are bigger and of higher back pressure. The instinctive reaction was that the cost of installation and penalty of operation was not warranted at this time in the context of the goals of the Noise Program.

It should be noted that the addition of peripheral devices above the mufflers tested provided only a marginal improvement not considered worth the expense or added complexity. The test work included a superstack after the mufflers and a resonator before the muffler. Another device not tested, but expected to be in the same category, is the splitter Tee which is a flow control device as well as a type of resonator.

4.3.7.3 Sound Liners (Acoustical Material): Part of the testing was performed with the additions of acoustical material in areas of sound sources. These materials did have some minor effect on the radiated sound from the engine and cooling system. To this extent, it is recommended that additional investigation should be made into the effect of using acoustical material to absorb sound and reduce reflection in the area of the tunnel walls. Another benefit of the acoustical material would be to reduce the sound transmitted to the cab of the truck, thereby reducing the interior sound level. Unfortunately for this program, there was not enough time to fully investigate all of the different combinations of acoustical material, or the methods of installation. It is expected that this would involve a small fleet of vehicles to field test the available materials, as one of the major criteria would be a durability assessment.

4.3.7.4 Sound Curtains: Sound curtains, in the context of the test work performed, represented a crude form of engine enclosure. The curtains tested were merely loose-hung panels of acoustical barrier material attached to the cab. In the results, it is shown that the concept was more effective in the Peterbilt than the Kenworth, up to 4 dB(A) in one instance. The same effect was realized by a fan change that was more direct and suffered none of the drawbacks of the curtains concept.

The malady of the sound curtains is the same one that affects all engine enclosures. The material hides the engine from convenient normal maintenance and tends to bottle up the engine heat as well as block airflow needed for cooling. This is not saying that some optimum design might not be made, but rather the results merely suggest that a benefit might be gained when other methods do not fully meet the criteria of lowering sound levels.

4.3.7.5 Interior Shutters: The results show no noticeable improvement in the sound level of the truck using interior shutters. In fact, the interior shutters show an increase in the sound level in most cases.

The Kenworth truck, with its longer inline 6 cylinder engine, is a difficult truck to try to install interior shutters on because of lack of physical room and restricted airflow characteristics. Because of this lack of room, the evacuation of air coming through the radiator is restricted. The cooling data

(Table 13, Air-to-Boil 132°F) illustrate that the 1.2:1 ratio fan drive is moving more air than necessary through the system which accentuates the need for sufficient clearance to preclude fan stall. Installing the interior shutters seemed to increase the pressure drop and further hinder this airflow.

Shutters are now being specified less on new vehicles due to new developments in engine thermostats and it appears likely that shutters will be obsolete in the next few years except for applications involving very low ambient temperatures.

4.4 MODIFIED-VEHICLE TESTING

After the testing information was reduced and analyzed, a particular set of components was selected which represented those most qualified to be modifications. These generally were components that produced the lowest sound levels for the truck, but they were also the most practical in terms of cost, installation, and maintenance. Other combinations might have given marginally lower sound levels, but they were considered impractical for one of several reasons. The goal was to achieve the lowest sound level reading with the least complex changes.

The modified configurations were essentially a cooling system change only. The Peterbilt fan was changed to a Flex-A-Lite 3228-4, 28x6 configuration mounted on a fan drive pulley turning at a speed ratio of 0.8:1. No other changes were made to the truck. It used an unmodified radiator setup, the stock exhaust system, standard air induction system, and air cleaner. The results are included with the Summary of Results section in Table 1. The Kenworth fan was changed to a Flex-A-Lite 3528 fan, a 28x8 configuration turning at a speed ratio of 1:1. An option is the Brookside 480302, a heavier 28x8 fan giving nearly identical sound and cooling results. The results in the Summary of Results section, Table 3, reflect the Flex-A-Lite fan.

4.5 SITE-TO-SITE COMPARISONS

Following the acquisition of the Unmodified Baseline data, some concern was expressed about the location of the site used for testing; it was thought that a better location might be secured where the sound level information would be more reliable. Some testing was done using the same truck configuration at a couple of different sites where the results could be compared. This is the basis for Figures 24 and 25 as well as the information in Table 20. The table is a cross-calculation of the differences in measurements for a run type for the same truck situation.

It is seen that the results are very scattered among the three sites. The Test Track produced the lowest runs typically, and Sand Point produced the highest values. The Backlot results were somewhere in between, but it was limited to only a stationary maximum RPM format, reducing its usefulness. Because the results were as unsymmetric, a correction factor cannot be calculated that would be meaningful. The information gathered at one site could only be compared to other information collected at the same location. Generalized trends could be made regarding information acquired at different locations, but only in a qualitative sense.

The conclusion was reached that the format of results obtained at different sites would be presented in a relative setting comparing similar sets of information. To further insure that misleading values would not be published, most

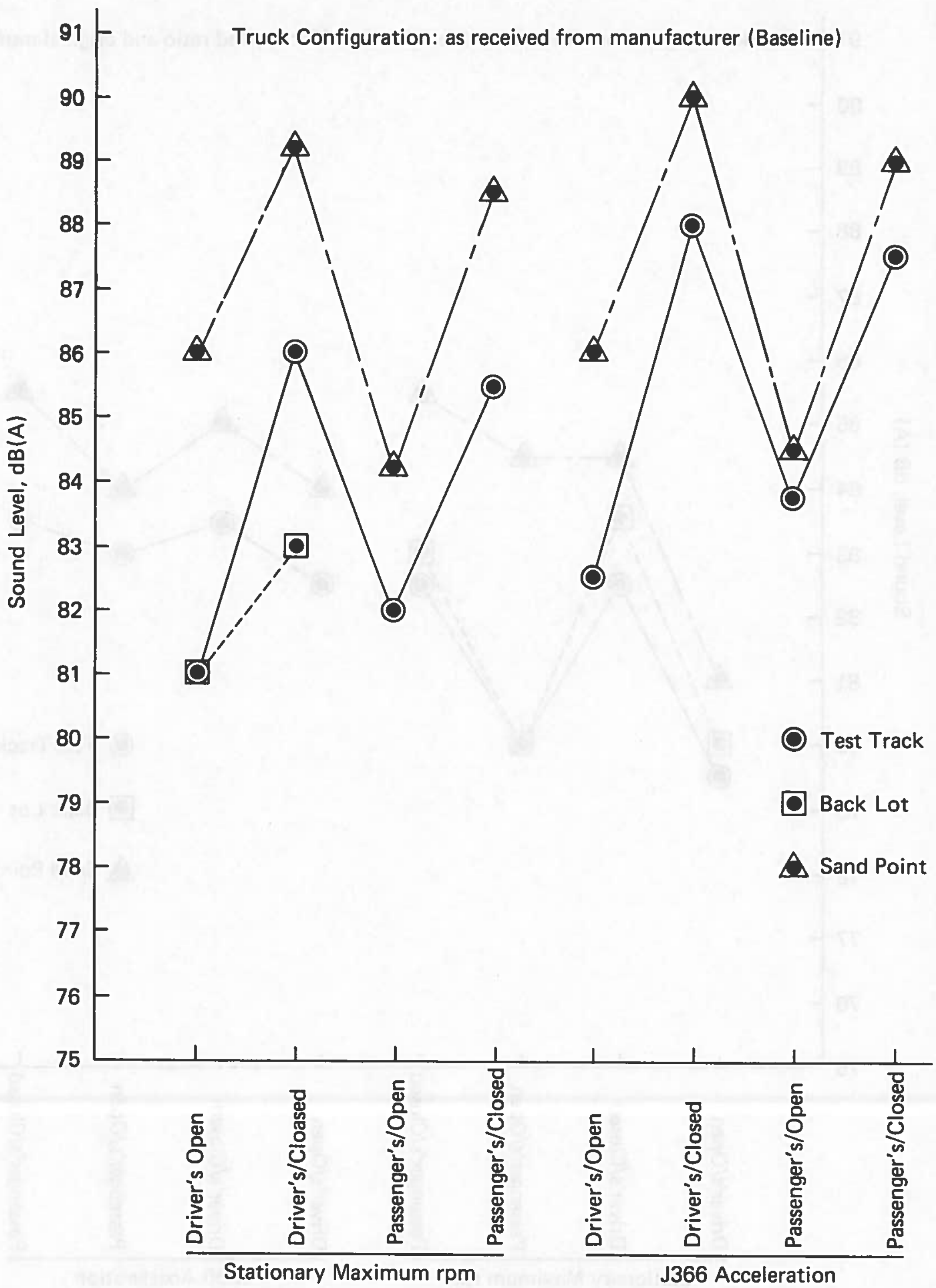


Figure 24. Site-to-Site Comparison with Peterbilt 352A

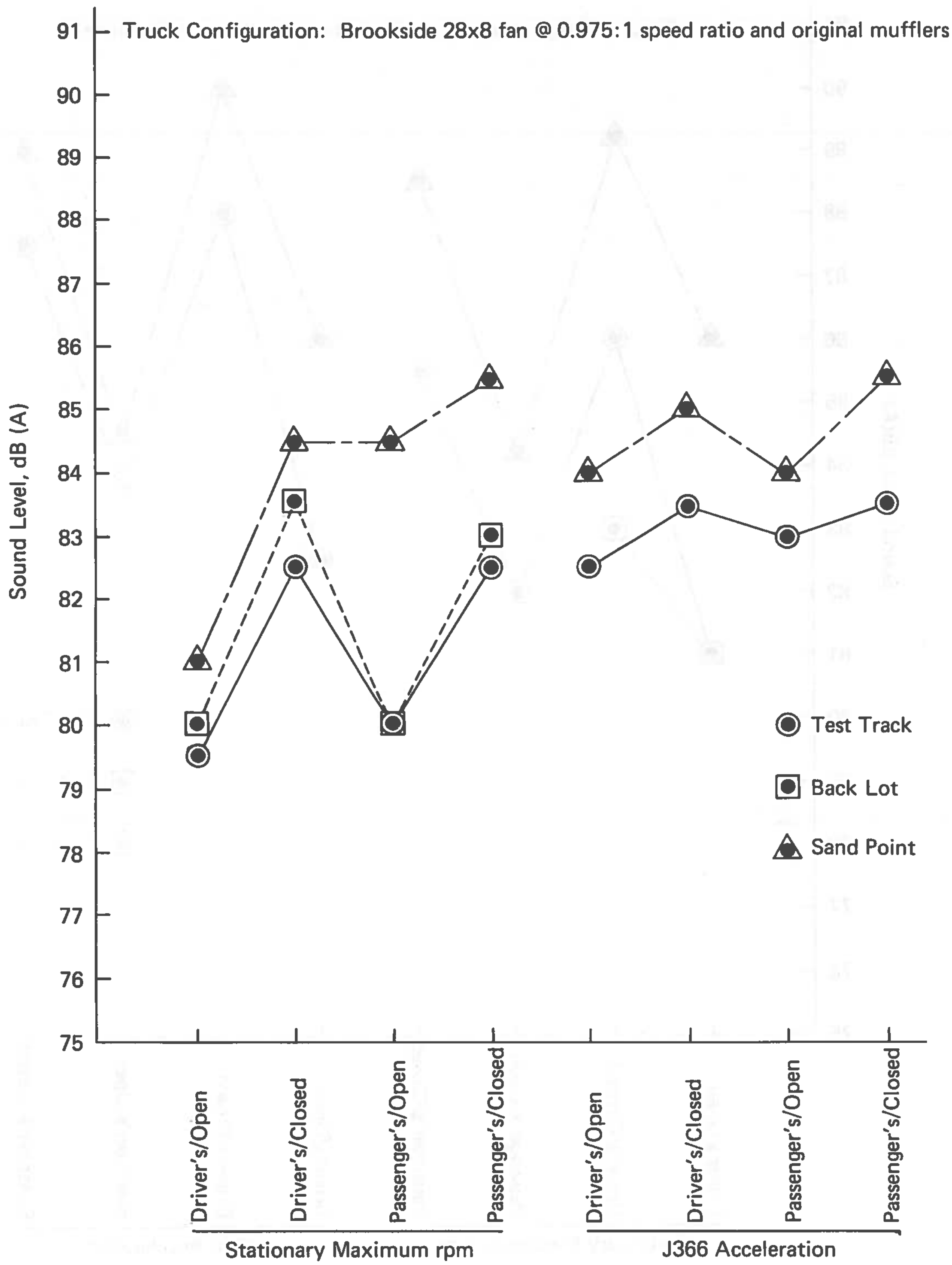


Figure 25. Site-to-Site Comparison with Kenworth K-123

TABLE 20

SITE-TO-SITE-VARIATIONS

ALL DIFFERENCE VALUES IN dB(A)

	Kenworth (K-123)			Peterbilt (352A)		
	Sand Point to Track	Sand Point to Backlot	Backlot to Track	Sand Point to Track	Sand Point to Backlot	Backlot to Track
Stationary Maximum RPM						
Driver's/open	1.5	1.0	0.5	3.5	5.0	-3.0
Driver's/closed	2.0	1.0	1.0	1.0	7.0	0
Passenger's/open	4.0	4.5	0	4.0	**	**
Passenger's/closed	3.0	2.5	0	1.0	**	**
J366 Acceleration						
Driver's/open	1.5	*	*	2.0	*	*
Driver's/closed	1.5	*	*	5.5	*	*
Passenger's/open	1.5	*	*	1.0	*	*
Passenger's/closed	2.0	*	*	5.0	*	*

* Not Appropriate for Comparison

** Not Recorded

of the results were put into differences, ignoring the actual dB(A) levels. The exceptions to the rule were allowed for "before and after" situations or where actual values were required to present certain information. This is the format used throughout this report.

All final overall levels reported were measured at the Sand Point site.

5. SELECTION PROCEDURE AND TRADEOFF

5.1 COOLING SYSTEM

The cooling system was the system with the greatest potential for noise reduction because it was found to be the dominant or controlling source for overall vehicle noise. The system also had some of the tightest restrictions on the performance to insure proper engine cooling. The task in working with the cooling system was to obtain the maximum benfit from the changes while staying within the performance boundaries.

5.1.1 Components

The number of components to be worked with in the cooling system is shown in the following list and discussion of the variations of each component. The discussion describes the variations that could be used in terms of sound level reductions as well as the restrictions placed on the components to insure proper operation.

5.1.1.1 Fans: The fan is the prime noise source in the cooling system. Different designs of fans were tried. These resulted in different airflows through the radiator. In addition, the number of blades on the fan, the blade spacing, and even the configuration of the blades all had some contribution to airflow and noise. Our intent was to find a fan that did the best at moving the proper amount of air past the radiator to give desired cooling with a minimum of noise generation.

5.1.1.2 Fan Drive Ratios: The controlling factor of fan noise is the rotational speed of the fan. (Fast-moving blades are louder than slow-moving blades.) Additionally, the fans tested, because of their design differences, differed in their efficiency/speed profiles. Some fans would be more efficient at higher speeds while others were best at lower speeds. Coupled with the selection of fans was the selection of the proper speed ratio for that fan. The Detroit Diesel engine supplied with the Peterbilt came with a 1:1 ratio that was able to use many different fans according to specified cooling abilities. The ratio was reduced to 0.8:1 when a pair of fans was found that would cool properly at that speed. The Kenworth came with a Cummins engine that had a 1.2:1 ratio installed. This was recognized early as being too fast, and the ratio was dropped to 1:1. The possibility exists to further lower the speed to 0.86:1, but no test work was performed at this speed.

5.1.1.3 Shroud: The cooling shroud is important in the system to contain the airflow through the radiator and prevent air recirculation. While changes in the shape of the shroud, reductions of the fan/shroud tip clearance, or the sealing of the shroud might not appreciably affect noise levels, these changes can promote more efficient cooling where a fan speed change could be made that would affect the sound level. Various shrouds were suggested and some alterations made to indicate the direction a better design should take, but no substantial investigations were completed to fully explore the range of possibilities.

5.1.1.4 Shutters: Shutters are a historical component in a heavy-duty truck used to control engine coolant temperature in parallel with a thermostat. The shutters open for more cooling and close for less, thereby creating a simple airflow control system. This sytem has been in use for a long time and is highly regarded by many operators. These systems create a noise problem when the shutters are closed against an operating fan. The resultant high pressure differential across the fan causes turbulence in the air stream (stall) and increased noise. Working with the components existing on the trucks meant optimizing the shutters. In this context, some different ideas for shutter design were tried by installing and testing interior shutters. Additional ideas included vertical vane shutters and interfacing shutters with a fan clutch operation; neither of these was attempted for several reasons relating to time and expense.

5.1.1.5 Fan Clutches: Fan clutches were viewed as a primary candidate to solve noise problems if allowed. Simply turn the fan off, and less noise is created. In one study conducted by a vendor, it was shown that fans need not be run the majority of time on the road. However, because of durability problems with early designs the reliability of present fan clutches for long-term use must be demonstrated. They are also expensive to install, but have some positive benefits in use. Two different manufacturers' clutches were installed in the test trucks and monitored for performance and noise simply to establish a feeling for their contribution. The results were encouraging.

5.1.2 Testing

Testing of the cooling system components consisted of two parts: a cooling test and the noise test. The two are treated separately.

5.1.2.1 Cooling Test: The cooling test used a procedure established in the industry as a reliable means to determine cooling ability. In this test, the truck was operated at maximum load against a dynamometer with the shutters open and the thermostats blocked open. If the difference between the temperature of the incoming water to the radiator and the ambient air through the radiator met established criteria, the system passed the cooling tests. Detroit Diesel established a criterion of 90°F Air-To-Water (ATW) as a maximum measured as the simple difference of inlet temperature to ambient. Cummins Engine specified a 50°C (122°F) Air-To-Boil (ATB) as a minimum, measured as the boiling temperature of water minus the radiator inlet temperature plus the ambient air temperature. This is essentially 100°C - ATW (in Celsius), but properly expressed as 100°C -Ti + Ta.

The particular setup used in testing the two trucks consisted of mounting an in-frame dynamometer, produced by Go-Power of Palo Alto, California, to the trucks in place of the drivelines. A typical setup is shown in Figures 26 and 27, where the dynamometer is in place on the Kenworth using a drop box to connect the driveline with the power absorption unit. Figure 28 shows the dynamometer installed in the Peterbilt. The truck was then situated just outside of a doorway to the shop where the door could be rolled down forming a recirculation shield on the top. A portable wind box (Figure 29) was placed in front of the truck aimed at the radiator four feet way; this was used to wash the front of the truck with 15 MPH ram air; a requirement of the cooling test. In some instances plywood boards were placed on each side of the truck and the bottom exposing only the radiator for additional recirculation prevention.

The truck was instrumented with 10 thermocouples to measure temperature. Two were placed in the water system, one at the inlet and the other to the outlet of the radiator. A thermocouple was set up two feet from the front of the radiator measuring ambient air into it. Another was put on top of the engine for

Figure 26. Dynamometer Installed on the Kenworth

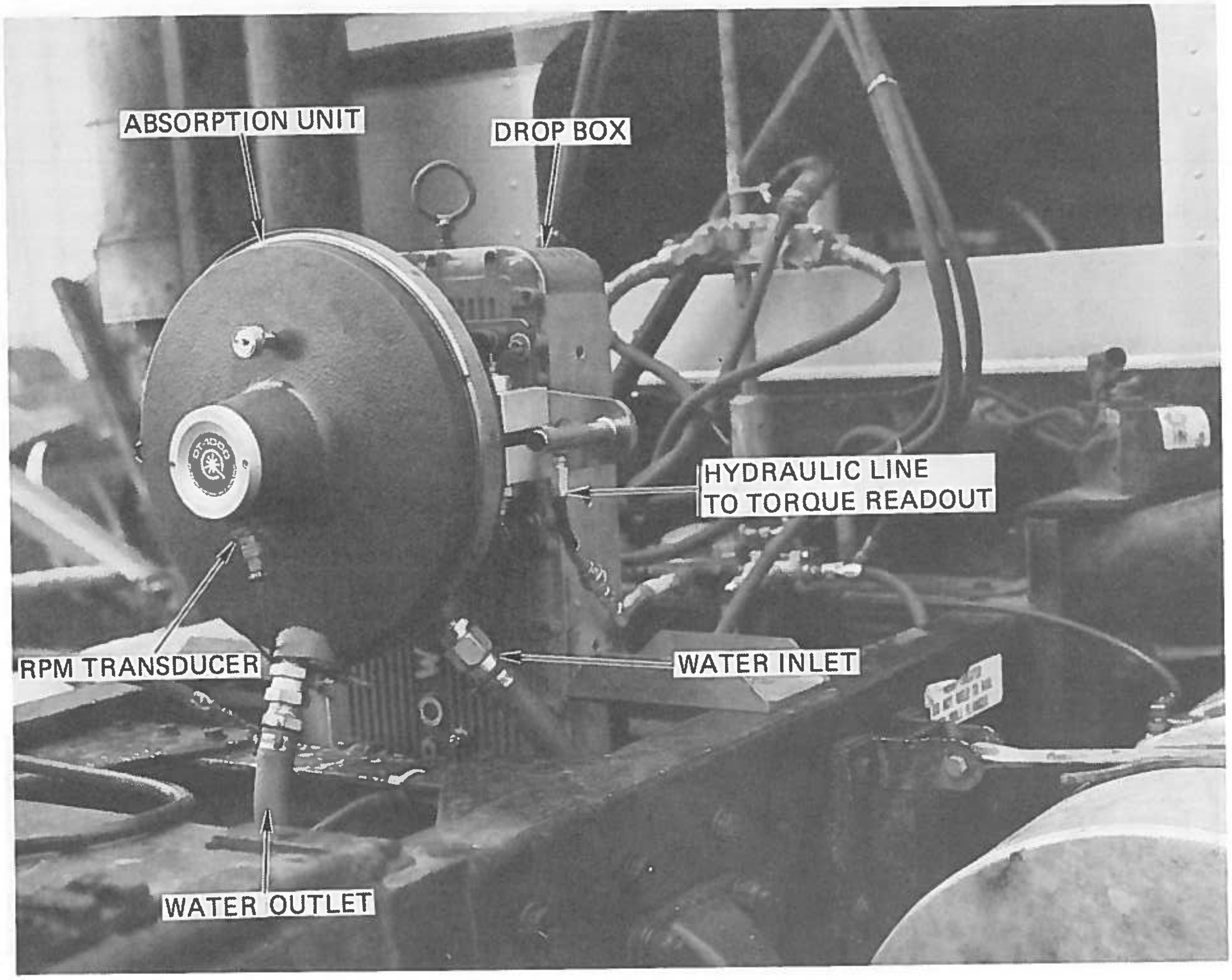


Figure 27. Closeup of Dynamometer on the Kenworth

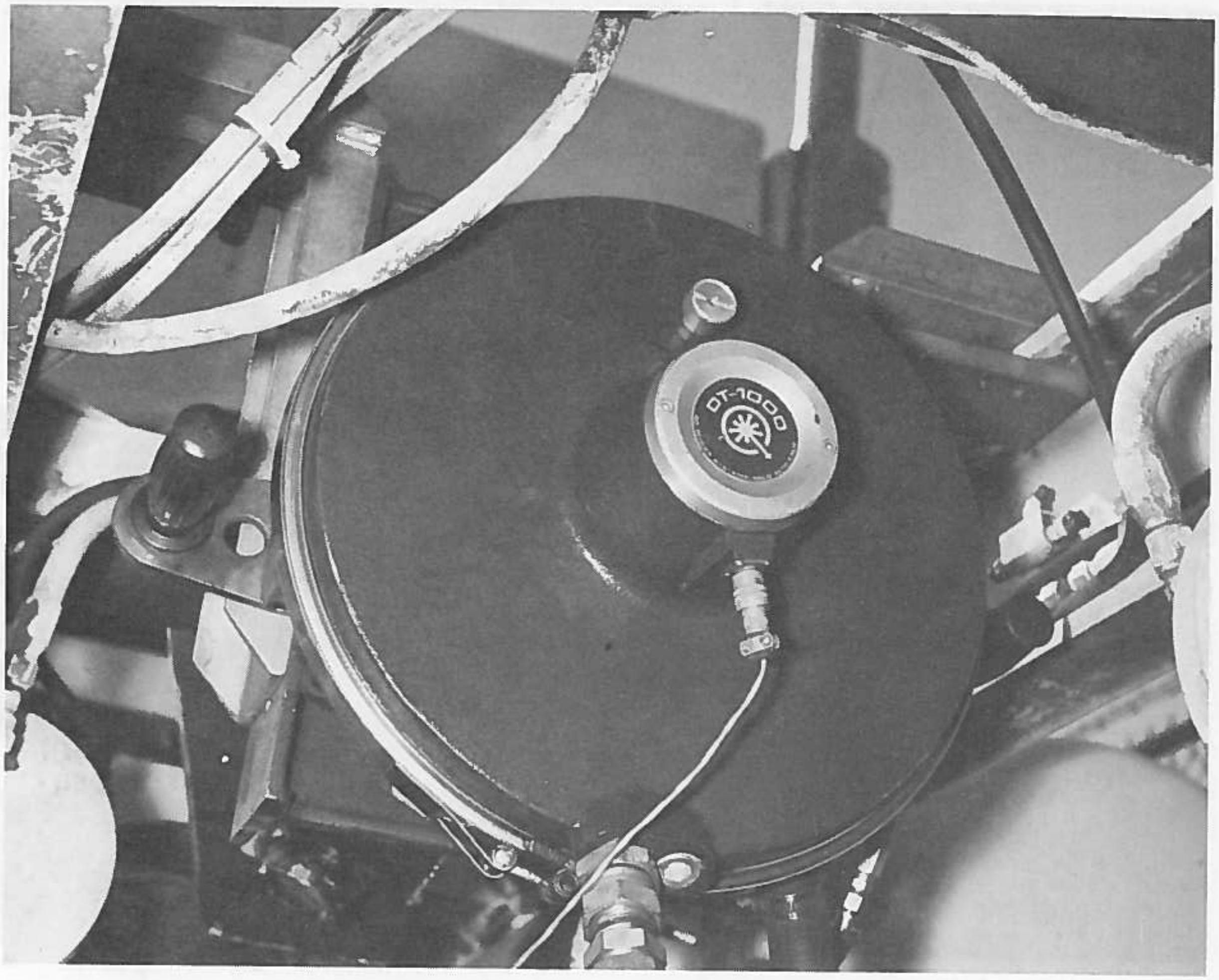


Figure 28. Dynamometer Installed on the Peterbilt

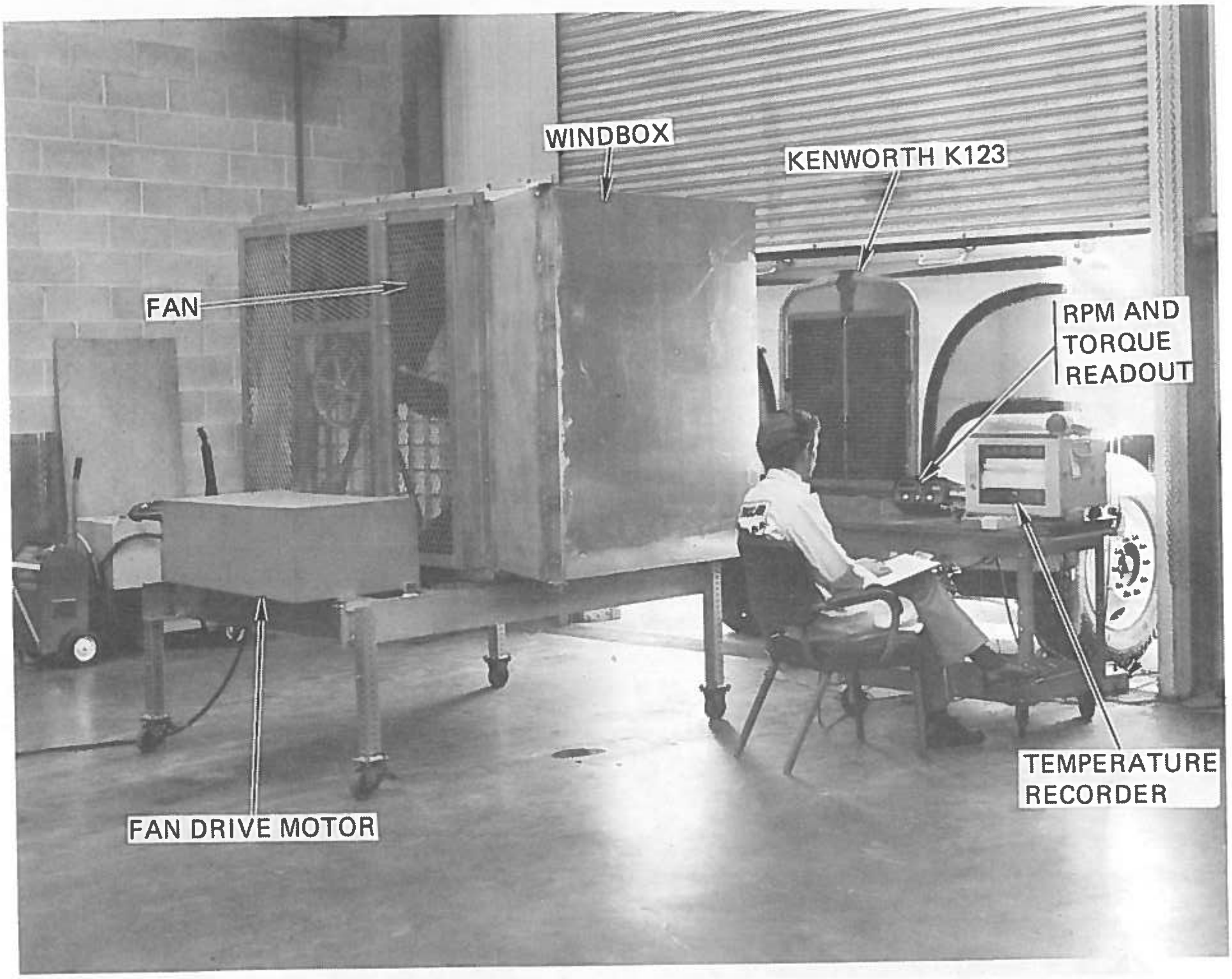


Figure 29. Cooling Test Setup

engine compartment temperature, and another in the inlet passage for air induction temperature. Five remaining thermocouples, shown in Figure 30, were fixed to the radiator grill to measure temperature variations in incoming air around the grill.

The test was run for thirty minutes after the engine coolant began to warm up. The time period gave the system an opportunity to stabilize under full engine load with the shop bays creating a plenum effect for the ambient air. During testing, conditions were monitored using all ten thermocouples to insure conditions were stable and within acceptable bounds.

The results of the test were calculated by subtracting the temperature of the ambient air from the temperature of the water inlet. For Detroit Diesel, this was the result. For the Cummins, this number was subtracted from the boiling point of water for the result. The remaining temperature readings were viewed with regards to the variations in temperature across the grill to insure even flow.

In addition to the temperature reading taken during the tests, the horsepower, engine speed, and dashboard gauges were read and recorded. While these readings had no bearing on the cooling tests, they form the basis for power evaluation of the selected systems.

5.1.2.2 Noise Testing: When the cooling system modifications were certified by the cooling test, sound level testing began. The preferred methods were to evaluate the system using drive-by testing, J366 acceleration, and other

Figure 30. Cooling Test Thermocouples on the Kenworth

methods. In many cases, however, this was not practical from several standpoints relating to availability of sites, site compatibility, or weather. In those instances, a stationary maximum RPM test was performed on the Backlot site where comparative testing was quick and sufficient for evaluation.

The results of both sound level test types are shown in the Selective Components Testing section of this report. The conclusions of this testing helped determine the fan to be specified for the Modified Vehicle testing based on the cooling test and sound level test results combined. The only time this format was not used was for the Flex-A-Lite 3228-4 fan, where Backlot testing was not performed. The vehicle was taken straight to Sand Point for drive-by testing because of the extreme promise of the sound levels of this fan. It performed as well as the Brookside 29x8 fan (x-3472) at a speed ratio of 0.8:1 in the cooling test. Both fans were tested at Sand Point with similar results; therefore, the smaller fan was preferred over the larger, which would have required shroud changes.

5.2 EXHAUST SYSTEM

5.2.1 Components

There are several components that make up an exhaust system, each contributing to the sound level of a truck. Under the restrictions of off-the-shelf hardware for component selections, the decision was made to emphasize mufflers and subsidiary muffler components. The field of other components, such as better clamps, double-wall pipe, better flexible hose, and different splitters, were simply surveyed for future reference.

5.2.2 Vendor Selection

The selection of mufflers from the vendors was a crucial part of the evaluation effort for the exhaust system. Each of the vendors has engaged in research and development effort for their products, including all of the parameters to be considered in the DOT Noise Program--cost, noise levels, and backpressure. PACCAR's effort included the physical factors involved with fitting the products to the truck.

Based on the available mufflers and peripheral equipment from different companies, a stock of parts was obtained. This stock was the foundation for muffler evaluation in the Noise Program. Some of these parts were valid for one truck or the other, each with a different engine, while others applied to both equally.

5.2.3 Noise Testing

Noise testing the muffler systems on the trucks consisted of installing the mufflers on the trucks and testing in various combinations. The preferred method was driveby, but most of the mufflers were evaluated in the Backlot for the same reasons as the fans. During Sound Source Definition, it was learned that the exhaust system was not the most significant sound source on the truck; therefore, any changes to the muffler system did not appreciably affect the overall sound level of the truck. The results of the Sound Source Definition and muffler testing with the stock truck are found respectively in the Sound Source Definition and Selective Components sections.

Cost was one of the factors considered during the evaluation. A larger muffler was viewed as more expensive than a smaller one, and the addition of a resonator or a superstack to the muffler would be more expensive yet. A superstack, for instance, is really a smaller version of a muffler and it costs about the same. To add one to the system would almost be adding a second muffler to the first. The results showed that the addition produced a minor reduction in sound level that was not economically justified at that time.

5.2.4 Backpressure

A specified level of backpressure is mandated at the maximum allowed by each of the engine manufacturers. Detroit Diesel has a maximum of 2.0 inches of mercury, while Cummins will allow 2.5 inches of mercury. Any muffler system that performs under these limits is satisfactory from a backpressure standpoint.

For this program, most backpressure specifications were taken from vendor's measurements. The vendors routinely made these measurements while this program would have had to make a concerted effort to obtain the numbers. A few measurements were taken with a stationary, unloaded runup as a check, as were a couple of over-the-road measurements to verify the vendor numbers. In the final analysis, the mufflers specified were the original equipment where the published backpressures were so low, and the possibility of any higher pressures so remote, that the expense of setting up a dynamometer to measure backpressure was not made. Engineering was satisfied that the backpressure restrictions would not be exceeded by using the original equipment mufflers.

5.3 INTAKE SYSTEM

The intake system was assumed to be a very low order system in terms of sound level which was proved by the Sound Source Definition testing. No major modifications were made or tested on the intake system. The original air cleaner, needed on the truck, was considered as more than ample to attenuate any possible intake sound below where modifications were required. An intake muffler was made and tried on the Kenworth during Sound Source Definition. This eliminated a 7,000 Hertz tone discernable to the ear, but made no reduction to the overall sound level of the fully wrapped, quieted truck.

5.4 ENGINE TREATMENT

There are two ways to treat engine noise--alter the engine to make less noise or cover it with a system to block and absorb sound radiation. The first method was out of the scope of this program, while the second was evaluated on one engine.

The Cummins NTC-350 diesel engine has a noise attenuating panel kit that is made as an accessory. It consists of a pan cover, a rocker cover, and several side covers made with a fiberglass material bonded to formed metal sheets produced to attach to the engine. These covers are designed to absorb and block the engine-related sounds. There are no comparable parts for the Detroit Diesel engines.

The pan cover was fitted to the Cummins NTC-350 in the Kenworth and tested for effect. The results are viewed in the Selective Components section on Sound Curtains. The results of this testing showed only negligible benefits as compared with the inconveniences of covers over the engine. These covers would increase the maintenance costs and difficulties with additional fire hazards associated with oil and dirt retention. The engine treatment kit was not considered necessary at that time because other methods of reducing sound level were available.

5.5 ACOUSTICAL TREATMENT

Acoustical treatment of the two test trucks was performed in two forms--sound barriers and sound liners. The results of both forms are presented in Selective Components Section under the appropriate titles. Discussion for the two forms is separate.

5.5.1 Sound Barriers

The sound barrier is really another form of an engine treatment package except that the barrier is spaced away from the engine rather than installed on it, rather like an enclosure. The extra spacing encompasses additional sound sources other than just the engine, such as the pumps, alternator, and other accessories, as well as allowing some increased cooling if sufficient airflow is provided.

The criterion for the sound barriers was the amount of sound reduction they afforded as compared with the cost of installation and inconvenience of operation with them installed. The curtains tested were not the final word on barrier design, but rather a first step in evaluation. If the reductions were adequate, some additional effort could have been made to design and install more substantial barriers close to ones that might have been specified for the Modified Vehicles. However, the results were not overly encouraging in comparison to other methods of sound reduction.

5.5.2 Sound Liners

Sound liners are being installed into production trucks at this time to reduce the in-cab noise levels due to sound from the engine area, the engine, accessories, and cooling system. If the material is properly selected, it will also absorb some acoustical energy.

The vendors of sound absorption material claim substantial noise reductions in certain frequency ranges. Depending on the material and its thicknesses, the materials will absorb most of the sound in frequency ranges of 1,000 to 5,000 Hertz with the percentages dropping off below and above these ranges. Unfortunately, the frequencies most often associated with truck noise are below 1,000 Hertz.

The two sound liners discussed in the Selective Components Section were installed in the test trucks for evaluation. Their contribution was slight, but noticeable. The one liner that was open-faced was unacceptable from a long-term standpoint, as it would have absorbed oil, water, and dirt within a short time. The other liner had protection from those elements except on the edges. However, edge sealing could have been accomplished, giving an acceptable rating for the liner. Several manufacturers are making sound liners for the engine side of engine tunnels and hoods.

6. EVALUATION OF MODIFICATIONS

6.1 DYNAMOMETER RESULTS

Initial and final dynamometer results were taken during the cooling tests. The truck engine was loaded by an in-frame dynamometer. The setup of this instrumentation is discussed in the Selection Procedures and Trade-Off Section under Cooling Tests. The results tabulated in Table 21 are those for the OEM and Modified Vehicle fans.

Those readings from the Go-Power dynamometer used in the cooling tests are those of the final stabilized cooling tabulation. These are the raw data without any corrections for ambient conditions. As these conditions were roughly equivalent, the corrections would be minor, if applied. Table 21 shows the OEM and Modified Fan horsepower readings and torque measurements.

TABLE 21

EFFECT OF COOLING SYSTEM MODIFICATION ON DRIVELINE POWER

	OEM FAN	MODIFIED FAN
HORSEPOWER (HP)		
Kenworth	310 @ 1.2:1	315 @ 1:1
Peterbilt	330 @ 1:1	336 @ 0.8:1
TORQUE (FT LB)		
Kenworth	780 @ 2100 RPM	793 @ 2100 RPM
Peterbilt	830 @ 2090 RPM	846 @ 2100 RPM

6.2 SYSTEM EVALUATION

6.2.1 Cooling System

The changes to the cooling system on both trucks are substitutions of one fan for another and a change of fan speed ratio. No other changes are intended. The effects of these changes are as follows:

Supply and Backpressures: No effect.

Fuel Consumption: Because of the minor changes in horsepower consumed by the fan drive, the available horsepower for tractive effort is slightly increased; see the effects on tractive power below. Any changes in fuel consumption should be commensurately minor to the negative side--less fuel should be consumed because more power is available to do the same work. Any differences should be very difficult to measure with other factors contributing more to the changes over a period of time.

Load Capacity: No changes to the load capacity of the truck--any differences in weight are negligible.

Tractive Power: The changes in the cooling system had slight effects on the amount of horsepower available to the drive axles. These changes were on the order of 5 horsepower for the Kenworth and 6 horsepower for the Peterbilt. These results are plotted and tabulated in the Dynamometer Results Section.

6.2.2 Exhaust System

There were no modifications made to the exhaust systems; the original equipment supplied with the trucks was considered as fully adequate and, in fact, about the best tested.

Supply and Backpressure: No changes.

Fuel Economy: No change.

Load Capacity: No change.

Tractive Power: No change.

6.2.3 Intake System

There were no modifications made to the intake system. The original equipment is not only required equipment for efficient operation, it is also fully effective for noise attenuation.

Supply and Backpressure: No change.

Fuel Economy: No changes.

Load Capacity: No change.

Tractive Power: No change.

6.2.4 Acoustical Material

The addition of acoustical material to underneath the engine tunnel was considered an option for the truck operators. It might take a variety of forms from a number of different manufacturers, but probably will be a self-adhesive flexible foam about one inch thick with a non-penetrable film barrier coating on the exposed side. Other variations might be applied, but would be roughly equivalent to the system described.

Supply and Backpressures: No effect.

Fuel Economy: No effect.

Load Capacity: The amount of weight incorporated in the addition of acoustical material amounts to an estimated 15 to 25 pounds; therefore, the reduction in load capacity is negligible. If the material absorbs and retains any water or oil, the load capacity of the truck could be further reduced by perhaps 50 to 100 pounds. If the material is installed correctly, however, with the edges sealed, there should be no problem with any absorption.

Tractive Power: No effect.

6.3 COST

The approximate cost figures were obtained from retail distributors for parts, and estimates from automotive jobbers for installation.

The only modifications that are recommended from an economic standpoint are a fan and fan speed change on each of the two trucks tested. This requires replacement of the fan, fan pulley, and belts.

6.3.1 Peterbilt

Fan, Flex-A-Lite 3228-4	$108
Pulley, 5122483	69
Belts (set of three)	16
Labor, 2.5 hr @ $21.00/hr	53
TOTAL	$246

6.3.2 Kenworth

Fan, Flex-A-Lite 3528	$139
Pulley, 146656	49
Belts, 178708 (2)	11
Labor, 2.5 hr @ $21.00/hr	53
TOTAL	$252

6.4 VEHICLE SAFETY

Vehicle safety will be discussed for the two modifications to the trucks--cooling fan changes and the optional acoustical material. There is no change in vehicle safety with the other systems as no changes were specified.

6.4.1 Cooling-System Changes

There should be no change to the vehicle safety from the cooling-system change.

6.4.2 Acoustical Material Addition

The addition of the acoustical material represents a potential fire hazard only if it is not installed correctly and oil or fuel accumulates in the foam material. However, the correct installation should include edge sealing, which precludes the possibility of any significant absorption of combustible liquids.

6.5 FEDERAL MOTOR-CARRIER SAFETY REGULATIONS

Interior noise level limits are established by Section 393.94 of the Federal Motor-Carrier Safety Regulations. This regulation states that the interior-noise level of a truck may not exceed 90 dB(A), $\pm$ 2 dB, when operated according to the Stationary Maximum RPM test procedure used during the PACCAR test program. The results from this test, in Tables 2 and 4, show that the proposed modifications to both trucks are necessary to reduce the interior noise to acceptable levels.

7. FIELD-SERVICE BULLETINS

Copies of the Field-Service Bulletins generated as a result of the sound level reduction effort are contained in Appendix A. These bulletins describe methods of reducing sound levels to the dealers of the trucks evaluated in this program. The Field-Service Bulletins detail the changes to produce specific reductions as well as the maximum sound levels to be expected with the specified equipment installed.

8. CONCLUSIONS

a. Most typical trucks can be reduced in sound level from present levels to under 86 dB(A), and nearly to 83 dB(A) in more favorable instances, by proper selection of existing hardware.

b. The predominant noise source on the two test trucks was the cooling fan operating in an unfavorable environment.

c. The total cooling system configuration is critical to overall vehicle sound levels. Proper fan selection, optimum spacing, and efficient shroud design are prerequisites to obtaining minimum noise and maximum cooling ability.

d. Fan systems can be specified with speeds higher than needed for effective engine cooling. These higher speeds cause increased noise. Optimum fan systems should be specified to move sufficient air volume and to minimize restrictions and turbulence.

e. Fan noise levels are increased by closing radiator shutters.

f. Light-weight, semi-flexible fans appear desirable for improved fan clutch reliability, reduced fan horsepower requirements, and reduced air recirculation.

g. Fan clutches appear to be suitable means of reducing sound levels and power losses by eliminating fan rotation for most vehicle operating conditions. Acceptable reliability, costs and benefits must be demonstrated to promote wide use.

h. Fan shroud design, properly fitted to prevent recirculation and create a plenum effect, can assist cooling ability and permit slower, quieter fan installations.

i. The engine mechanical noise is the second major noise source and represents a difficult problem for further sound level reductions.

j. Engine enclosures and sound reductions kits have promise for sound level reduction but with penalties of difficult access to the engine compartment for maintenance, increased heat retention, and the possibility of flammable liquid retention.

k. The exhaust system is the third major noise source. Several possibilities exist for further reductions in sound level for this system, but would not produce a significant reduction in vehicle sound levels due to the magnitude of other source levels.

l. Currently available well designed and constructed mufflers in leak-tight exhaust systems are adequate to reduce exhaust system sound levels to current regulation limits.

m. Peripheral exhaust system components (resonators, superstacks, and similar devices) are unwarranted for retrofit applications at present sound level limits but may be required for new trucks as overall sound level limits are reduced.

n. An engine brake installed on a truck with a properly fitted exhaust system is not a high order sound level source in comparison with acceleration or high RPM conditions on the same truck.

o. The intake systems on the two test trucks did not need modification; their contributed sound levels were too low to be accurately measured.

p. Drive train noise will become significant as overall truck sound levels are reduced; these sources are transient and difficult to diagnose.

q. Interior sound levels are influenced by the same sources that influence exterior sound levels but not in the same proportion.

r. Test results show no significant differences between loaded and bobtail configurations for sound level.

s. Digital spectral analysis techniques have tremendous potential for expanding the scope of knowledge in acoustical testing, especially in transient noise conditions.

t. Acoustical materials reduce sound level if properly selected and installed, but they should be considered only after optimizing existing configurations.

u. Site selection for proper sound level testing is a paramount requirement for accurate data collection.

9. RECOMMENDATIONS

a. The parameters controlling cooling performance and noise levels in truck environments should be thoroughly studied and documented with the following aims:

1) Maintaining the cooling ability with decreased airflow requirements (i.e., advanced radiator design and higher coolant temperatures).
2) Decreased the fan tip-to-shroud clearance.
3) Decreasing the restrictions to airflow behind the fan/radiator combination.
4) Determining the optimum shroud configurations for airflow with acoustical reductions.
5) Developing improved design techniques to increase cooling and reduce the sound levels.

b. Evaluate the feasibility of interlocking the operation of radiator shutters with the operation of a fan clutch to preclude a fan on/shutter closed condition for retrofit application on trucks using shutters.

c. Monitor the progress of fan clutch research and testing in truck environments to determine the economics associated with using fan clutches for noise and power reduction coupled with fuel economy increases.

d. Conduct research and testing on the effectiveness, durability, and safety of acoustical materials for truck application.

e. Improved methods for sound source definition testing and data analysis should be developed to streamline and simplify this important aspect to truck acoustical testing; special consideration should be given to methods of sound source definition without acoustical wrapping (i.e., using fine resolution computer spectral analysis procedures).

f. Designs and concepts for improved engine enclosures and/or noise kits should be tested and evaluated for sound level reduction, maintenance feasibility, heat retention, and fire safety with a goal of specifying a system that would be effective and would require a minimum increase in capital and maintenance costs.

g. Continued development and evaluation of exhaust system components should be encouraged towards improving their acoustical performance, durability, and ease of installation reducing backpressure and eliminating leakage.

h. A special study to determine the causes of, and practical solutions to, drive train noise problems should be undertaken before the overall sound levels of applicable trucks are lowered to levels where drive-train-related sound levels are contributory.

i. Engine and transmission support members and isolation components should be studied for reduction of acoustical energy transmission; metal-to-metal supports for both the engine and transmission should be discouraged.

j. Panel vibration diagnostic techniques should be refined and simplified for truck body applications in a factory environment to analyze resonant conditions for the large number of combinations produced; simplified guidelines should be developed to effectively dampen resonant conditions in these panels.

k. The design of low noise in-frame and chassis dynamometers should be encouraged for the truck market to allow controlled power loading for truck sound level research.

l. Methods to calibrate noise testing sites should be established to minimize the effect of site-to-site variations.

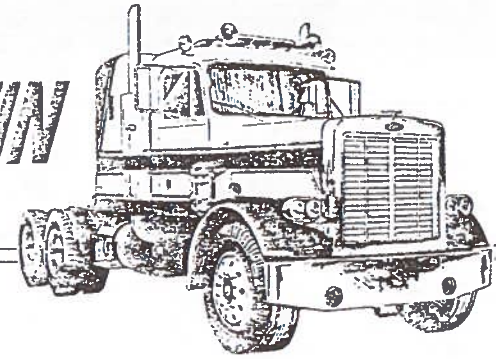
APPENDIX A

FIELD-SERVICE BULLETINS

OF PETERBILT AND

KENWORTH

FIELD SERVICE BULLETIN



DATE ______________________

FILE GROUP __________ SECTION ______________________

SUBJECT: 352A Sound Level Reduction

This bulletin concerns reducing the noise levels of a Peterbilt 352A COE of the following specifications:

Make: Peterbilt Cabover
Model: 352A86
Engine: DD8V-71T 350 HP N751NJ
Transmission: Fuller RTO-9513
Radiator: Heatex 75523-2855, 1020 sq.in. (PB Part No. 07-03135)
Radiator Fan: Brookside 28x8, 3.23 inch P.W. at 1:1 ratio
Fan Shroud: Stamped steel two-piece with 30" opening
Exhaust System: Dual vertical 5 inch
Mufflers: Donaldson MPM09-0161
Exhaust Stacks: 36 inch diagonal cut
Intake System: In-cab snorkel to single dry-element air cleaner
Air Cleaner: Donaldson EBA15-0006

The following changes in equipment should reduce the exterior sound level per standard SAE J366 test procedures to a maximum of 84.5 dB(A) and interior sound levels per BMCS guidelines to a maximum of 88.0 dB(A).

Radiator Fan: Flex-A-Lite 3228-4, 28x6 with 4.0 inch P.W.
Fan Pulley: 0.8:1 using a 9.125 inch pulley
Fan Spacers: Those needed to give 2/3 fan penetration into the shroud (1.5 inch spacers used)

The fan and pulley change should not adversely affect either the operation of the truck or the fuel consumption.

It is emphasized that the sound levels quoted can be attained only with a vehicle in proper mechanical condition and operating ability. The sound levels are applicable for the particular make, model, engine, and cooling system cited and projection of sound levels to other configurations cannot be guaranteed.

BULLETIN ______________________
A-2

KENWORTH TRUCK COMPANY

FIELD SERVICE LETTER

TO: KENWORTH DEALERS
SUBJECT: K-123 SOUND LEVEL REDUCTION

This bulletin concerns reducing the noise levels of a Kenworth K-123 COE of the following specifications:

Make: Kenworth Cabover
Model: K-123
Engine: Cummins NTC 350
Transmission: Fuller RTO-12513
Radiator: Heatex H-5 Core, 1200 sq.in. (KW Part No. K194-876)
Radiator Fan: Brookside 460380 28x6, 3.12 inch P.W. at 1.2:1 ratio
Fan Shroud: One piece molded fiberglass
Exhaust System: Dual Vertical 5 inch
Mufflers: Donaldson MPM09-0161
Exhaust Stacks: 36 inch square cut
Intake System: Exterior snorkel to single dry-element air cleaner
Air Cleaner: Donaldson EBA15-0006

The following changes in equipment should reduce the exterior sound level per standard SAE J366 test procedures to a maximum of 86.5 dB(A) and interior sound levels per BMCS guidelines to a maximum of 89.0 dB(A).

Radiator Fan: Flex-A-Lite 3528, 28x8 with 3.25 inch P.W.
<u>or</u> Brookside 480302, 28x8 with 3.23 inch P.W.
Fan Pulley: 1:1 ratio using 7.50 inch diameter fan drive pulley
Fan Spacers: Those needed to give 2/3 fan penetration into the shroud

The fan and pulley change should not adversely affect the operation of the truck or the fuel consumption of the vehicle.

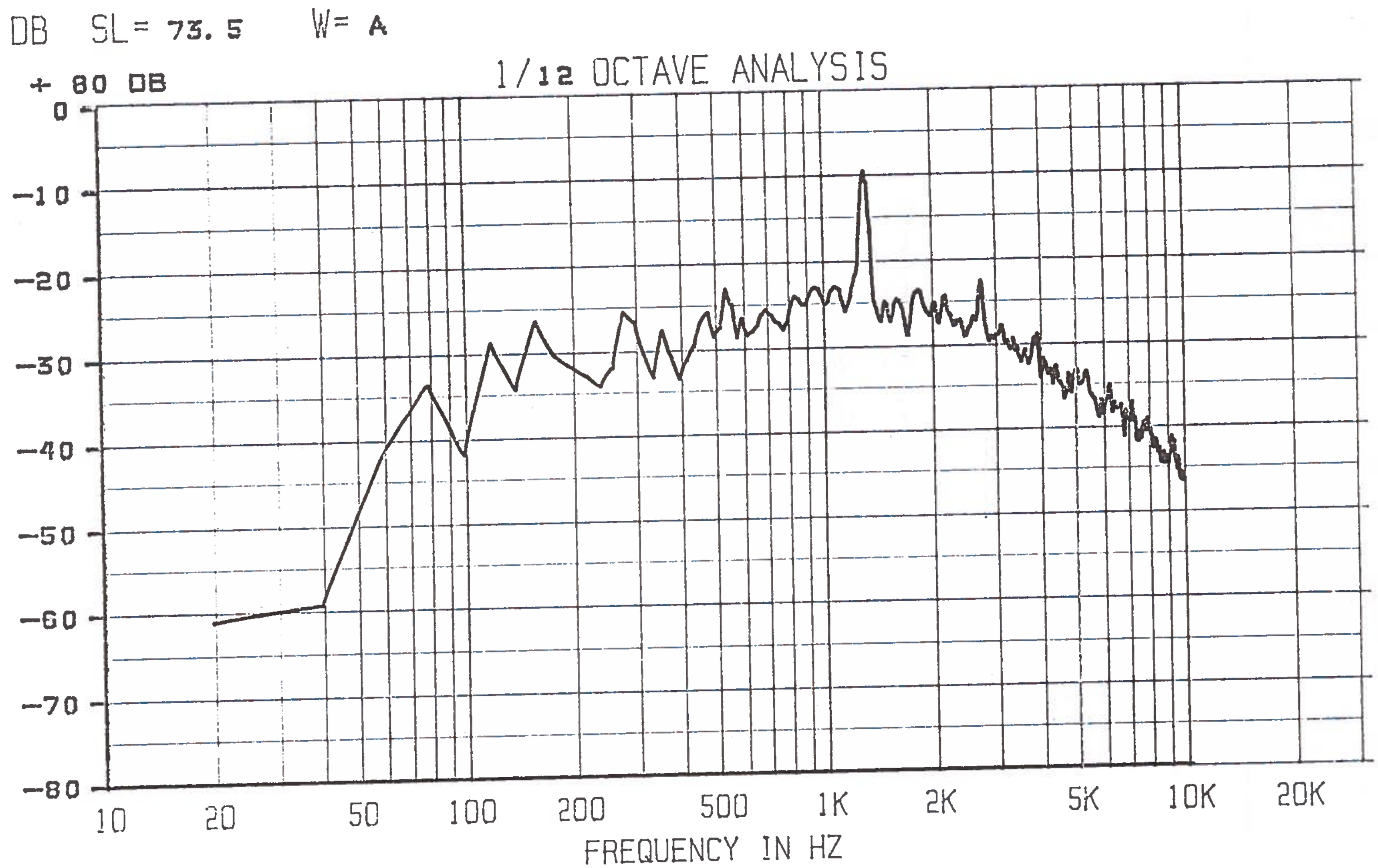
It should be emphasized that the sound levels quoted can be attained only with a vehicle in proper mechanical condition and operating ability. The sound levels are applicable for the particular make, model, engine, and cooling system cited and projections of sound levels to other configurations cannot be guaranteed.

APPENDIX B

SPECTRAL ANALYSES OF SOUND MEASUREMENTS

PETERBILT, MODEL 352A

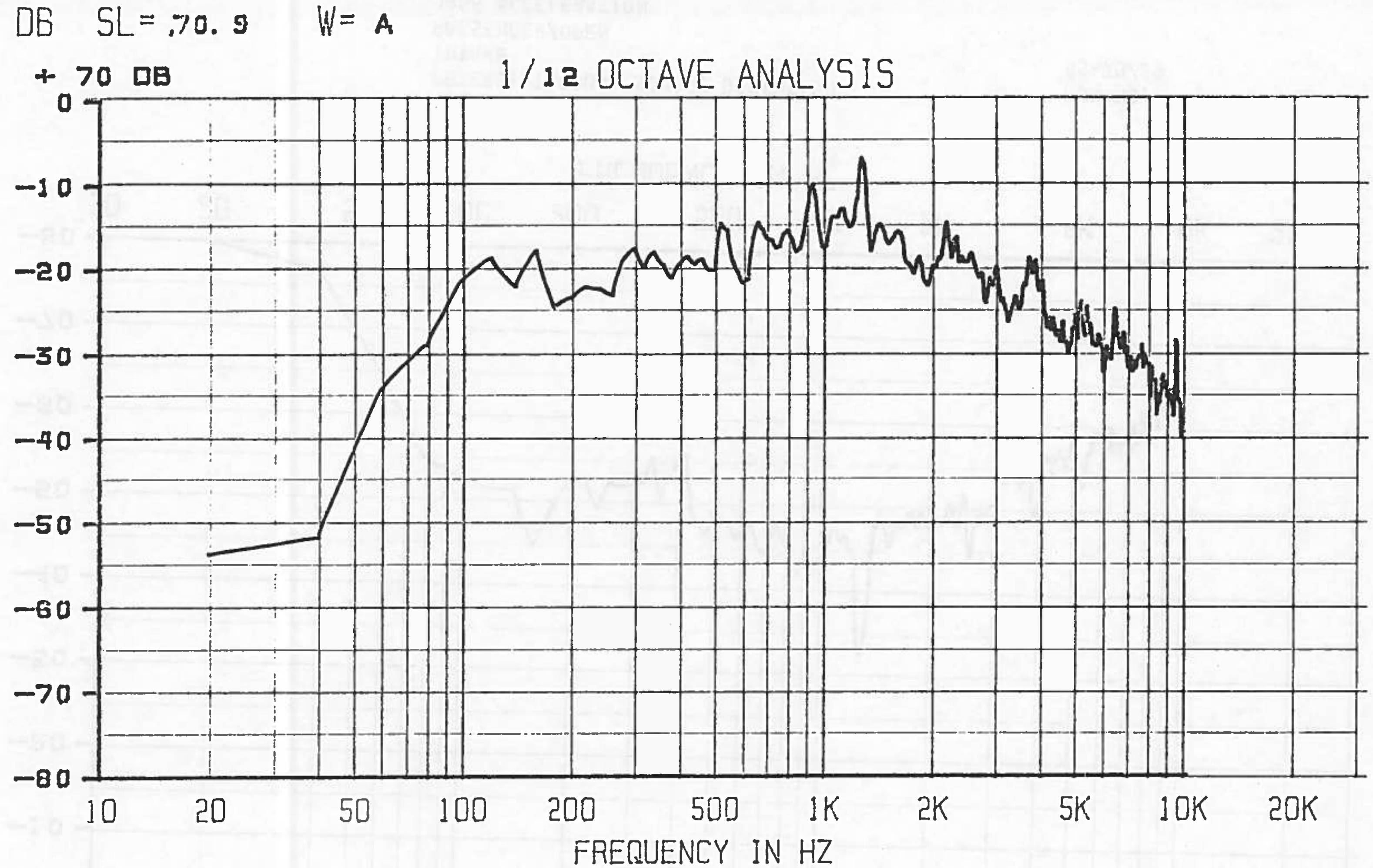
FIGURES B-1 THROUGH B-30



PETERBILT SOUND SOURCE DEFINITION
FULLY WRAPPED
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-79/10

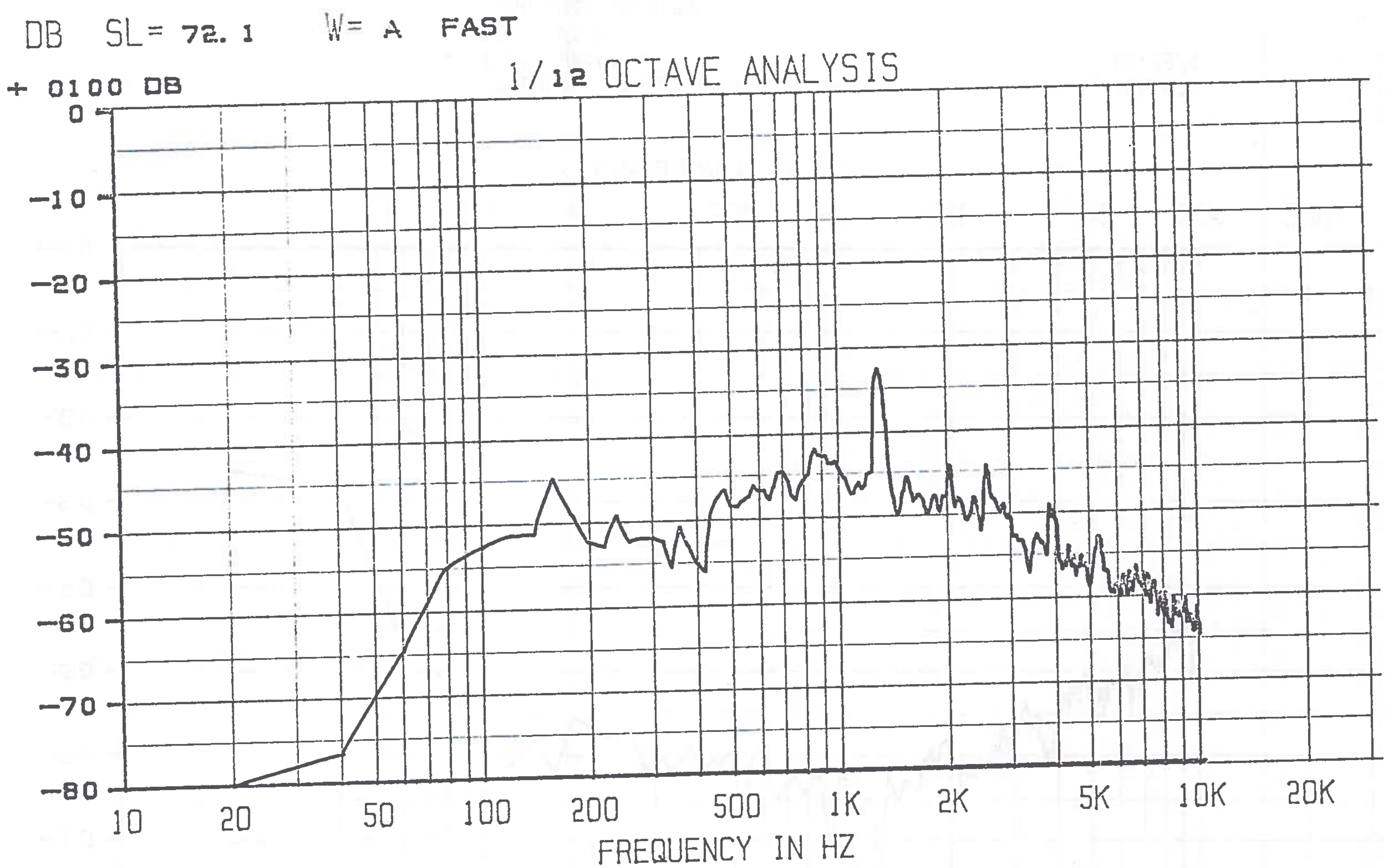
FIGURE B-1



PETERBILT SOUND SOURCE DEFINITION
FULLY WRAPPED
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-79/5

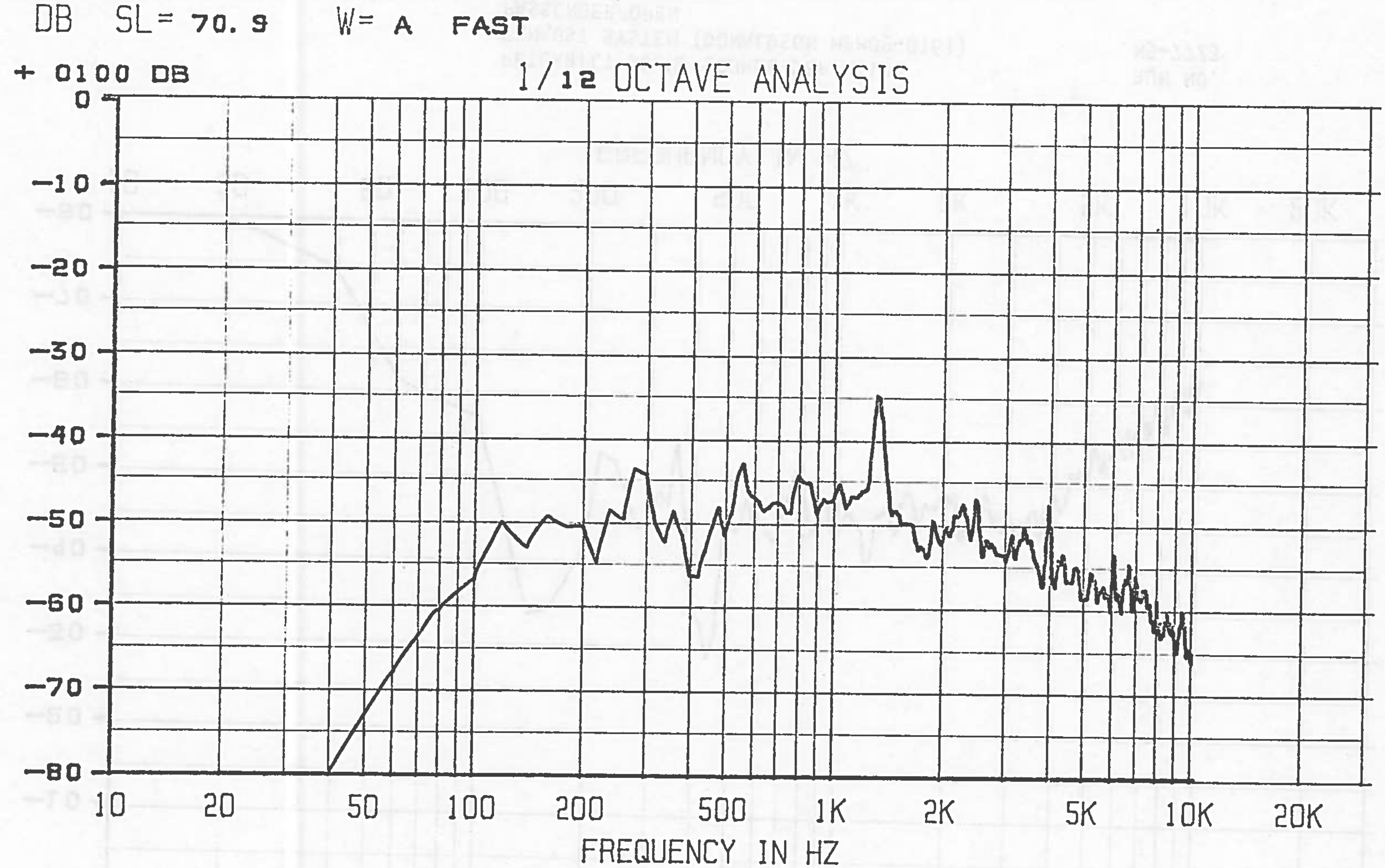
FIGURE B-2



PETERBILT SOUND SOURCE DEFINTION
INTAKE
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-79/29

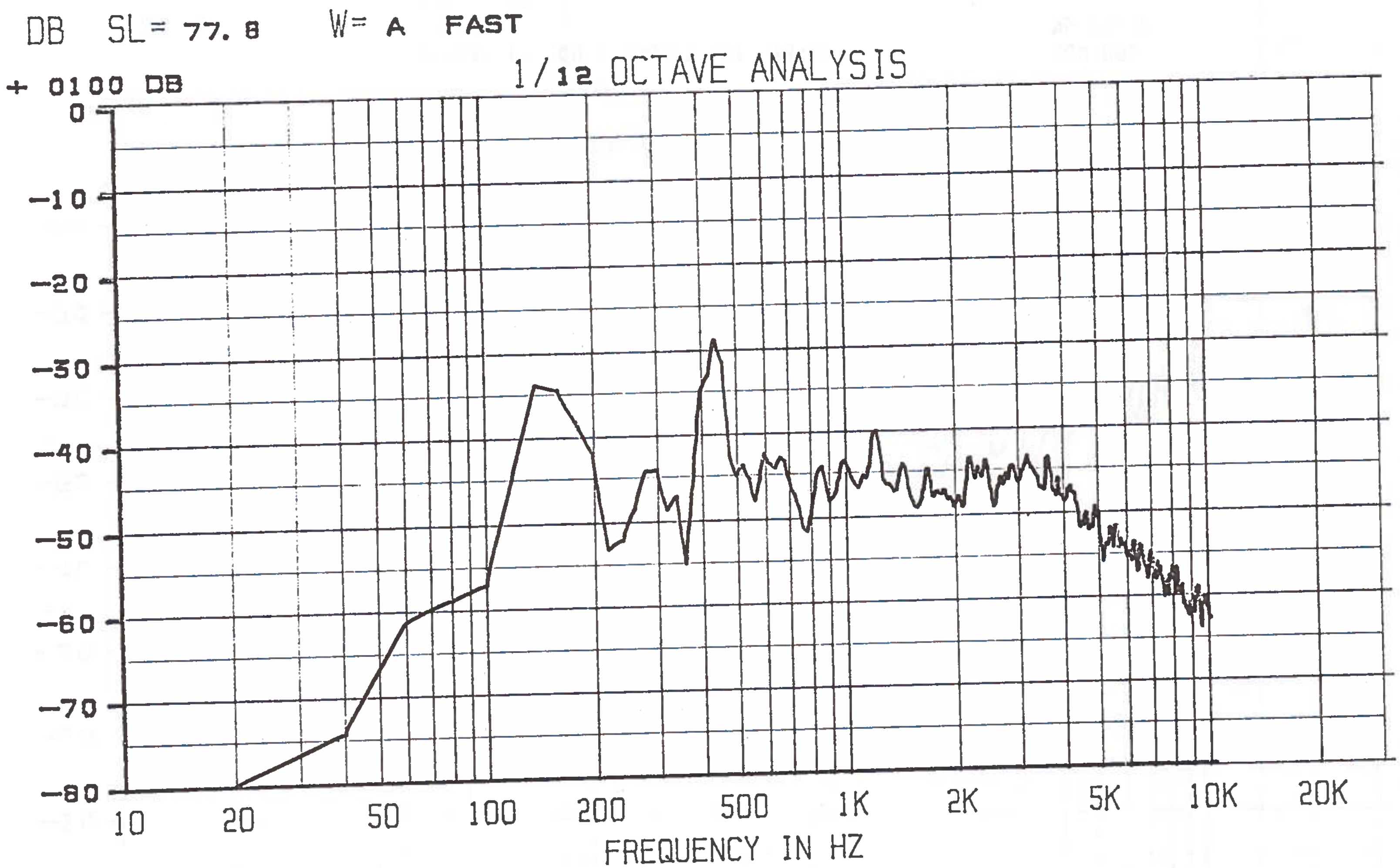
FIGURE B-3



PETERBILT SOUND SOURCE DEFINITION
INTAKE
DRIVER/OPEN
J366 ACCELERATION

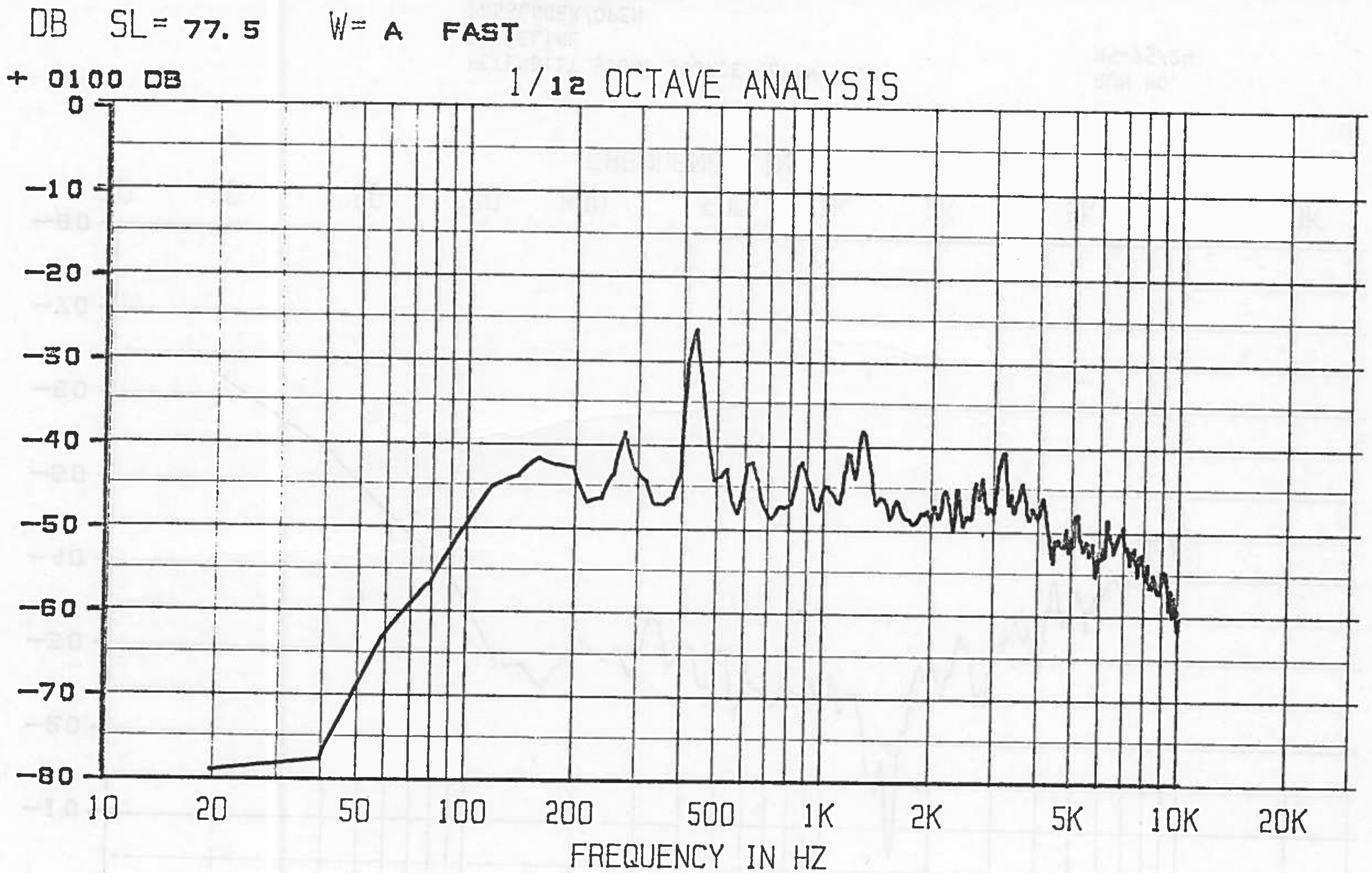
RUN NO.
N5-79/32

FIGURE B-4



PETERBILT SOUND SOURCE DEFINTION
EXHAUST SYSTEM (DONALDSON MPM09-0161)
PASSENGER/OPEN
J366 ACCELERATION

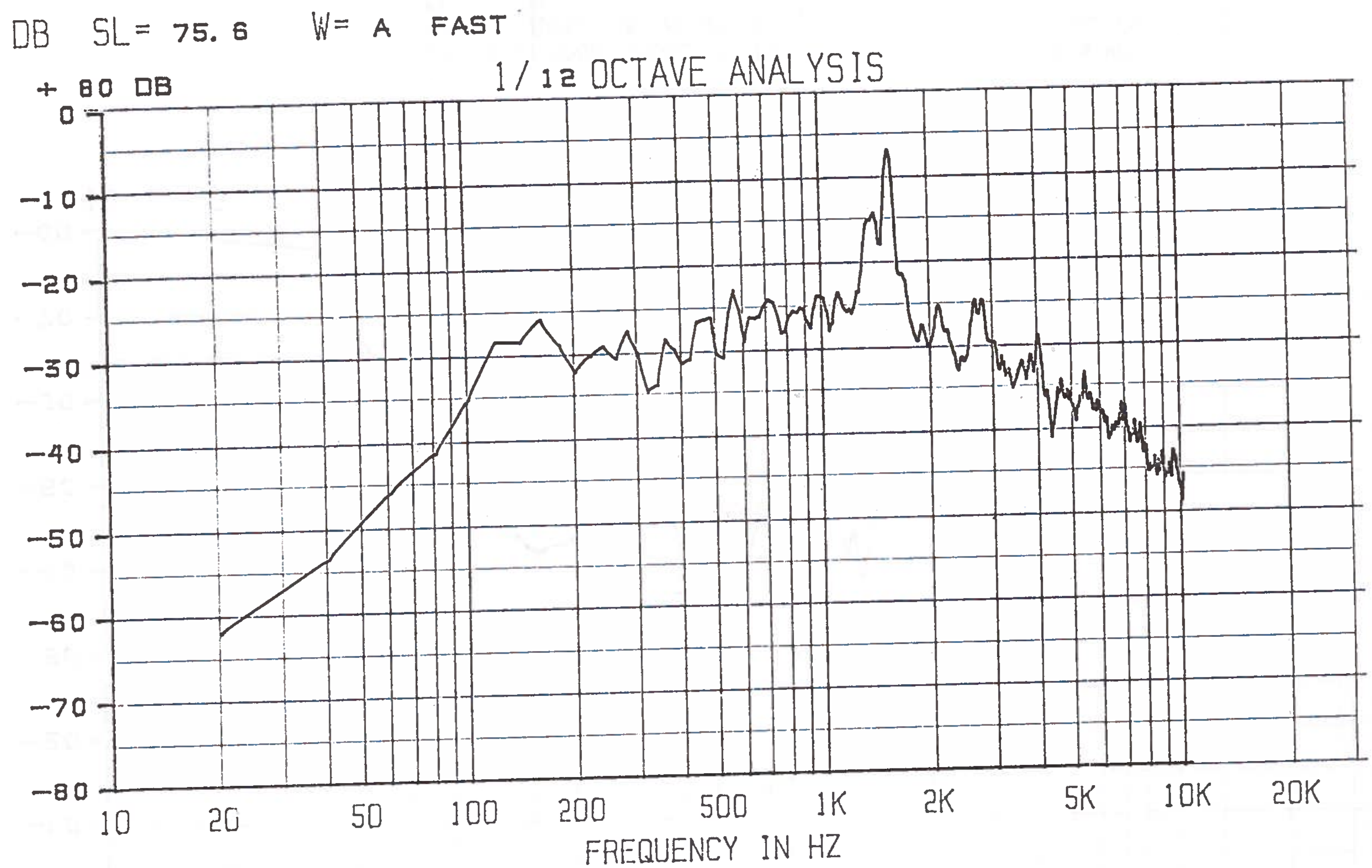
RUN NO.
N5-77/3



PETERBILT SOUND SOURCE DEFINITION
EXHAUST (DONALDSON MPM09-0161)
DRIVER/OPEN
J366 ACCELERATION

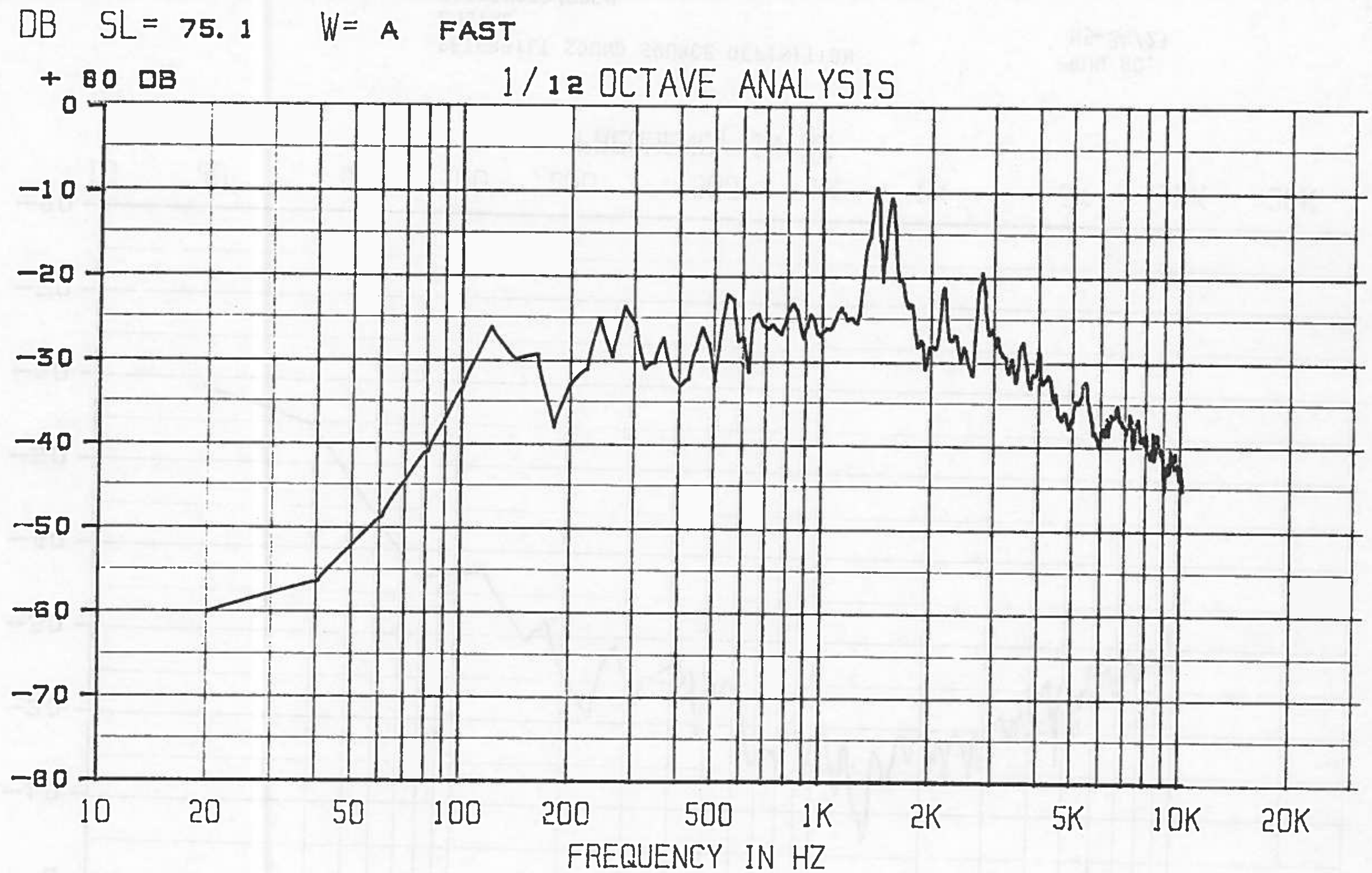
RUN NO.
N5-77/9

FIGURE B-6



PETERBILT SOUND SOURCE DEFINITION
DRIVELINE
PASSENGER/OPEN
J366 ACCELERATION

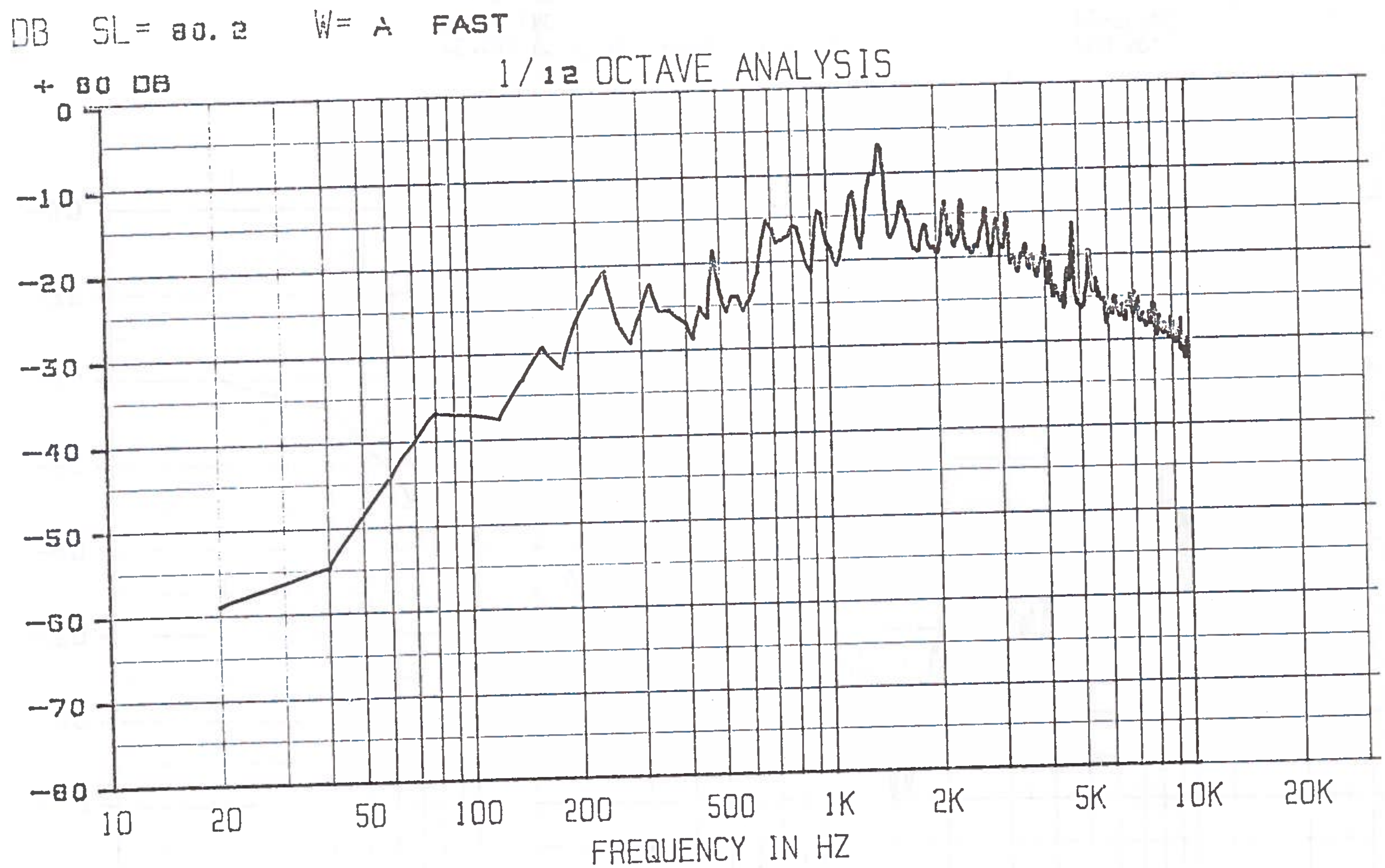
RUN NO.
N5-75/24



PETERBILT SOUND SOURCE DEFINITION
DRIVELINE
DRIVER/OPEN
J366 ACCELERATION

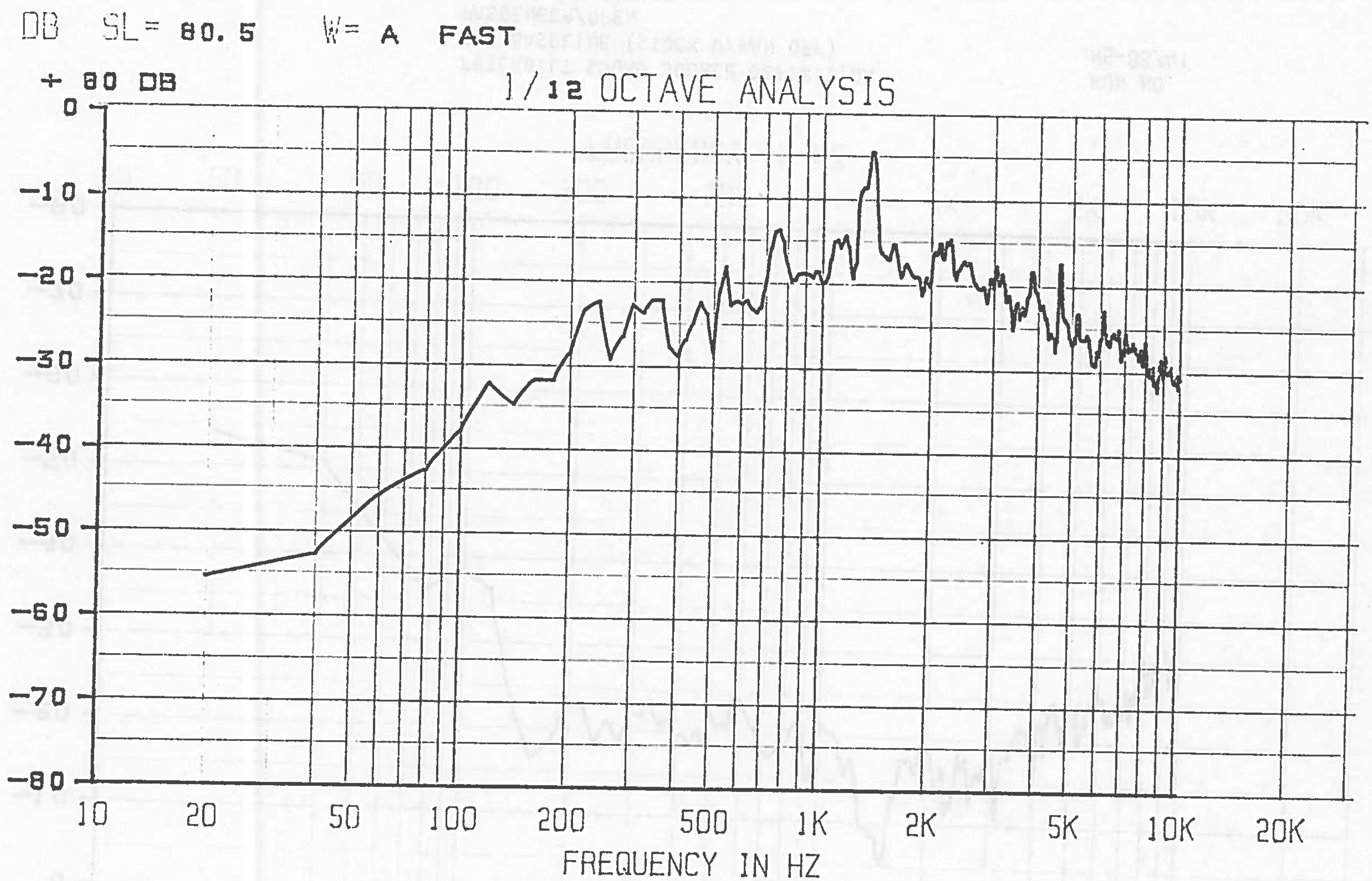
RUN NO.
N5-75/28

FIGURE B-8



PETERBILT SOUND SOURCE DEFINITION
ENGINE
PASSENGER/OPEN
J366 ACCELERATION

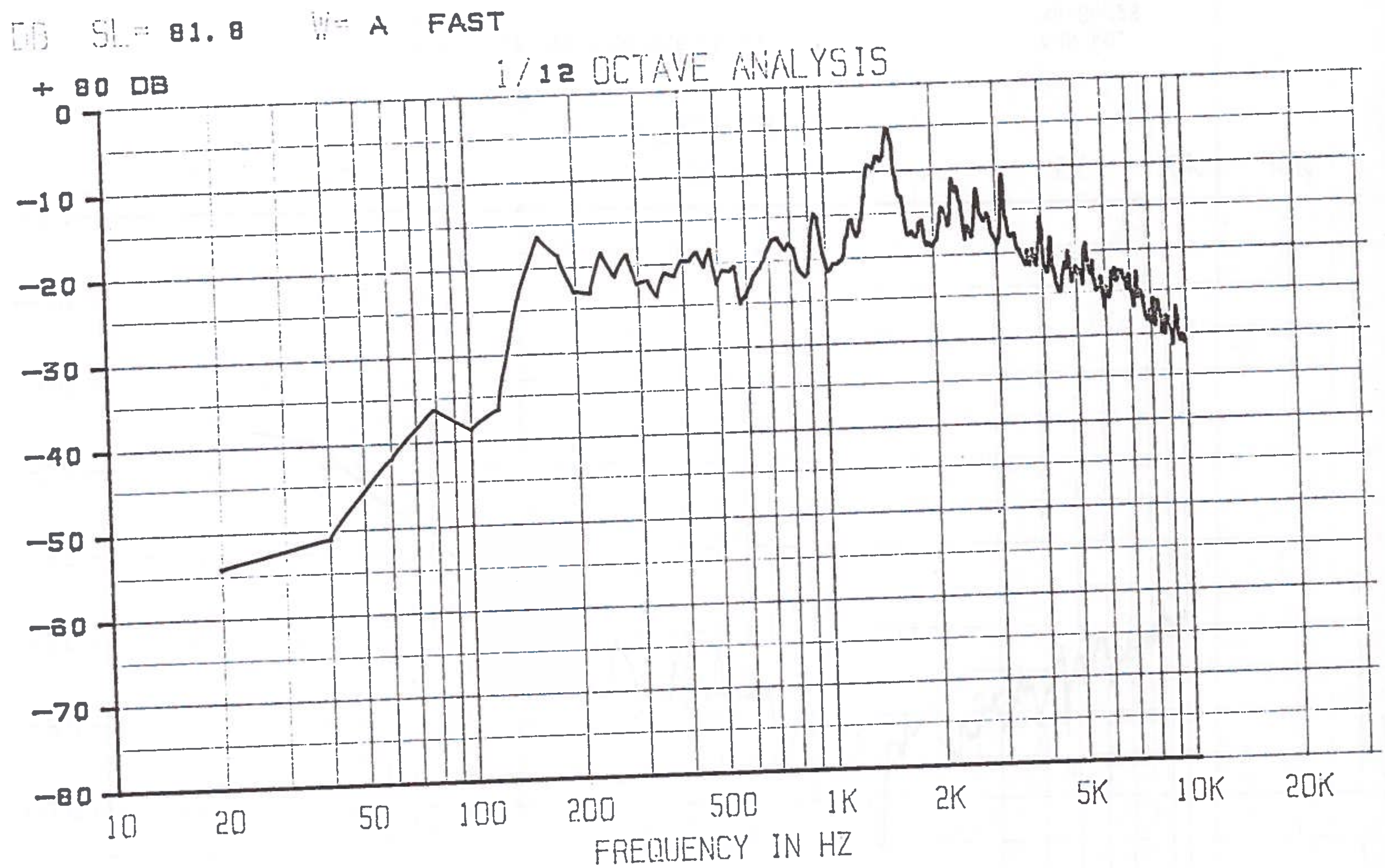
RUN NO.
N5-84/21



PETERBILT SOUND SOURCE DEFINITION
ENGINE
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-84/25

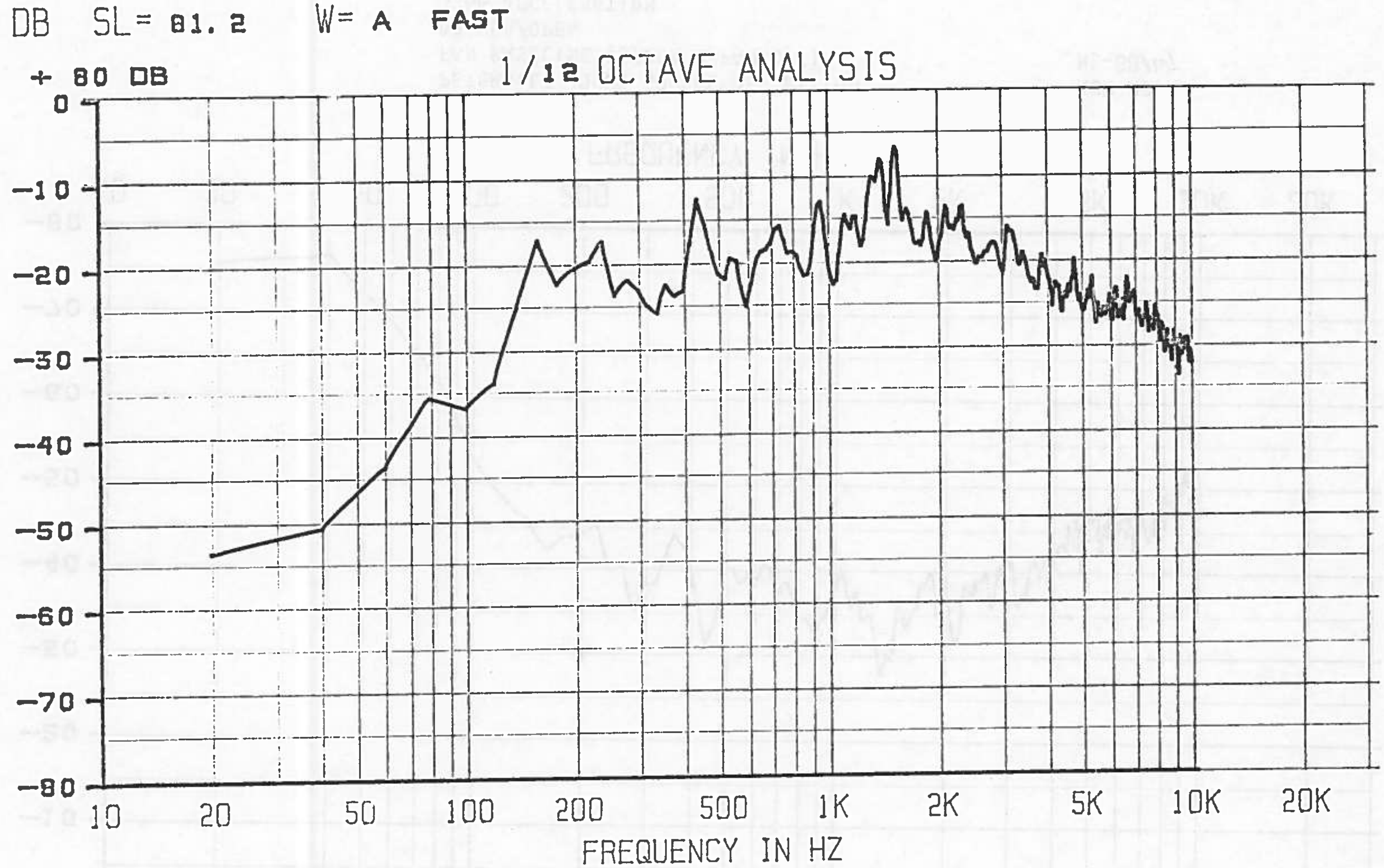
FIGURE B-10



PETERBILT SOUND SOURCE DEFINITION
FAN BASELINE (STOCK W/FAN OFF)
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-88/41

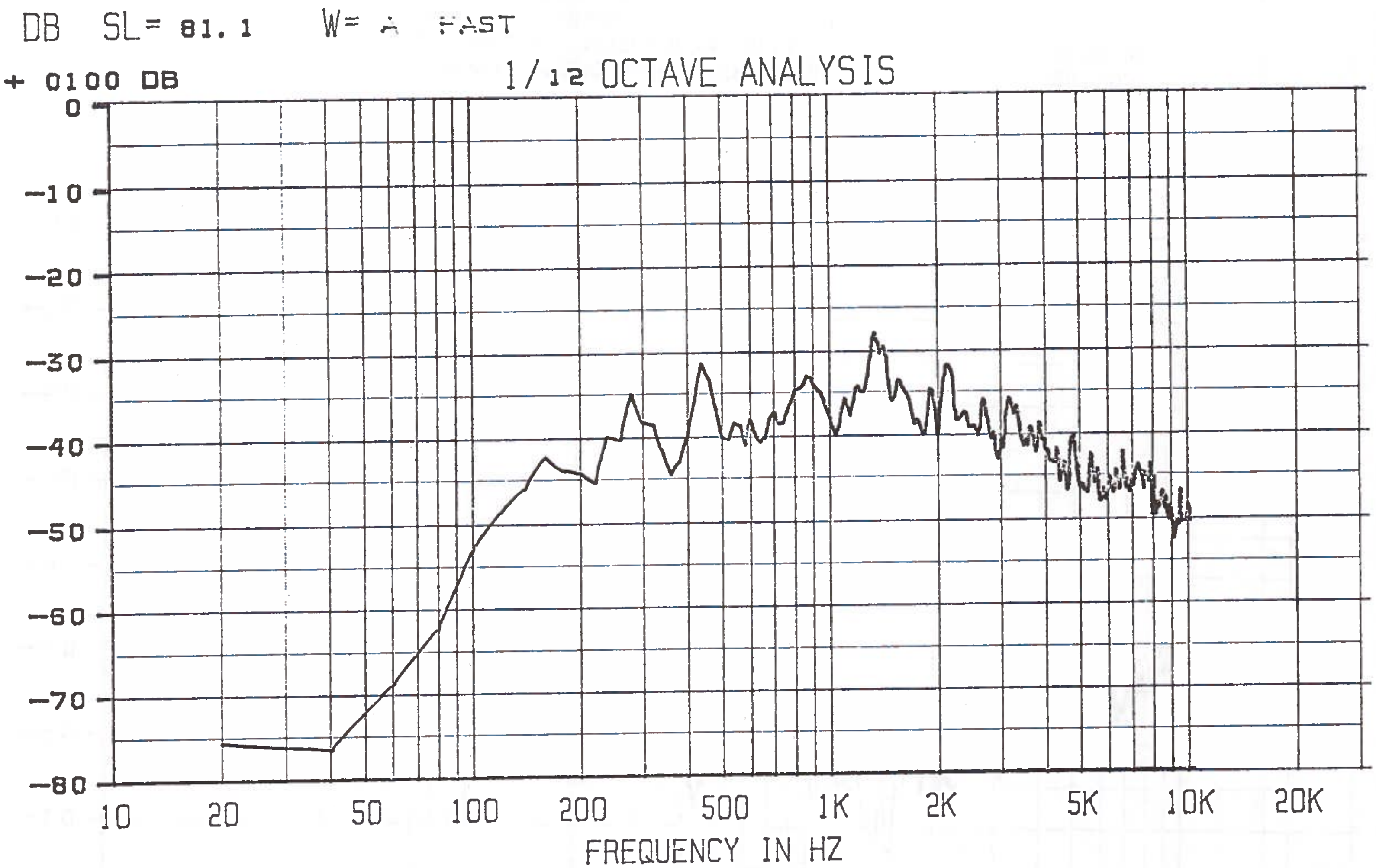
FIGURE B-11



PETERBILT SOUND SOURCE DEFINITION
FAN BASELINE (STOCK W/FAN OFF)
PASSENGER/CLOSED
J366 ACCELERATION

RUN NO.
N5-88/45

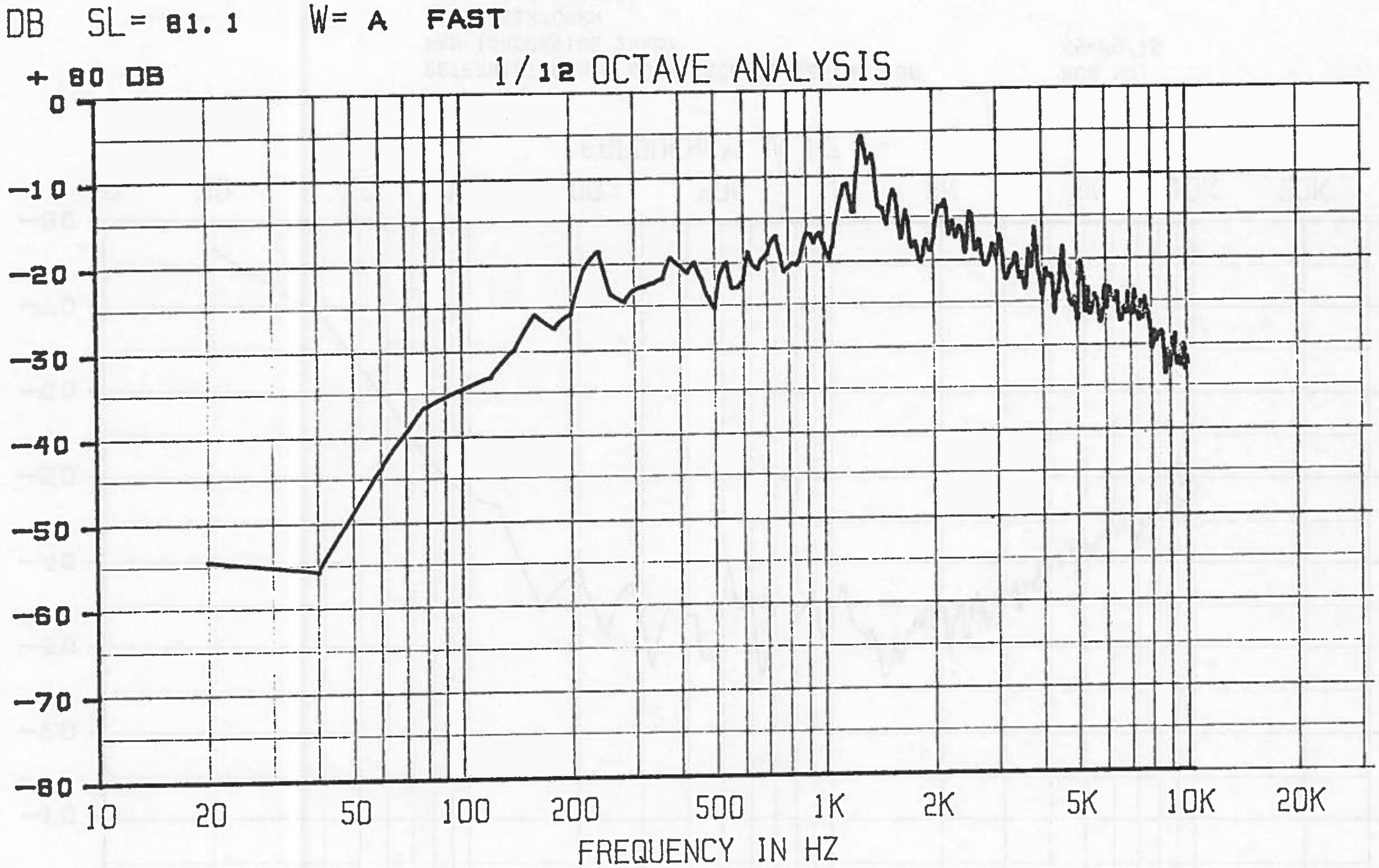
FIGURE B-12



PETERBILT SOUND SOURCE DEFINITION
FAN BASELINE (STOCK W/FAN OFF)
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-88/47

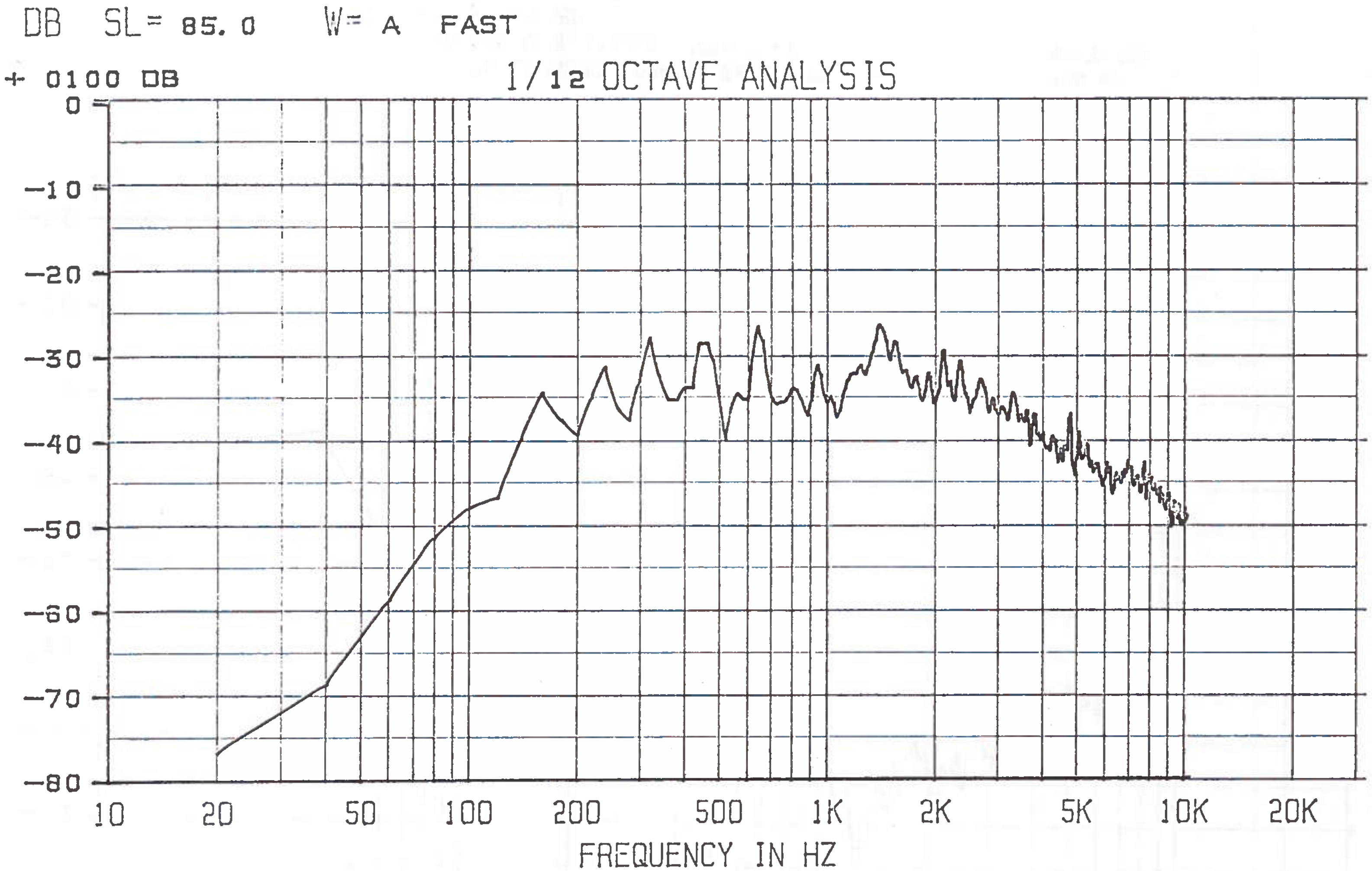
FIGURE B-13



PETERBILT SOUND SOURCE DEFINITION
FAN BASELINE (STOCK W/FAN OFF)
DRIVER/CLOSED
J366 ACCELERATION

RUN NO.
N5-88/50

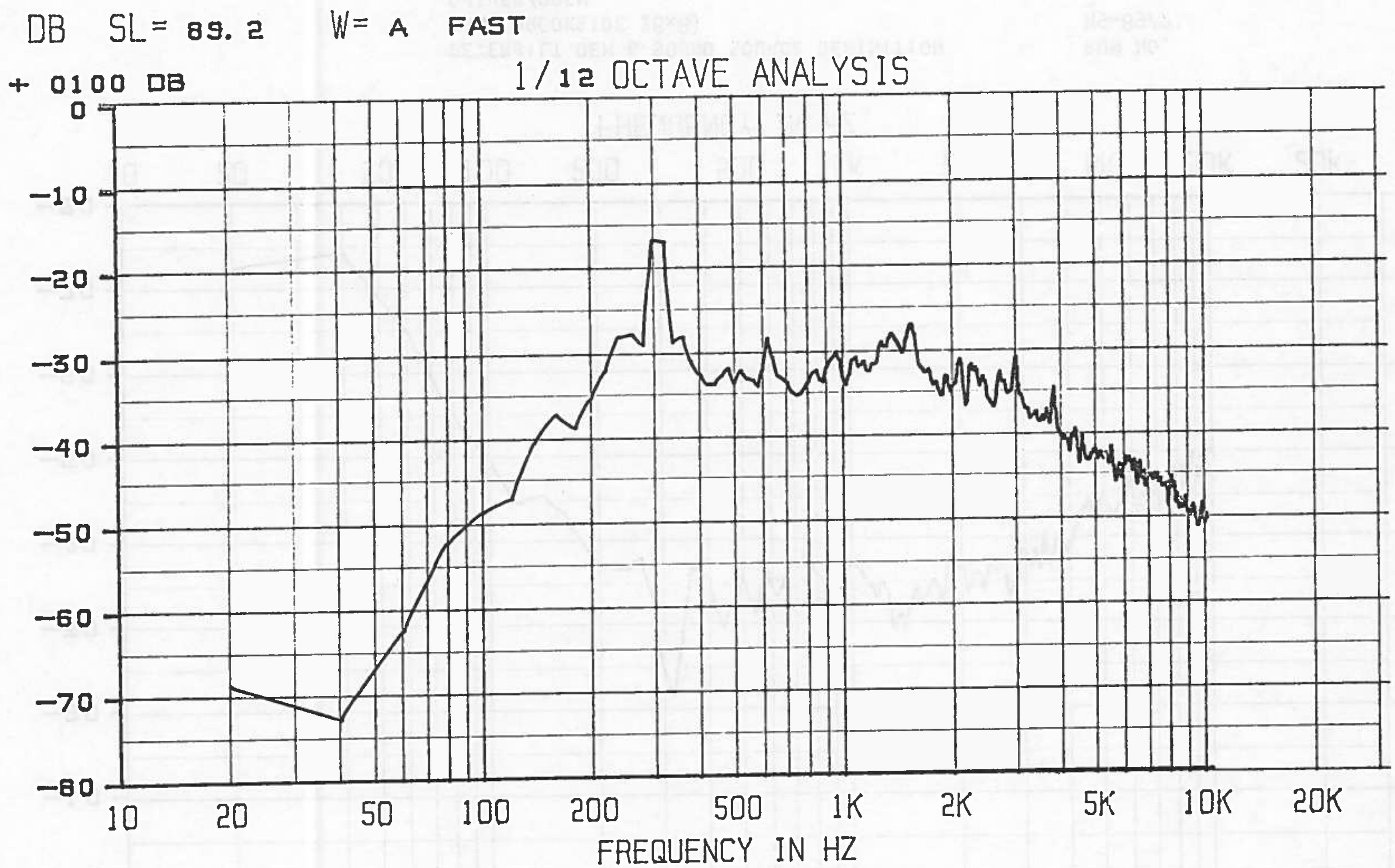
FIGURE B-14



PETERBILT OEM & SOUND SOURCE DEFINITION
FAN (BROOKSIDE 28x8)
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-89/15

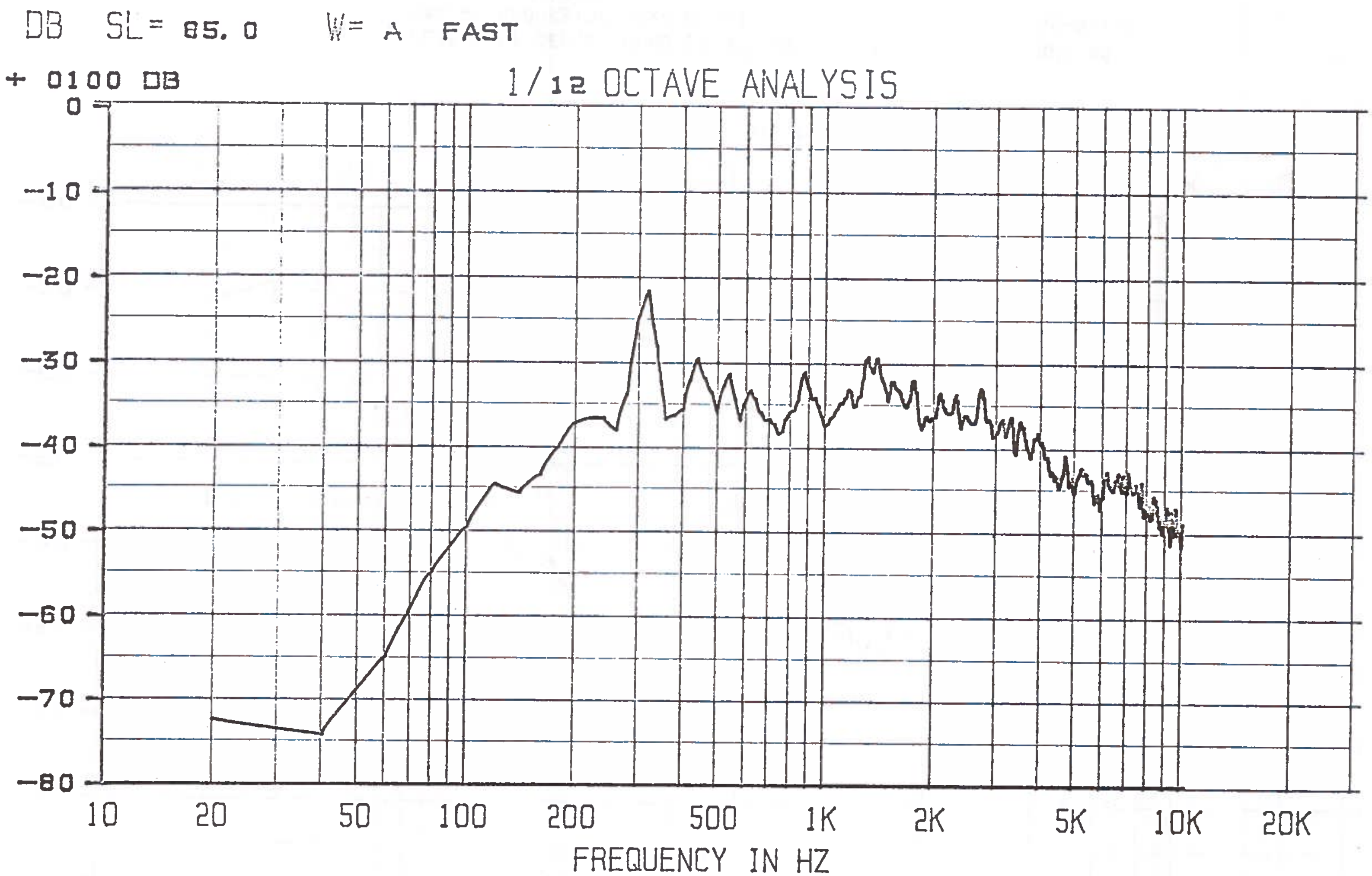
FIGURE B-15



PETERBILT OEM & SOUND SOURCE DEFINITION
FAN -- BROOKSIDE 28x8 @ 1:1
PASSENGER/CLOSED
J366 ACCELERATION

RUN NO.
N5-89/18

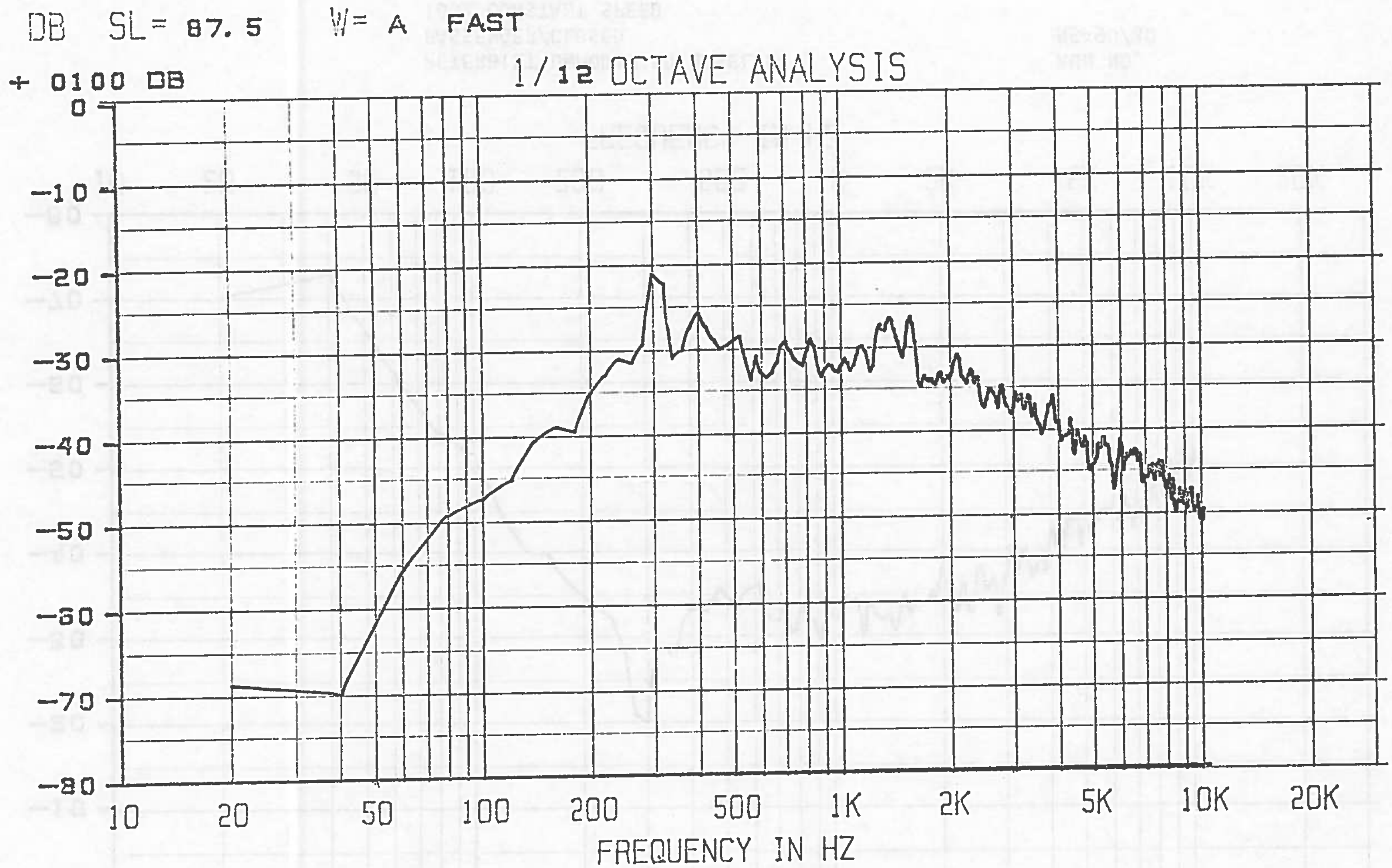
FIGURE B-16



PETERBILT OEM & SOUND SOURCE DEFINITION
FAN (BROOKSIDE 28x8)
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-89/2'

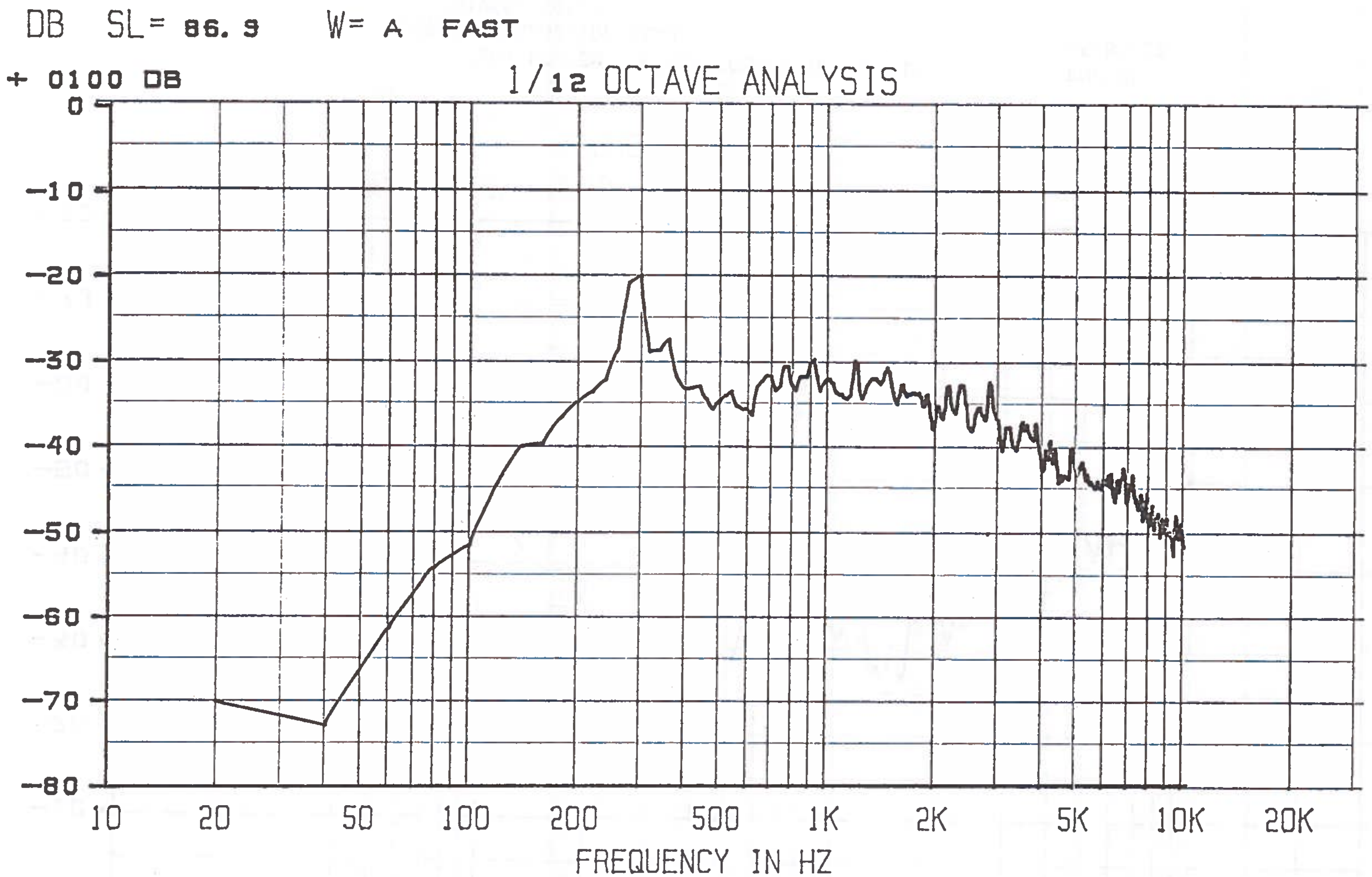
FIGURE B-17



PETERBILT OEM & SOUND SOURCE DEFINITION
FAN (BROOKSIDE 28x8)
DRIVER/CLOSED
J366 ACCELERATION

RUN NO.
N5-89/22

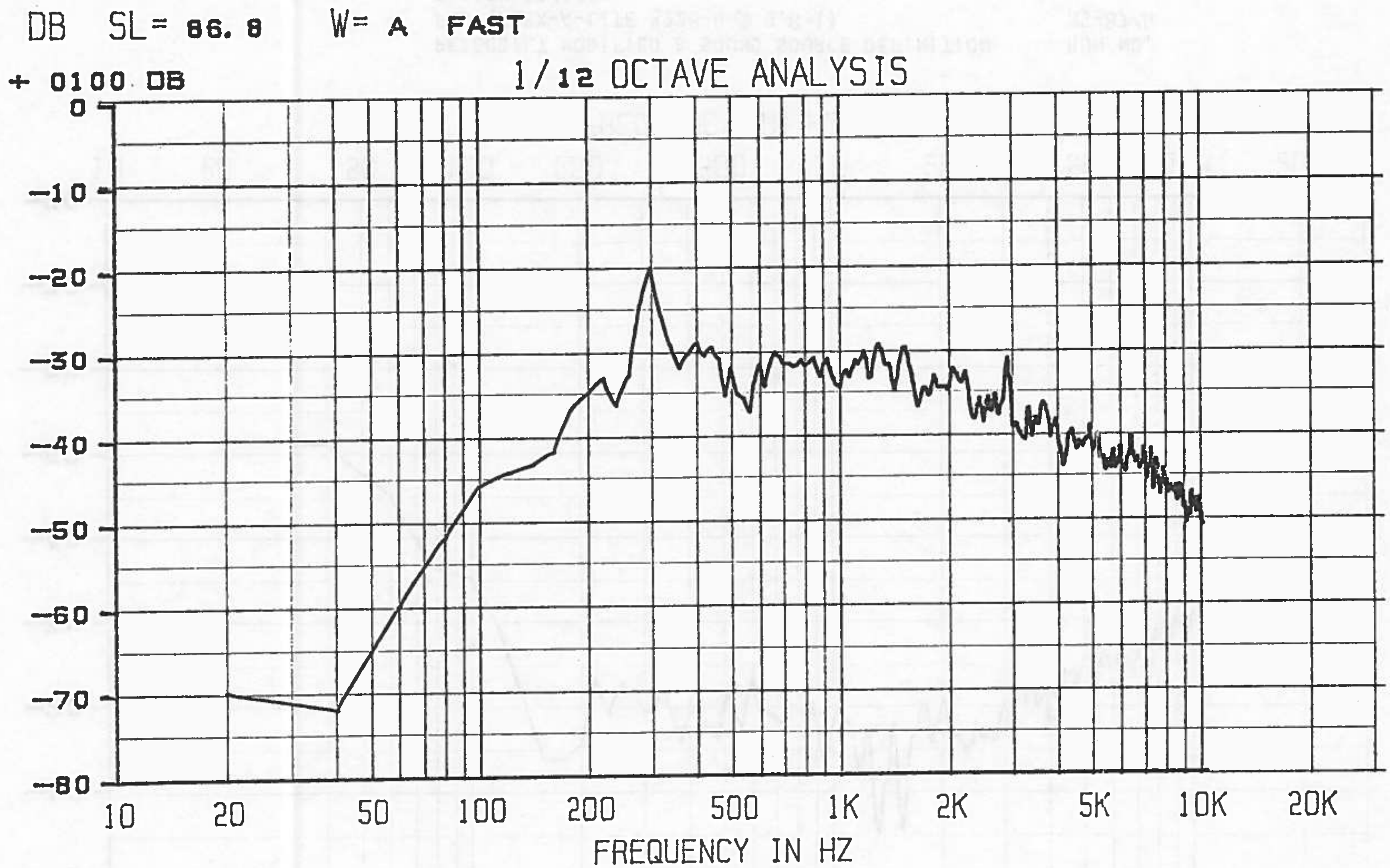
FIGURE B-18



PETERBILT UNMODIFIED BASELINE
PASSENGER/CLOSED
100% CONSTANT SPEED

RUN NO.
N5-90/30

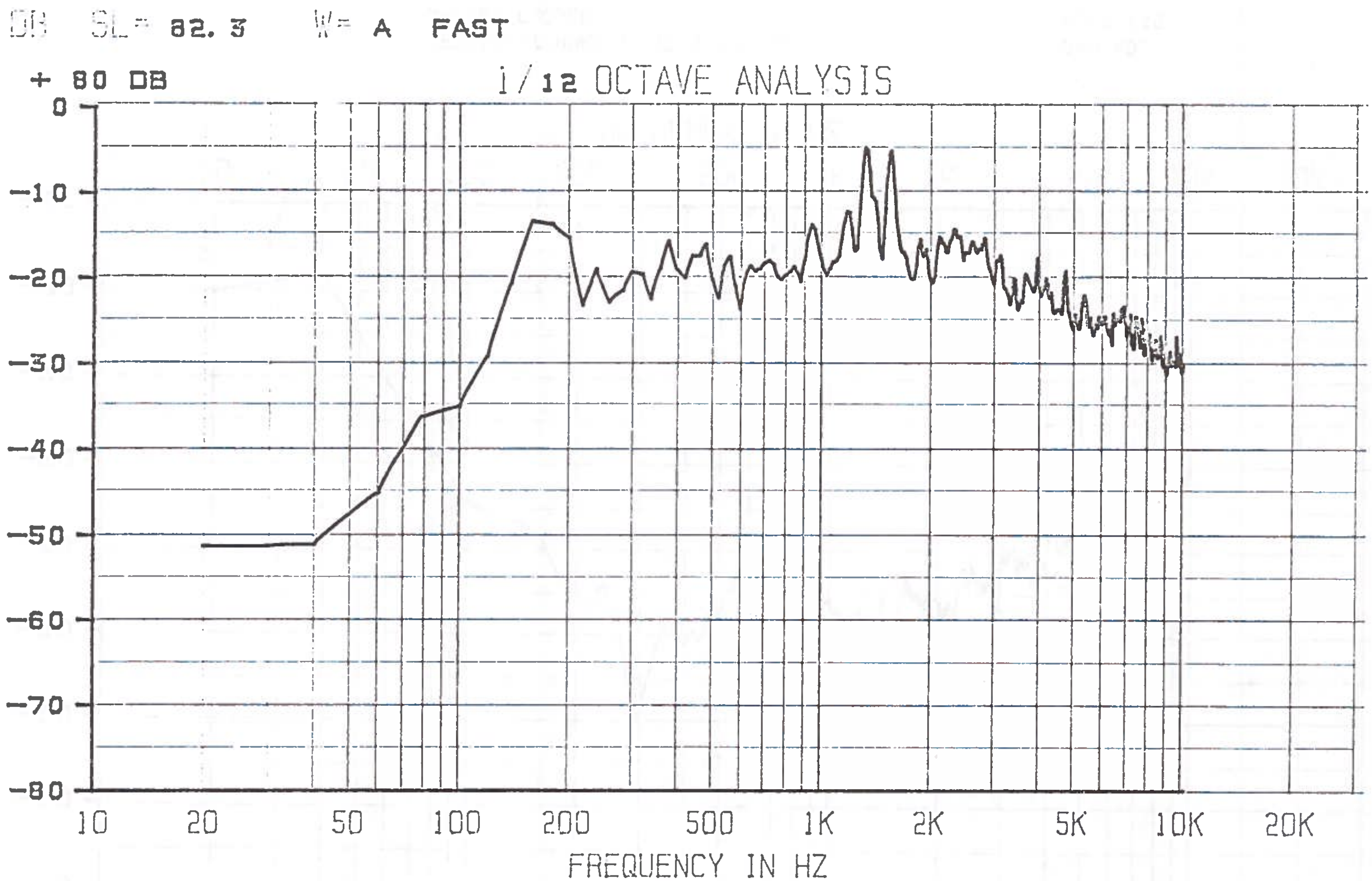
FIGURE B-19



PETERBILT UNMODIFIED BASELINE
DRIVER/CLOSED
100% CONSTANT SPEED

RUN NO.
N5-90/35

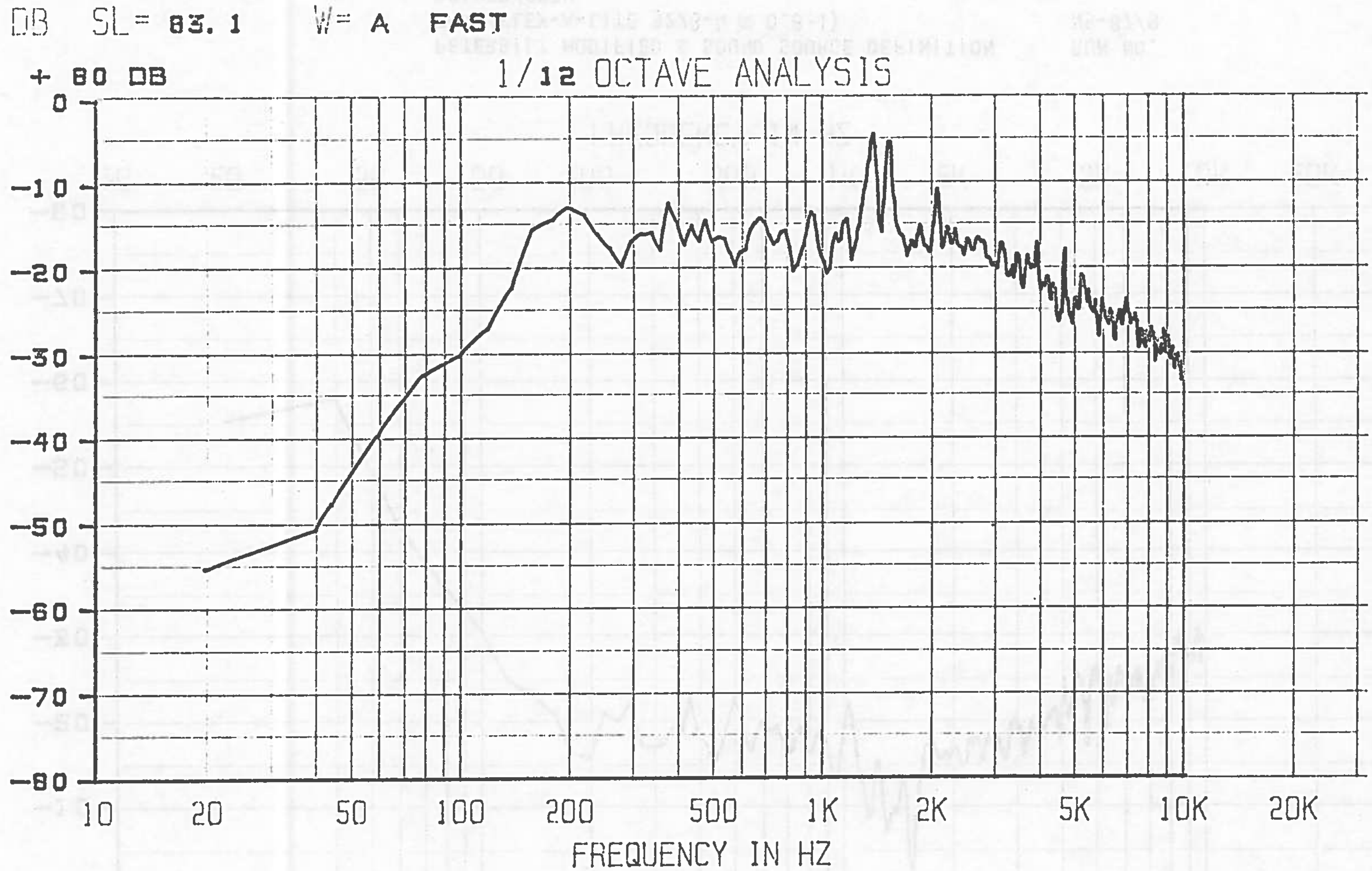
FIGURE B-20



PETERBILT MODIFIED & SOUND SOURCE DEFINITION
FAN (FLEX-A-LITE 3228-4 @ 0.8:1)
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-87/4

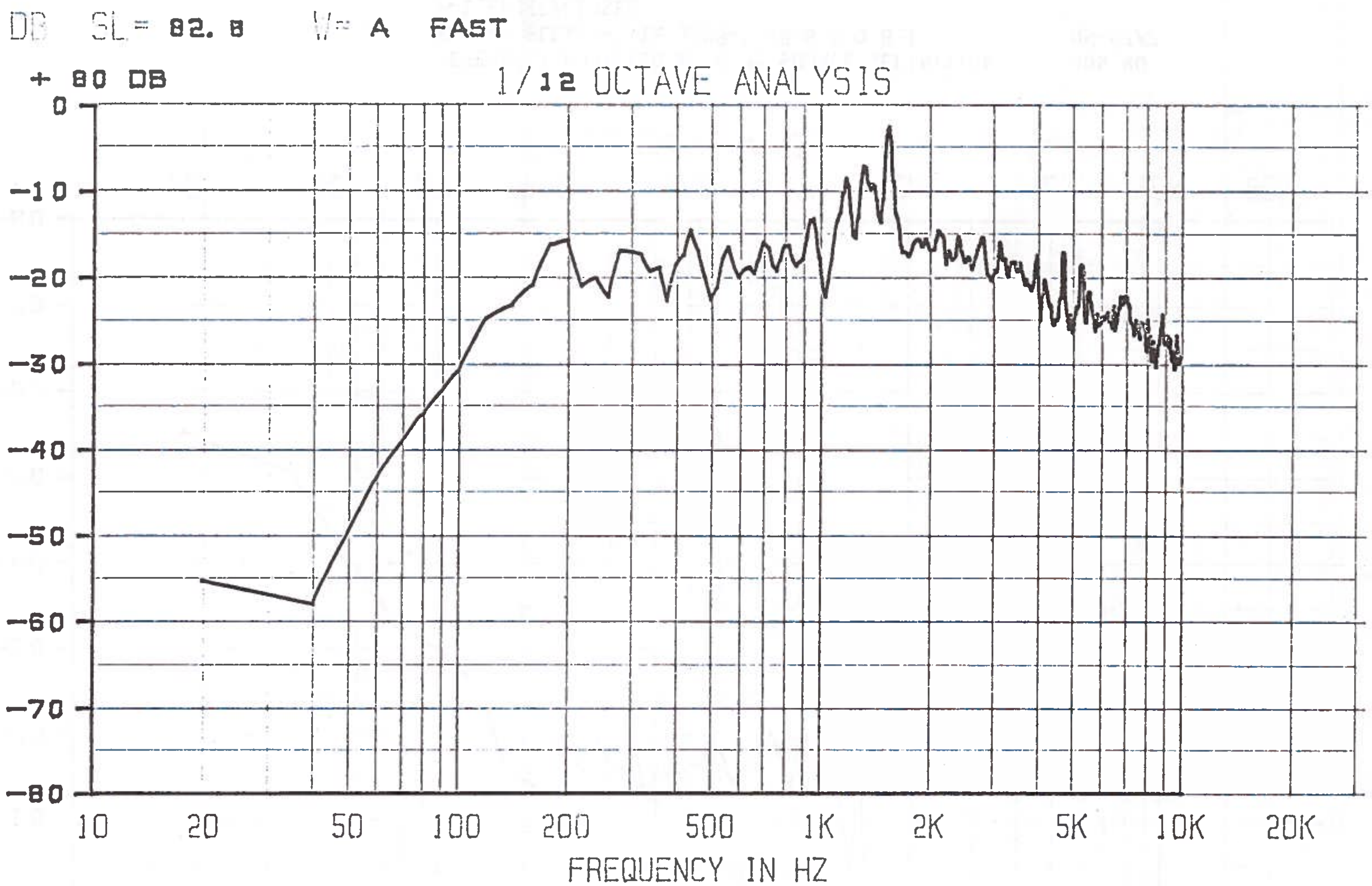
FIGURE B-21



PETERBILT MODIFIED & SOUND SOURCE DEFINITION
FAN -- FLEX-A-LITE 3228-4 28x6 @ 0.8:1
PASSENGER/CLOSED
J366 ACCELERATION

RUN NO.
N5-87/7

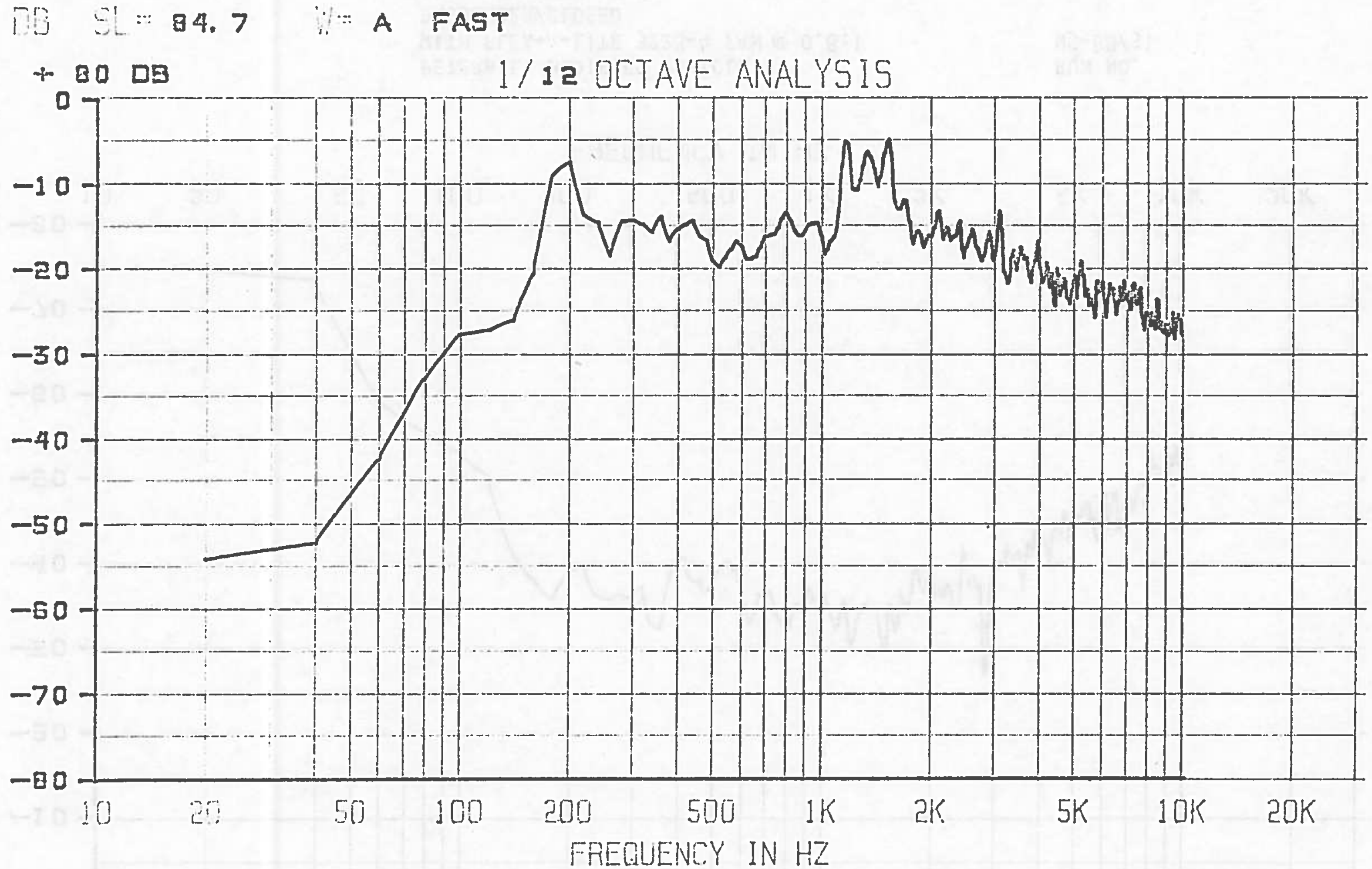
FIGURE B-22



PETERBILT MODIFIED & SOUND SOURCE DEFINITION
FAN (FLEX-A-LITE 3228-4 @ 0.8:1)
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-87/9

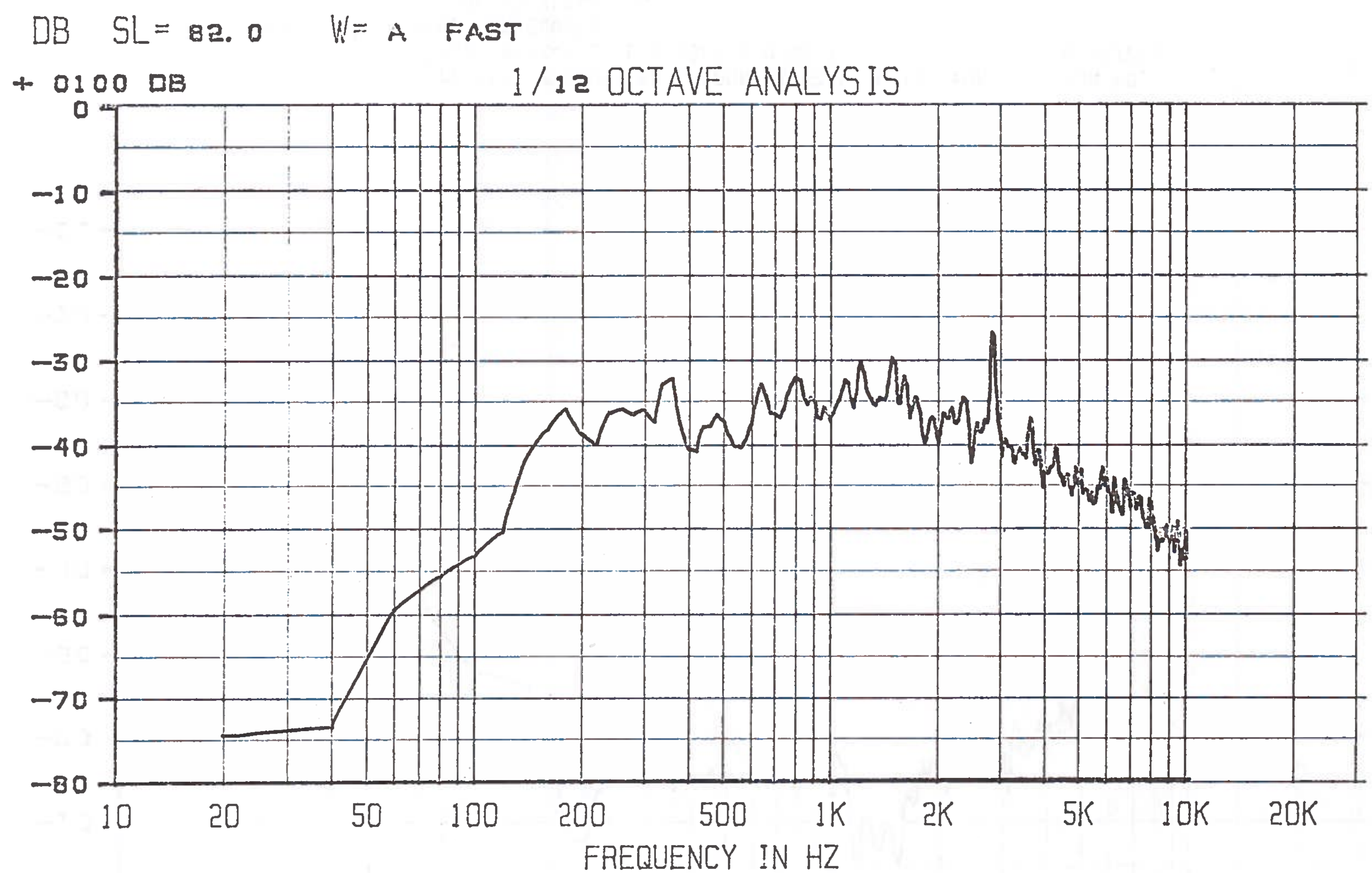
FIGURE B-23



PETERBILT MODIFIED & SOUND SOURCE DEFINITION
FAN (FLEX-A-LITE 3228-4 @ 0.8:1)
DRIVER/CLOSED
J366 ACCELERATION

RUN NO.
N5-87/13

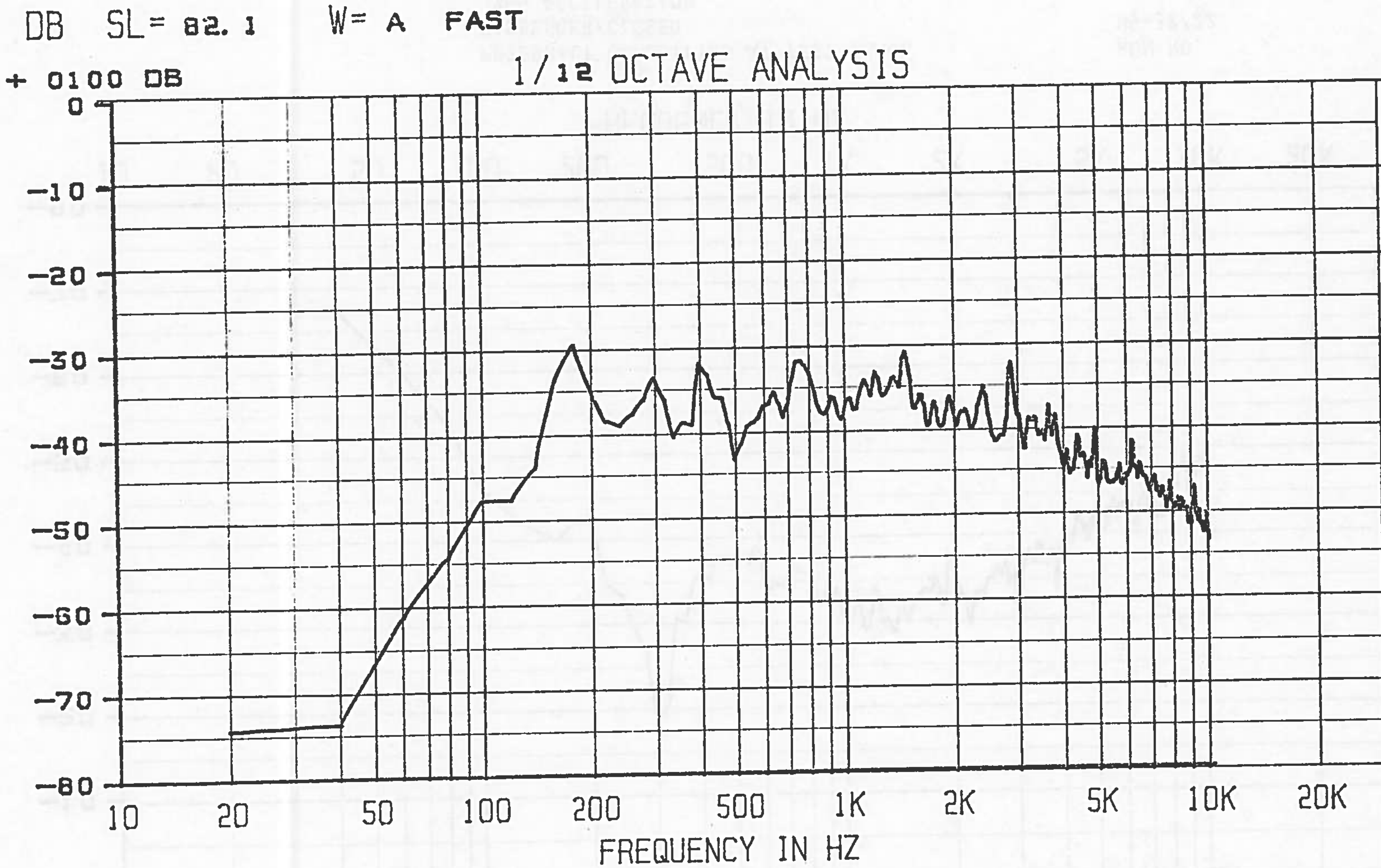
FIGURE B-24



PETERBILT MODIFIED VEHICLE
WITH FLEX-A-LITE 3228-4 FAN @ 0.8:1
PASSENGER/CLOSED
100% CONSTANT SPEED

RUN NO.
N5-88/31

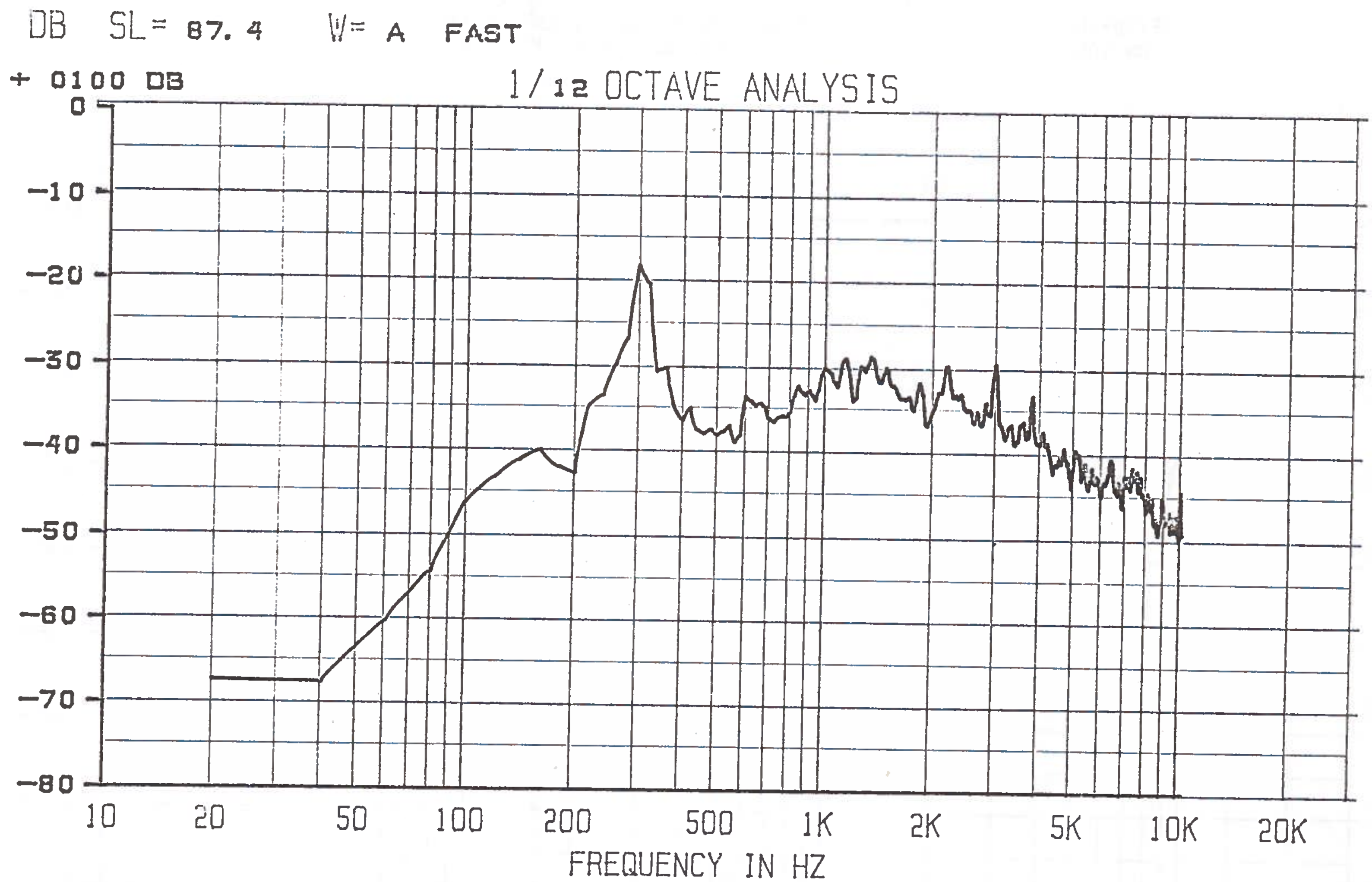
FIGURE B-25



PETERBILT MODIFIED VEHICLE
WITH FLEX-A-LITE 3228-4 FAN @ 0.8:1
DRIVER/CLOSED
100% CONSTANT SPEED

RUN NO.
N5-88/36

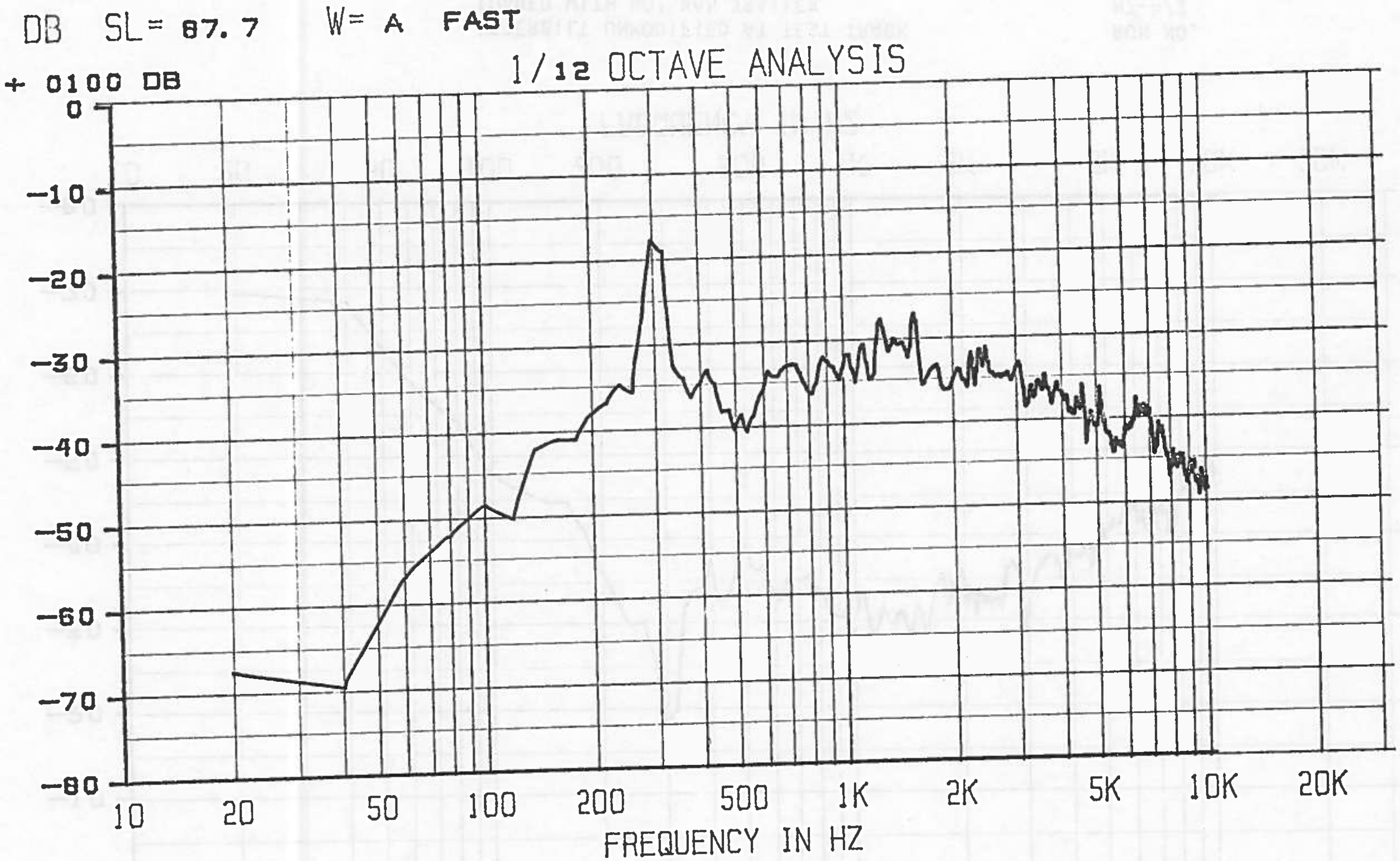
FIGURE B-26



PETERBILT UNMODIFIED AT TEST TRACK
PASSENGER/CLOSED
J366 ACCELERATION

RUN NO.
N5-32/22

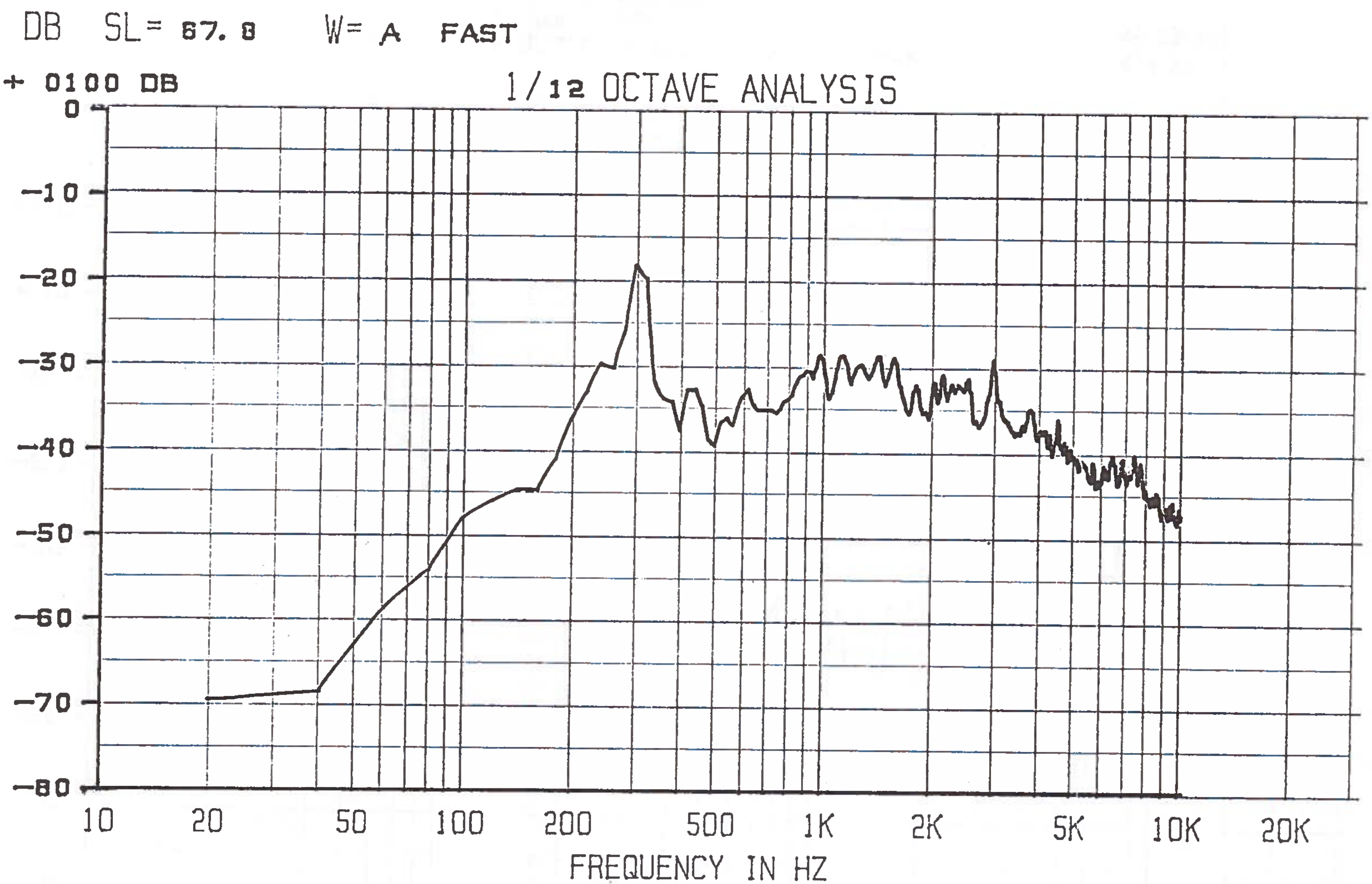
FIGURE B-27



PETERBILT UNMODIFIED AT TEST TRACK
DRIVER/CLOSED
J366 ACCELERATION

RUN NO.
N5-29/22

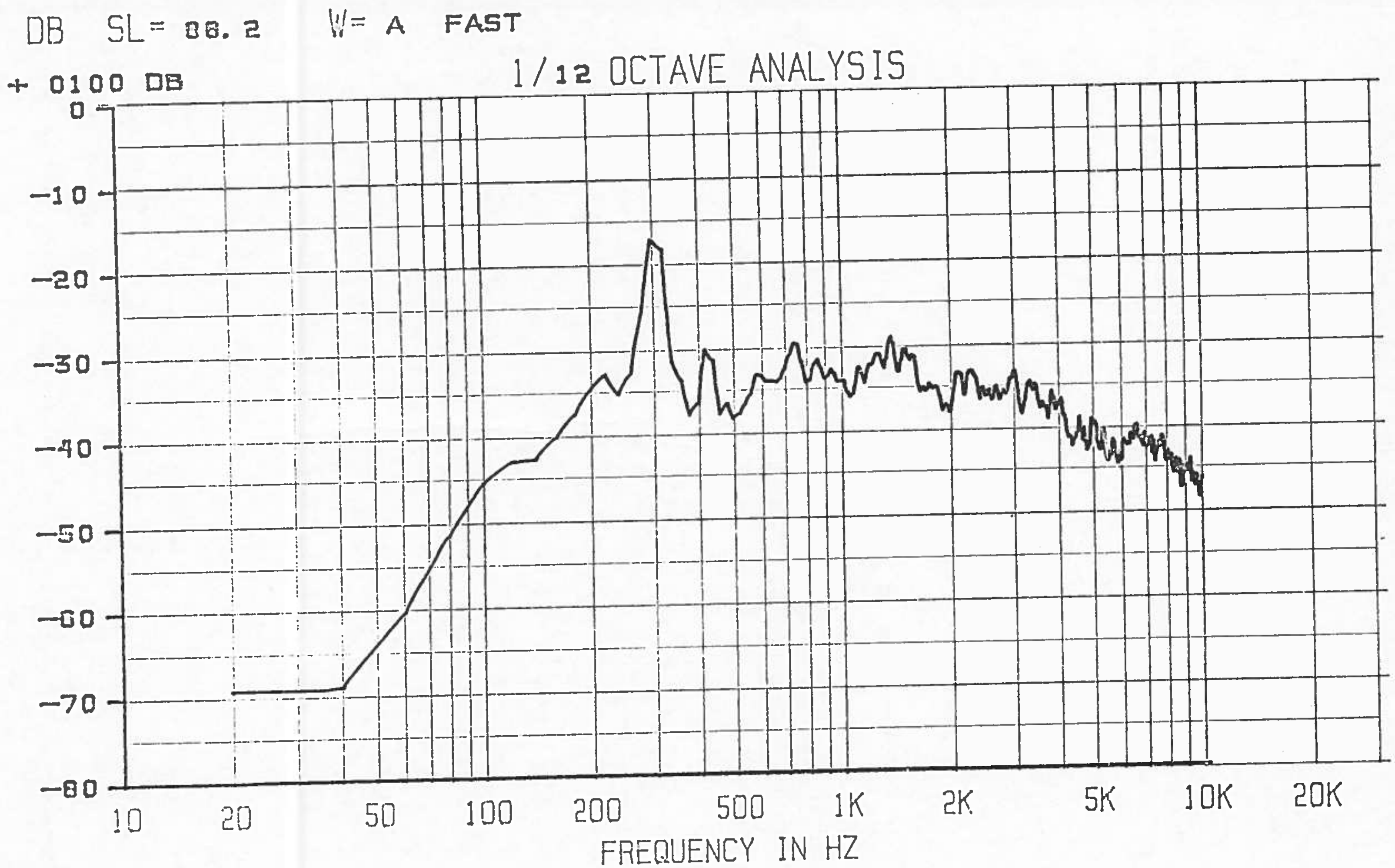
FIGURE B-28



PETERBILT UNMODIFIED AT TEST TRACK
LOADED WITH 40' VAN TRAILER
PASSENGER/CLOSED
J366 ACCELERATION

RUN NO.
N7-4/2

FIGURE B-29



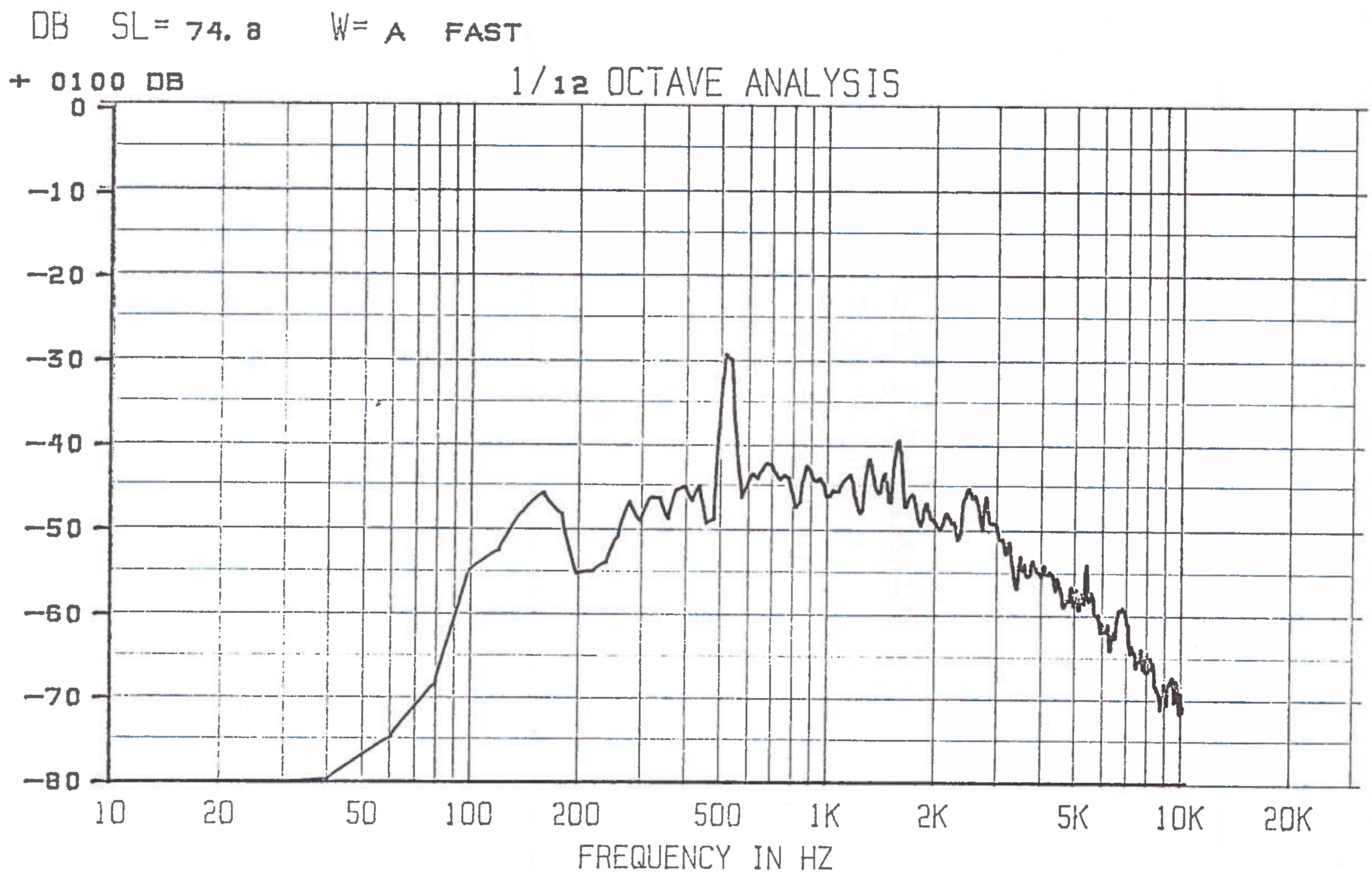
PETERBILT UNMODIFIED AT TEST TRACK
LOADED WITH 40'VAN TRAILER
DRIVER/CLOSED
J366 ACCELERATION

RUN NO.
N7-6/1

FIGURE B-30

APPENDIX C

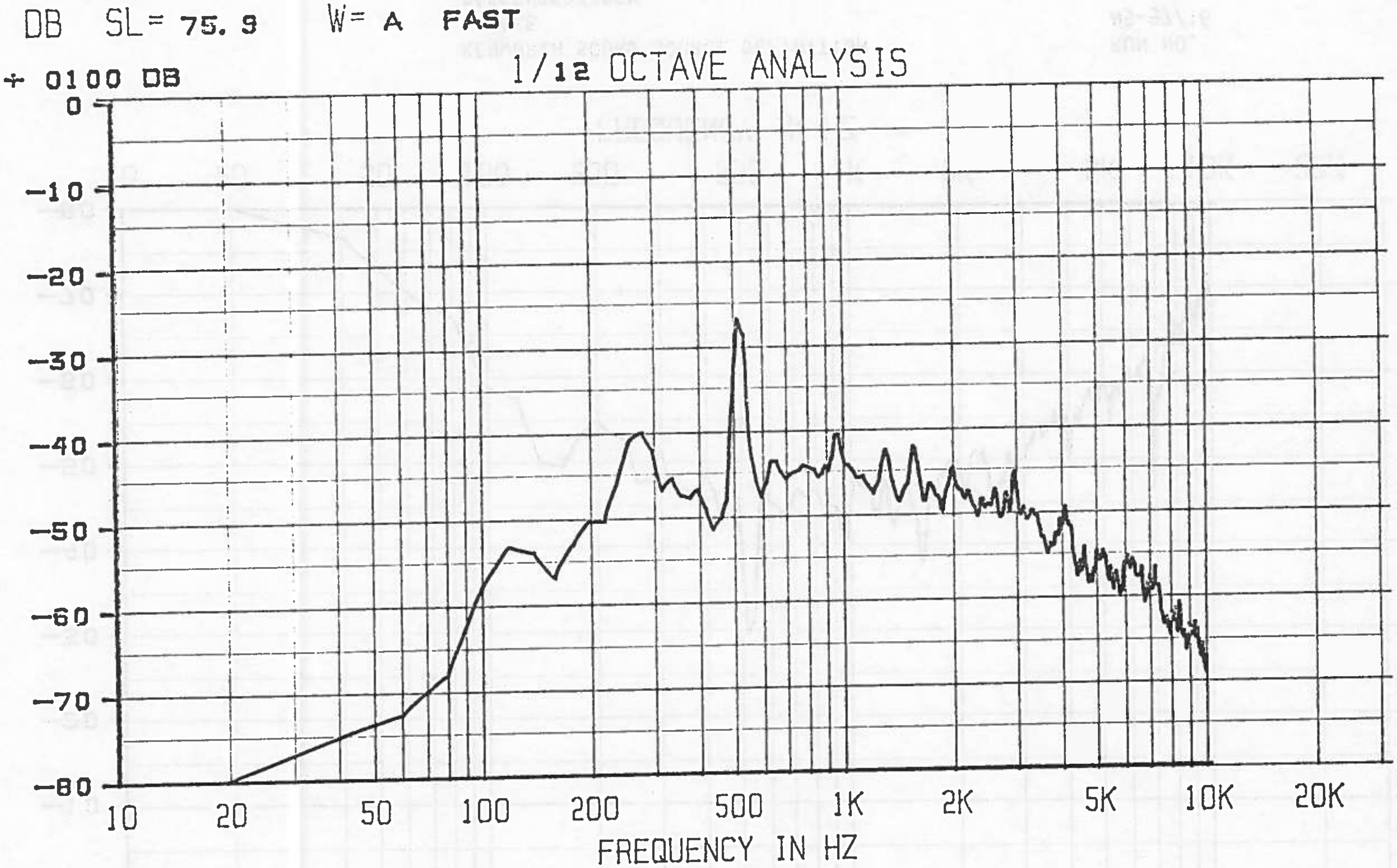
SPECTRAL ANALYSES OF MEASUREMENTS, KENWORTH, MODEL K-125, FIGURES C-1 THROUGH C-24



KENWORTH SOUND SOURCE DEFINITION
FULLY WRAPPED
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-96/14

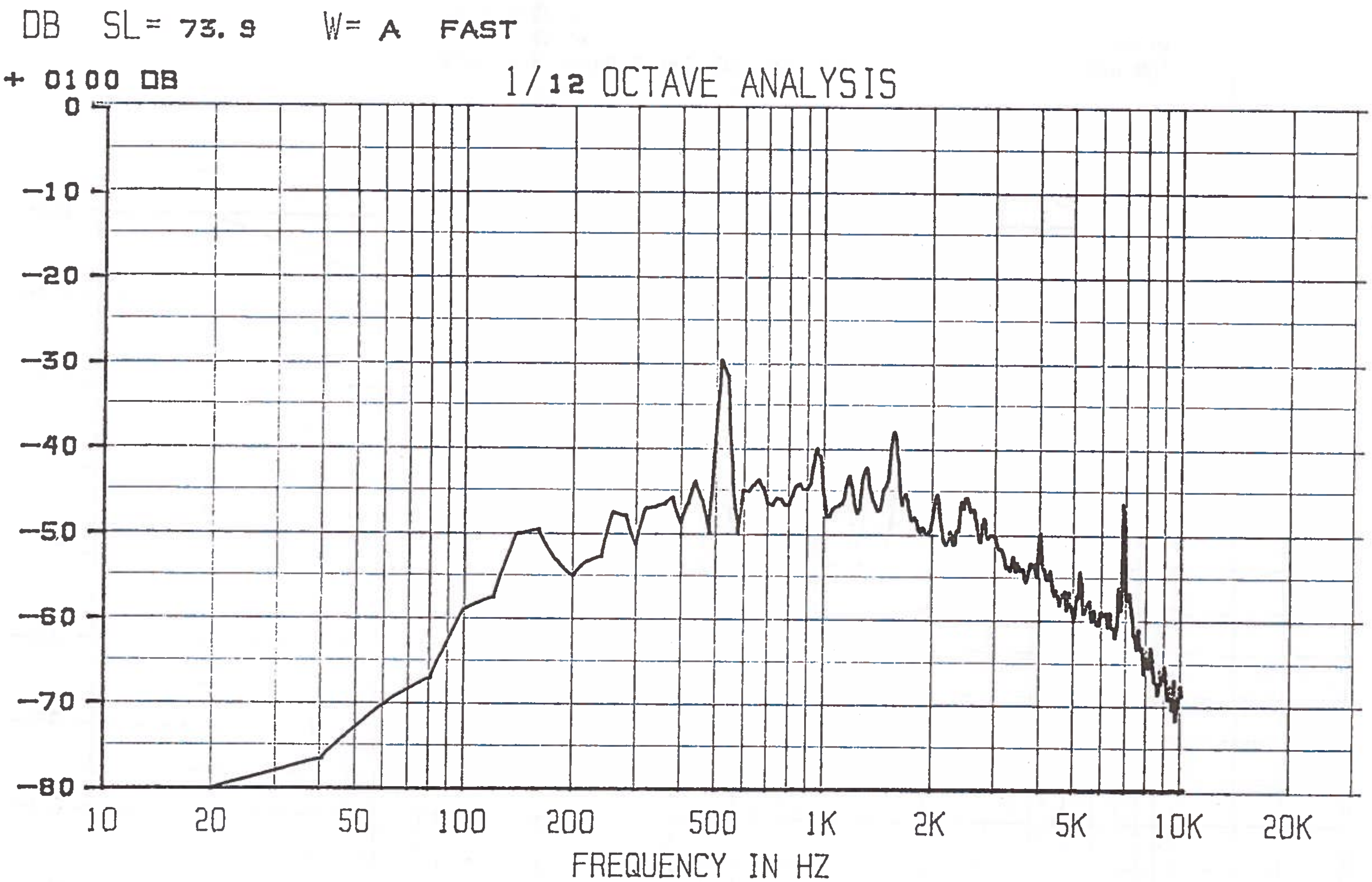
FIGURE C-1



KENWORTH SOUND SOURCE DEFINITION
FULLY WRAPPED
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-95/8

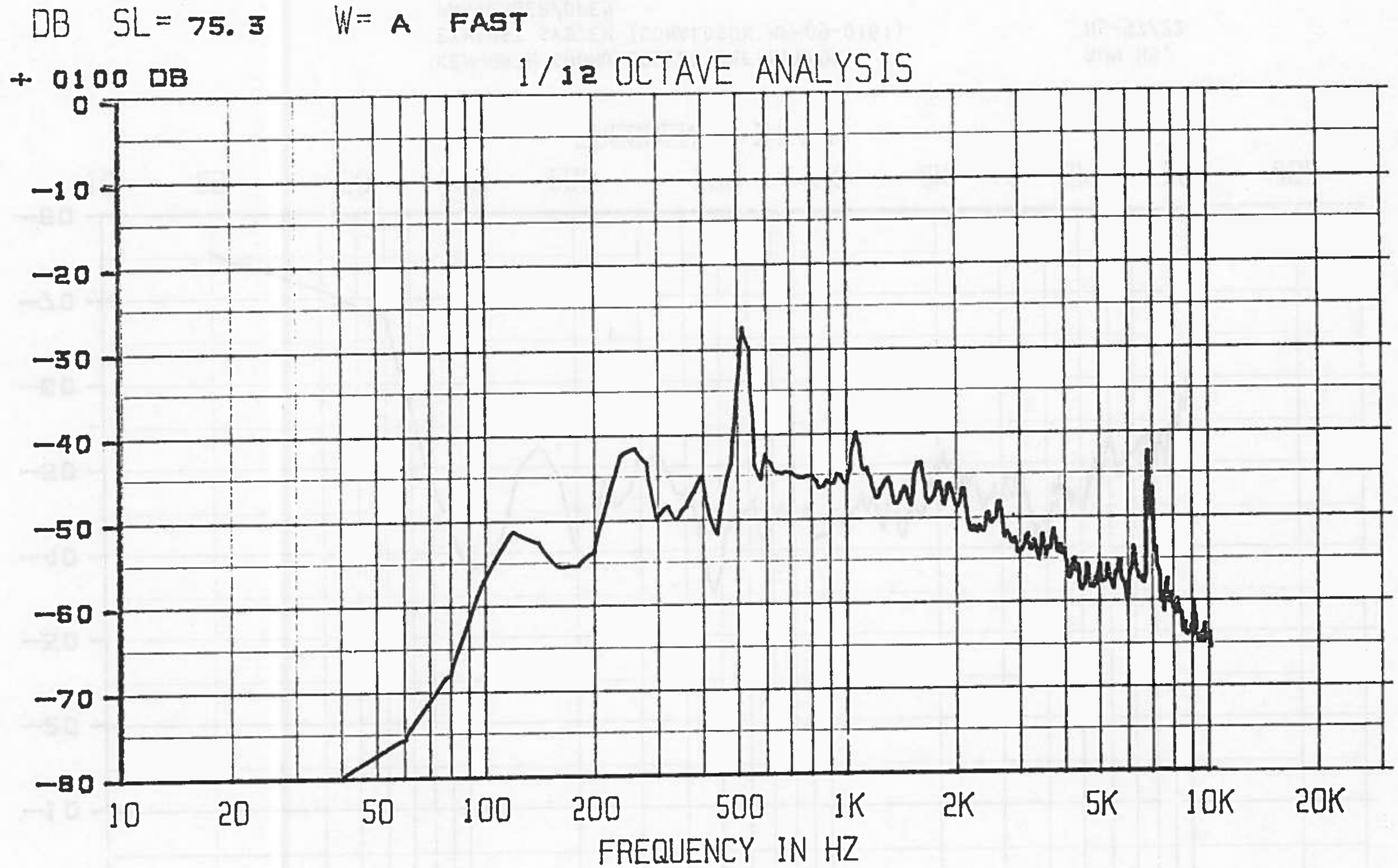
FIGURE C-2



KENWORTH SOUND SOURCE DEFINITION
INTAKE
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-97/16

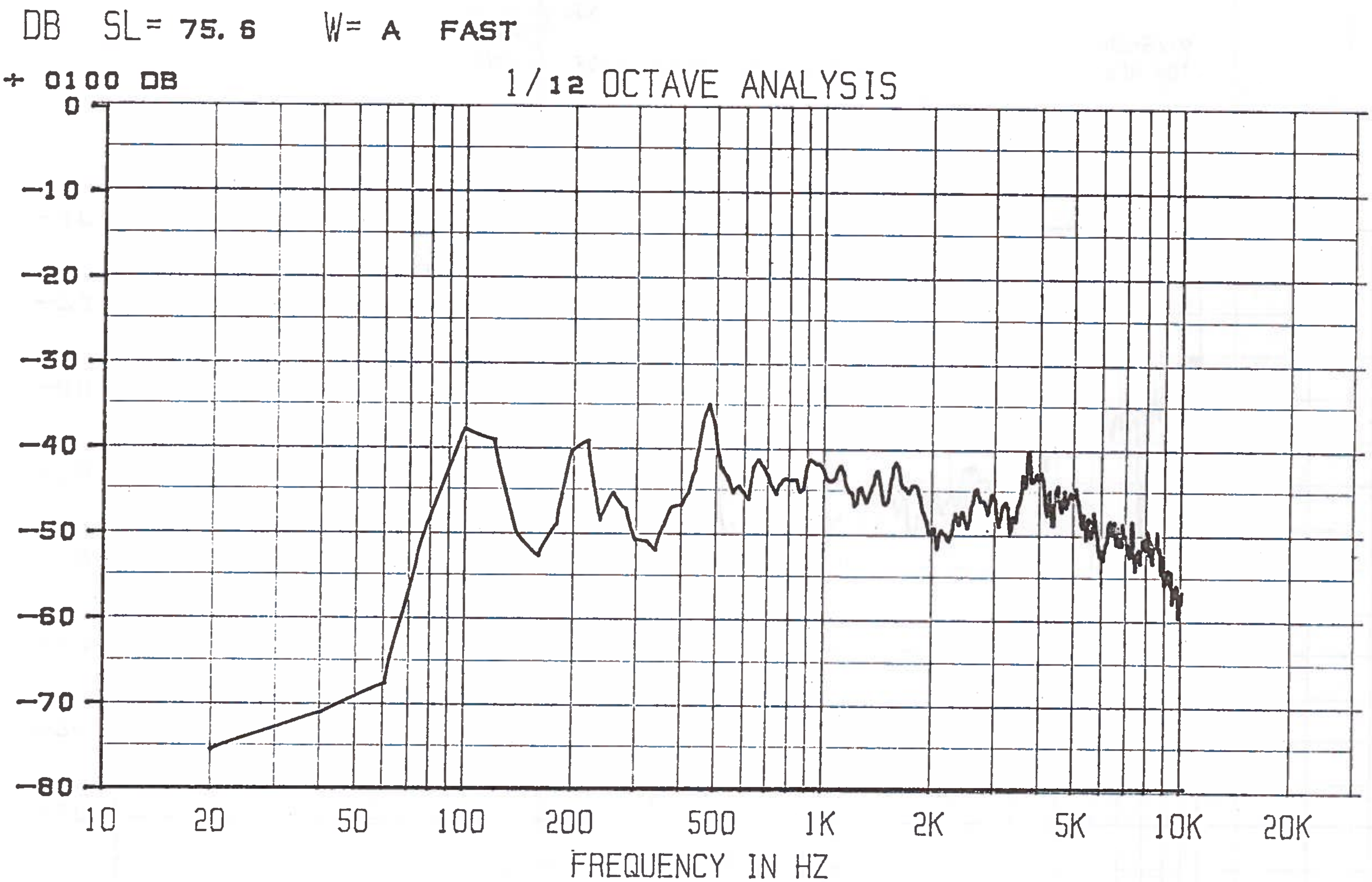
FIGURE C-3



KENWORTH SOUND SOURCE DEFINITION
INTAKE
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-97/8

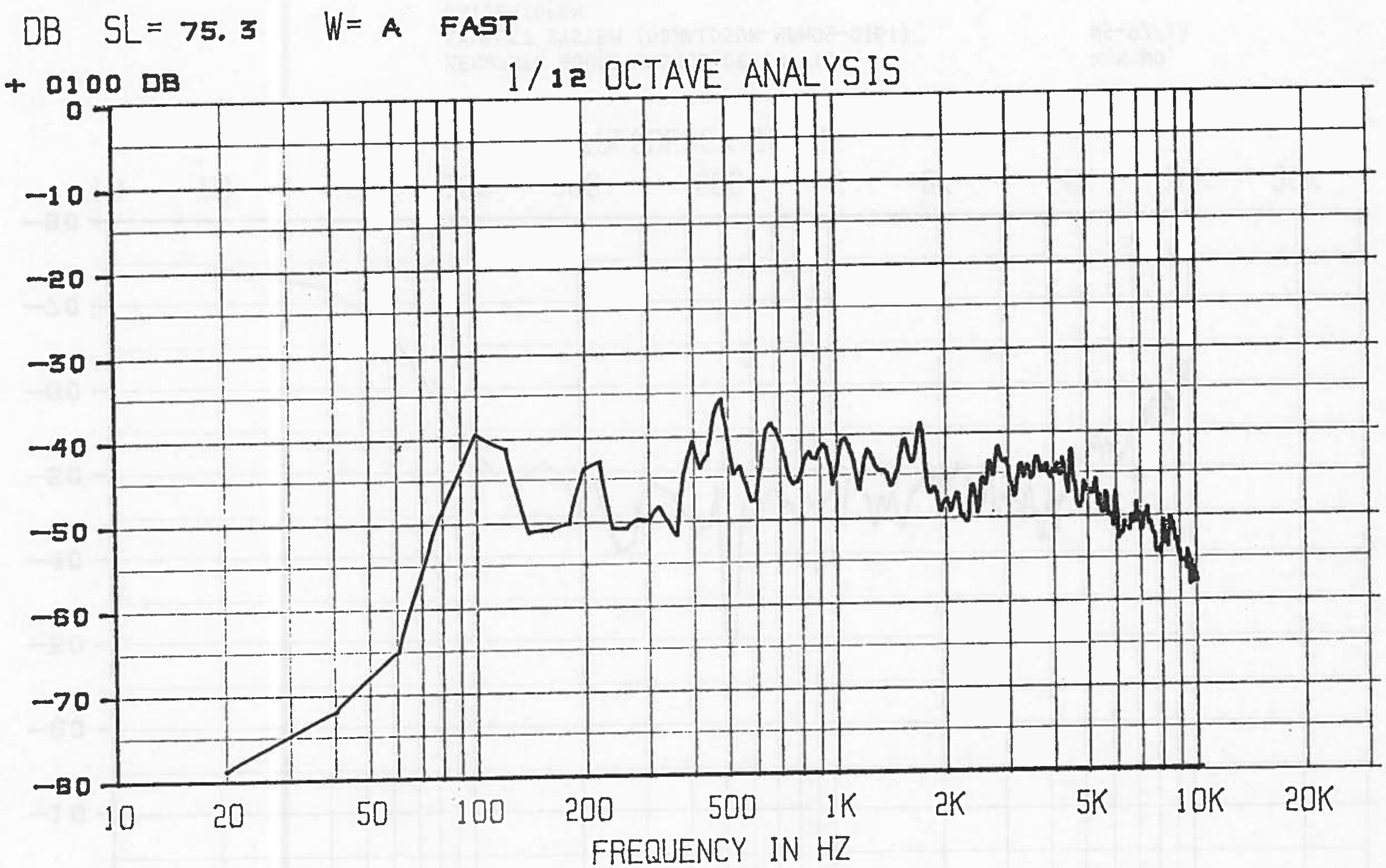
FIGURE C-4



KENWORTH SOUND SOURCE DEFINITION
EXHAUST SYSTEM (DONALDSON MPM09-0161)
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-97/22

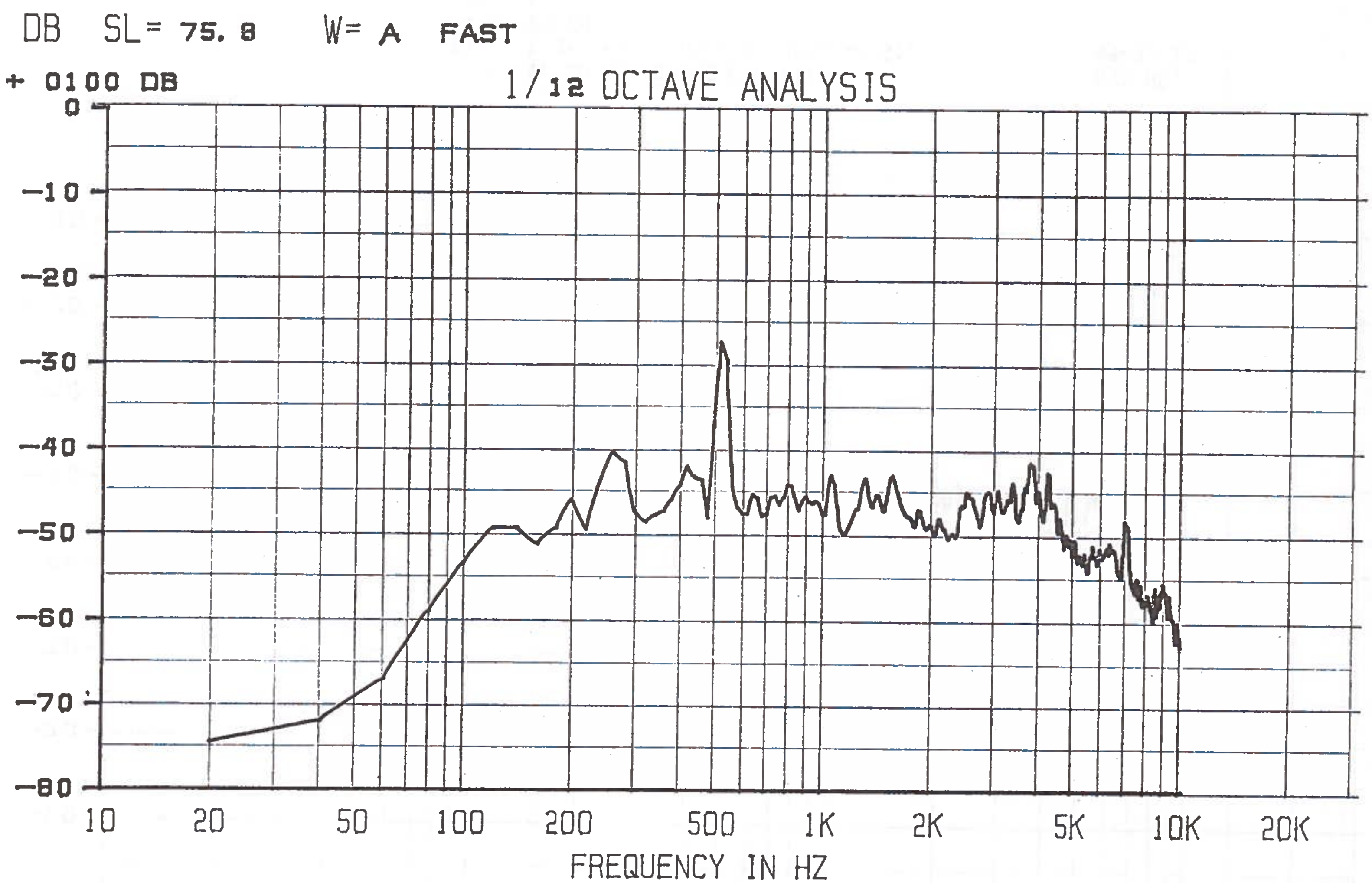
FIGURE C-5



KENWORTH SOUND SOURCE DEFINITION
EXHAUST SYSTEM (DONALDSON MPM09-0161)
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-97/23

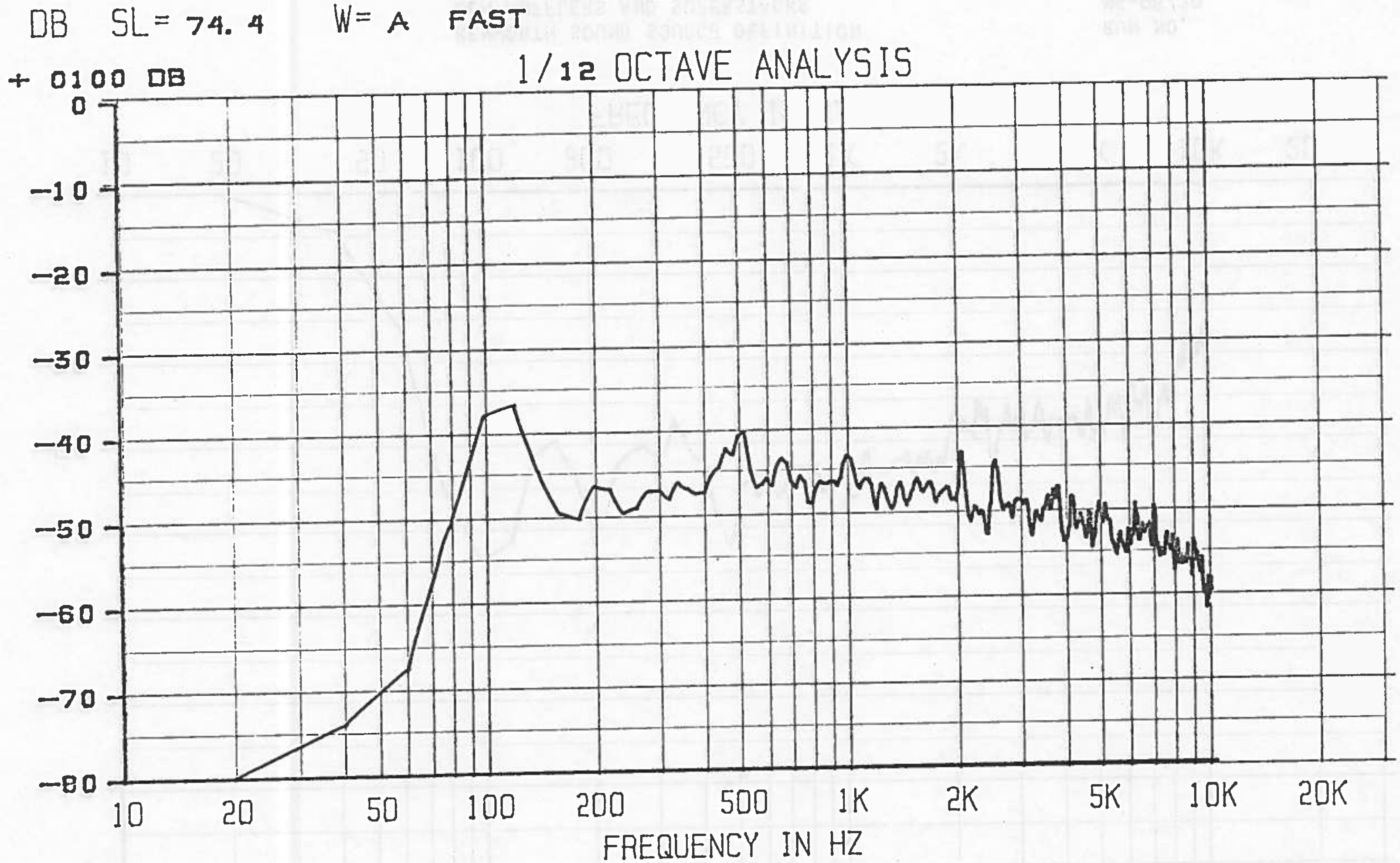
FIGURE C-6



KENWORTH SOUND SOURCE DEFINITION
EXHAUST SYSTEM (DONALDSON MPM09-0161)
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-97/24

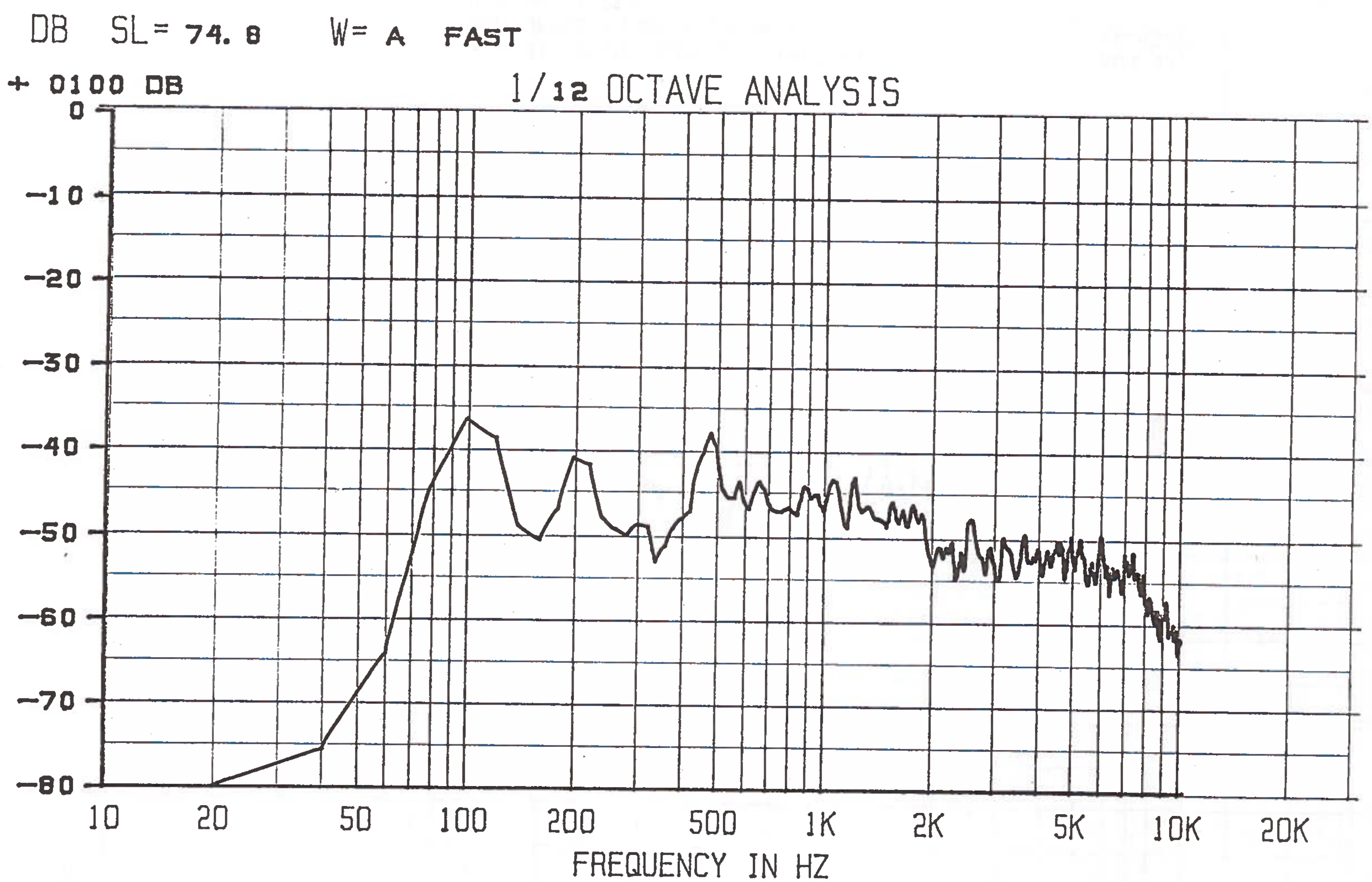
FIGURE C-7



KENWORTH SOUND SOURCE DEFINITION
OEM MUFFLERS AND SUPERSTACKS
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-98/17

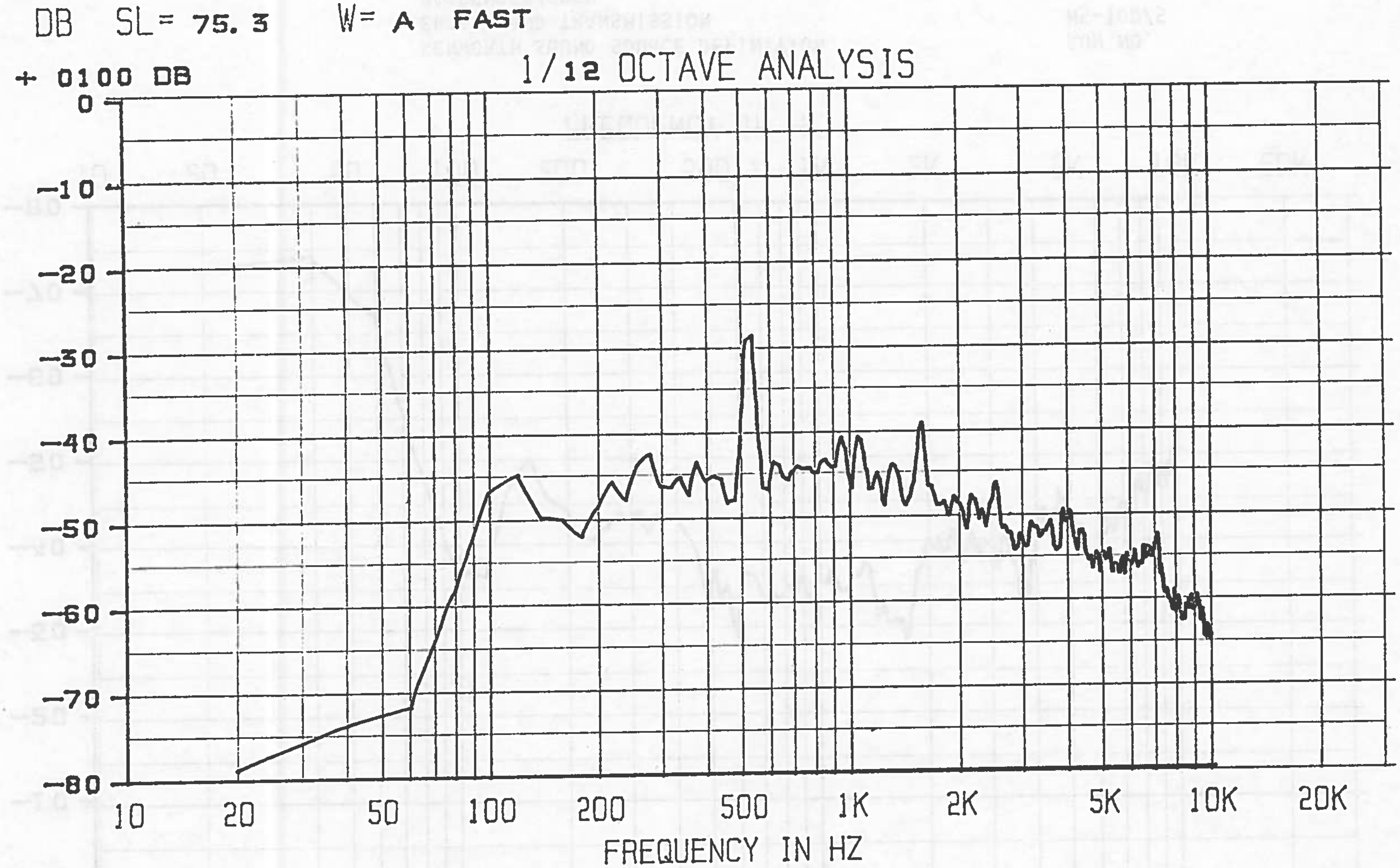
FIGURE C-8



KENWORTH SOUND SOURCE DEFINITION
OEM MUFFLERS AND SUPERSTACKS
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-98/20

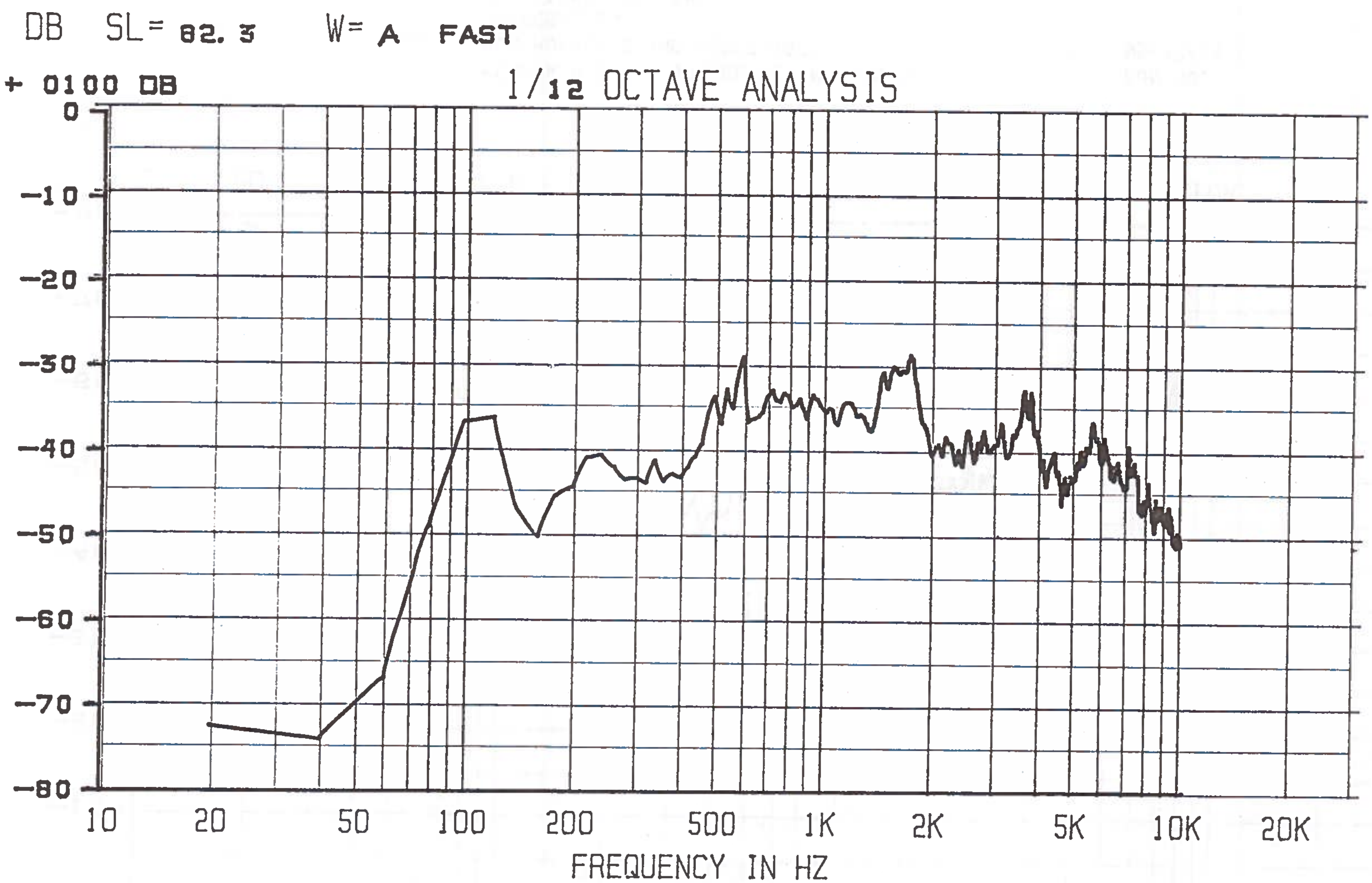
FIGURE C-9



KENWORTH SOUND SOURCE DEFINITION
OEM MUFFLERS AND SUPERSTACKS
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-98/23

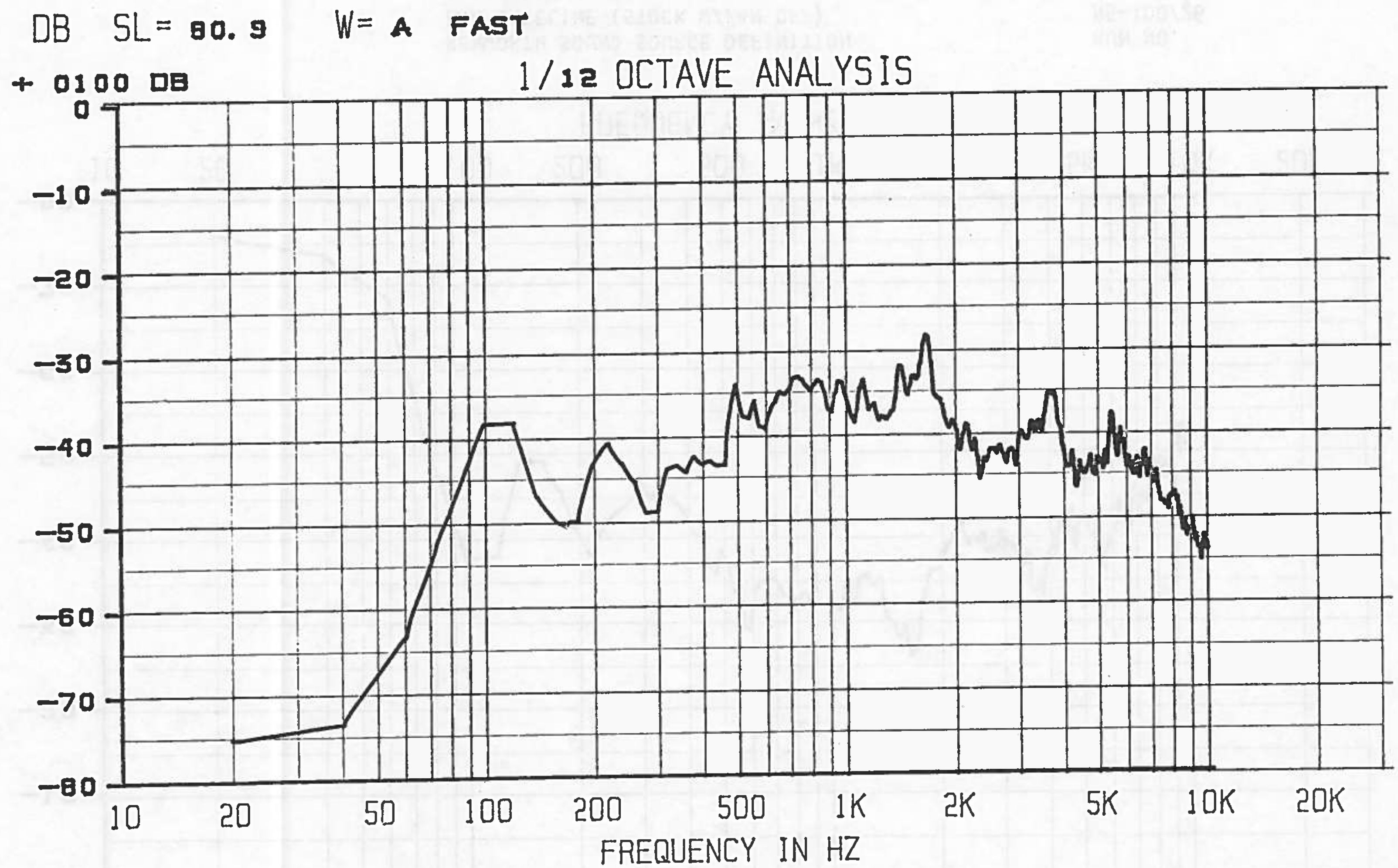
FIGURE C-10



KENWORTH SOUND SOURCE DEFINITION
ENGINE AND TRANSMISSION
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-100/5

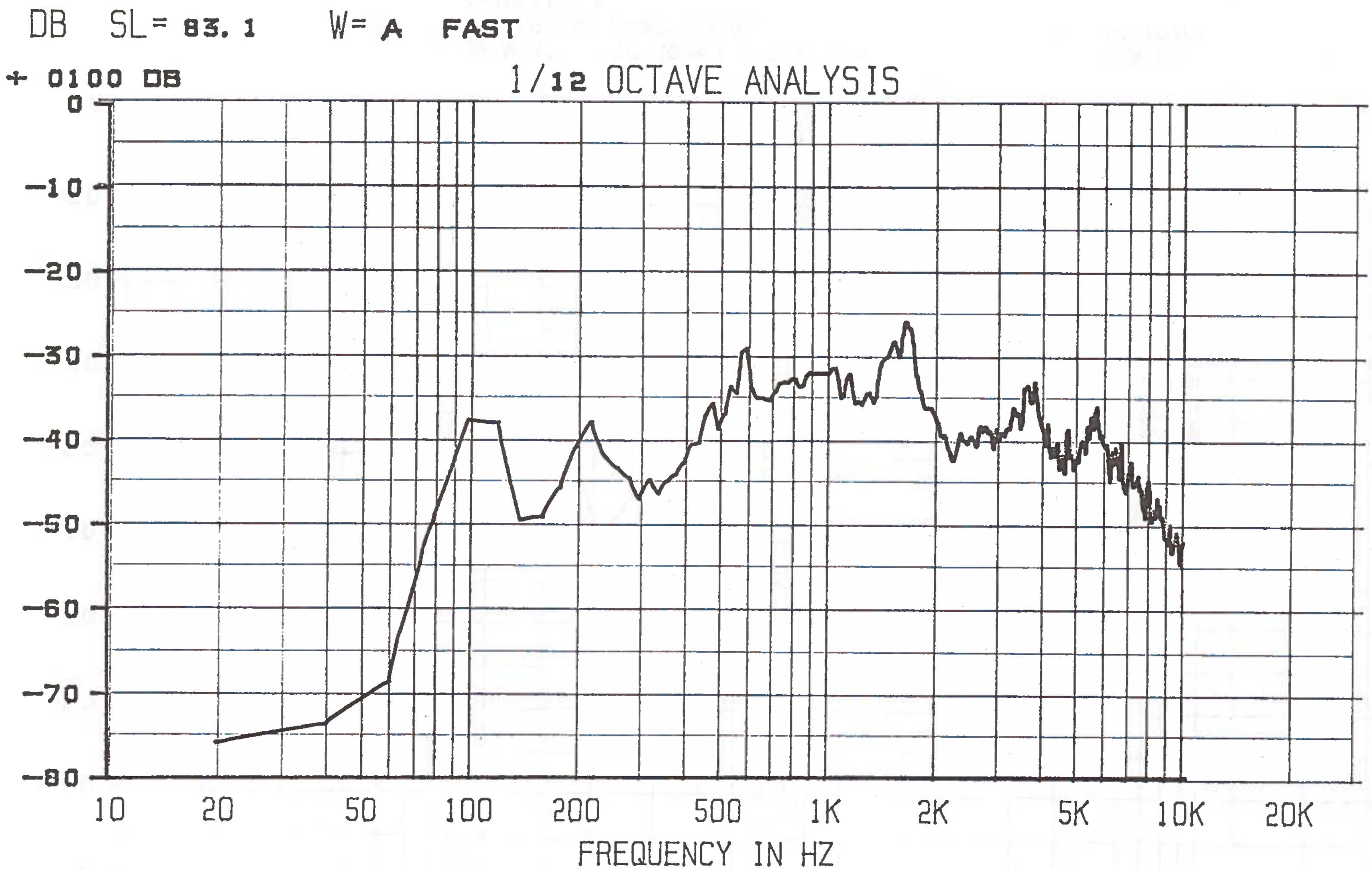
FIGURE C-11



KENWORTH SOUND SOURCE DEFINITION
ENGINE AND TRANSMISSION
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-100/7

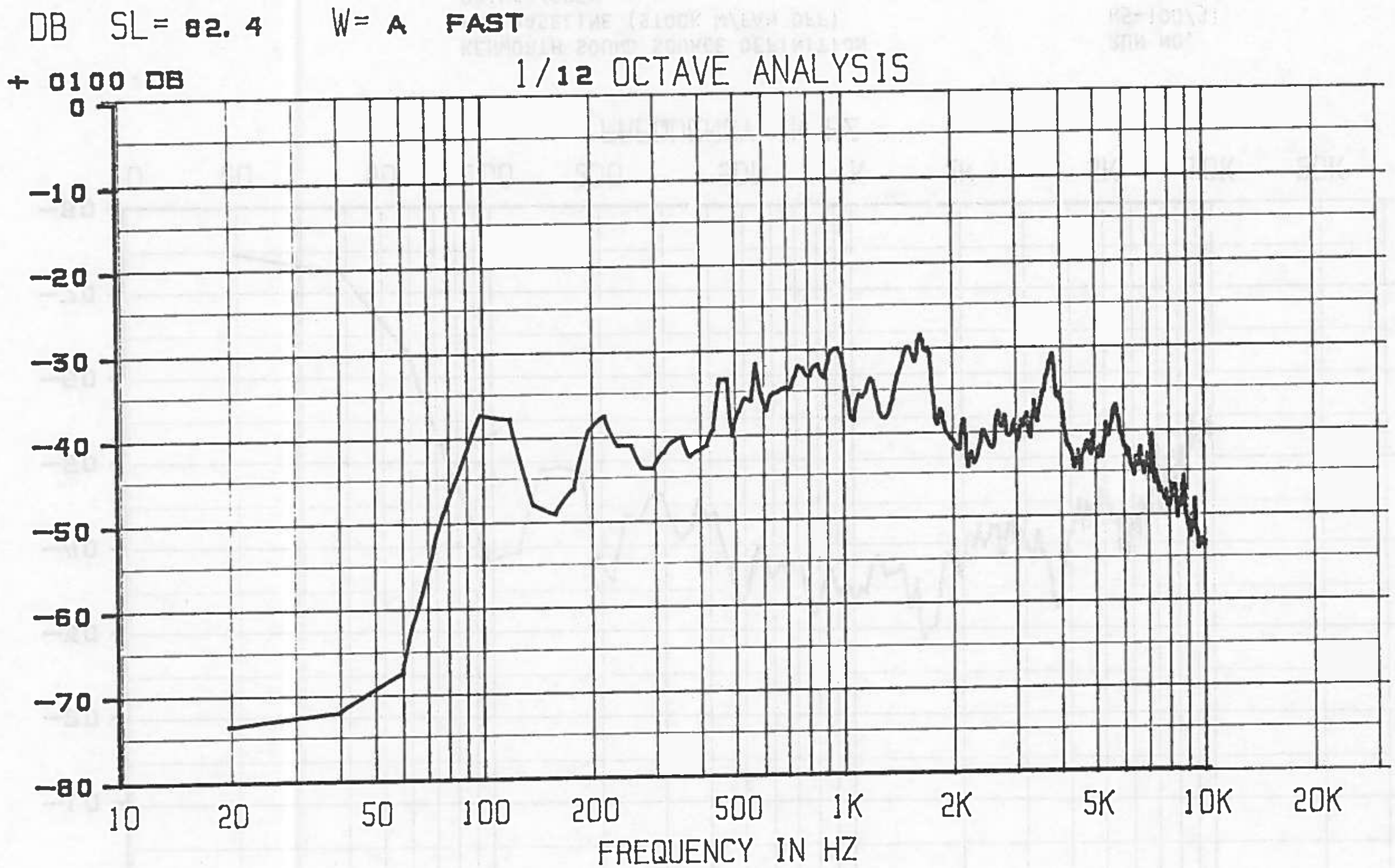
FIGURE C-12



KENWORTH SOUND SOURCE DEFINITION
FAN BASELINE (STOCK W/FAN OFF)
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-100/26

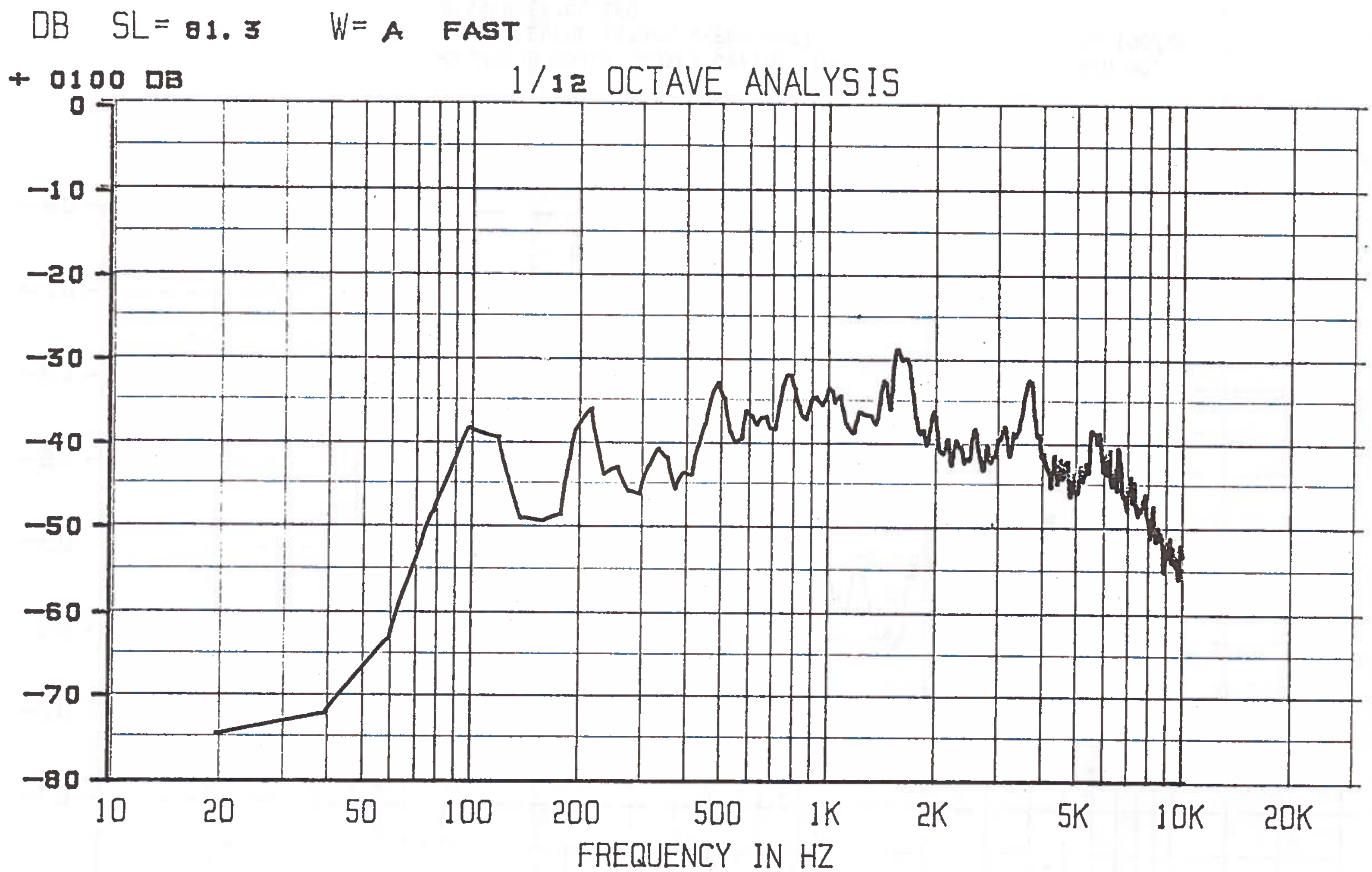
FIGURE C-13



KENWORTH SOUND SOURCE DEFINITION
FAN BASELINE (STOCK W/FAN OFF)
PASSENGER/CLOSED
J366 ACCELERATION

RUN NO.
N5-100/29

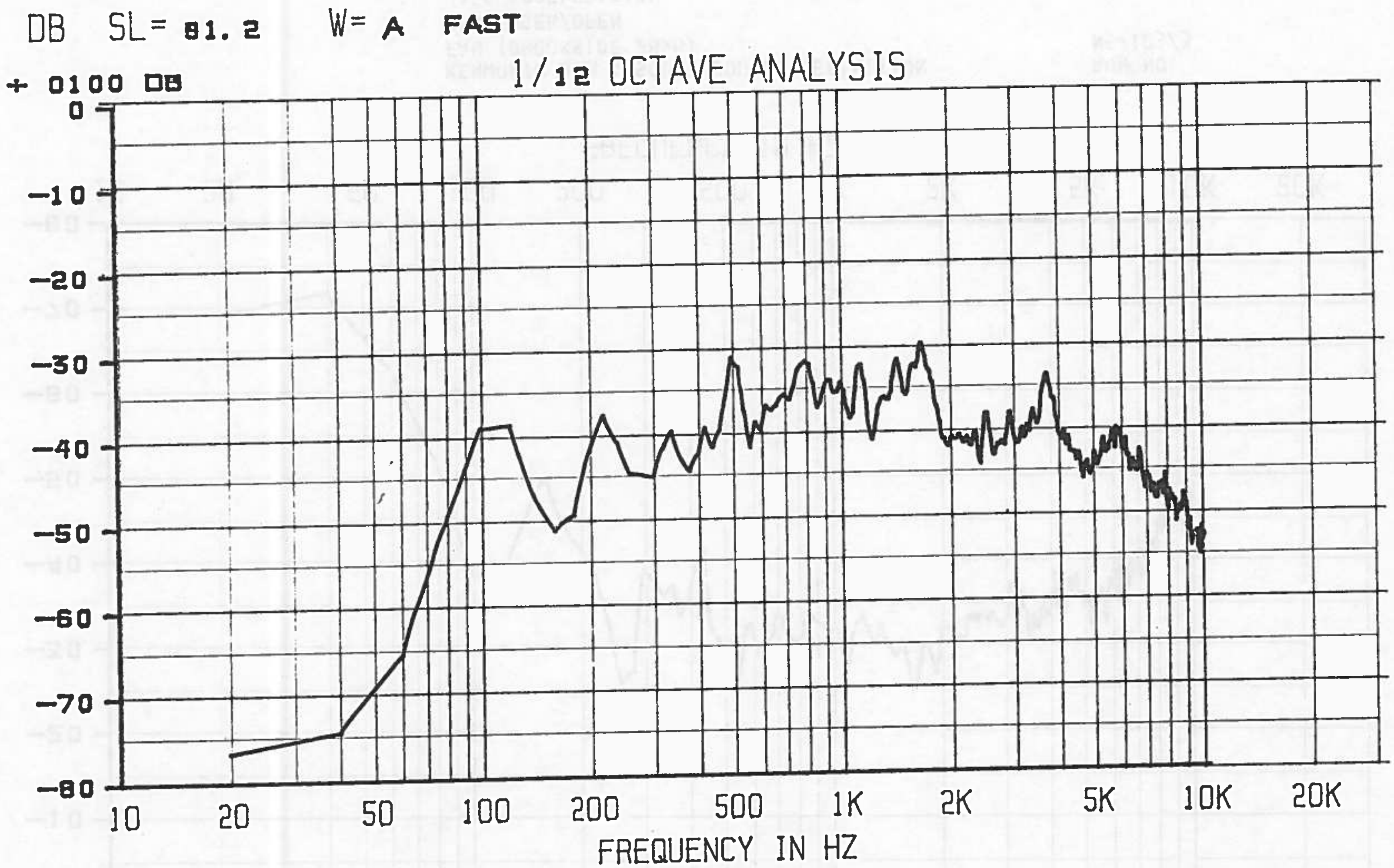
FIGURE C-14



KENWORTH SOUND SOURCE DEFINITION
FAN BASELINE (STOCK W/FAN OFF)
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-100/31

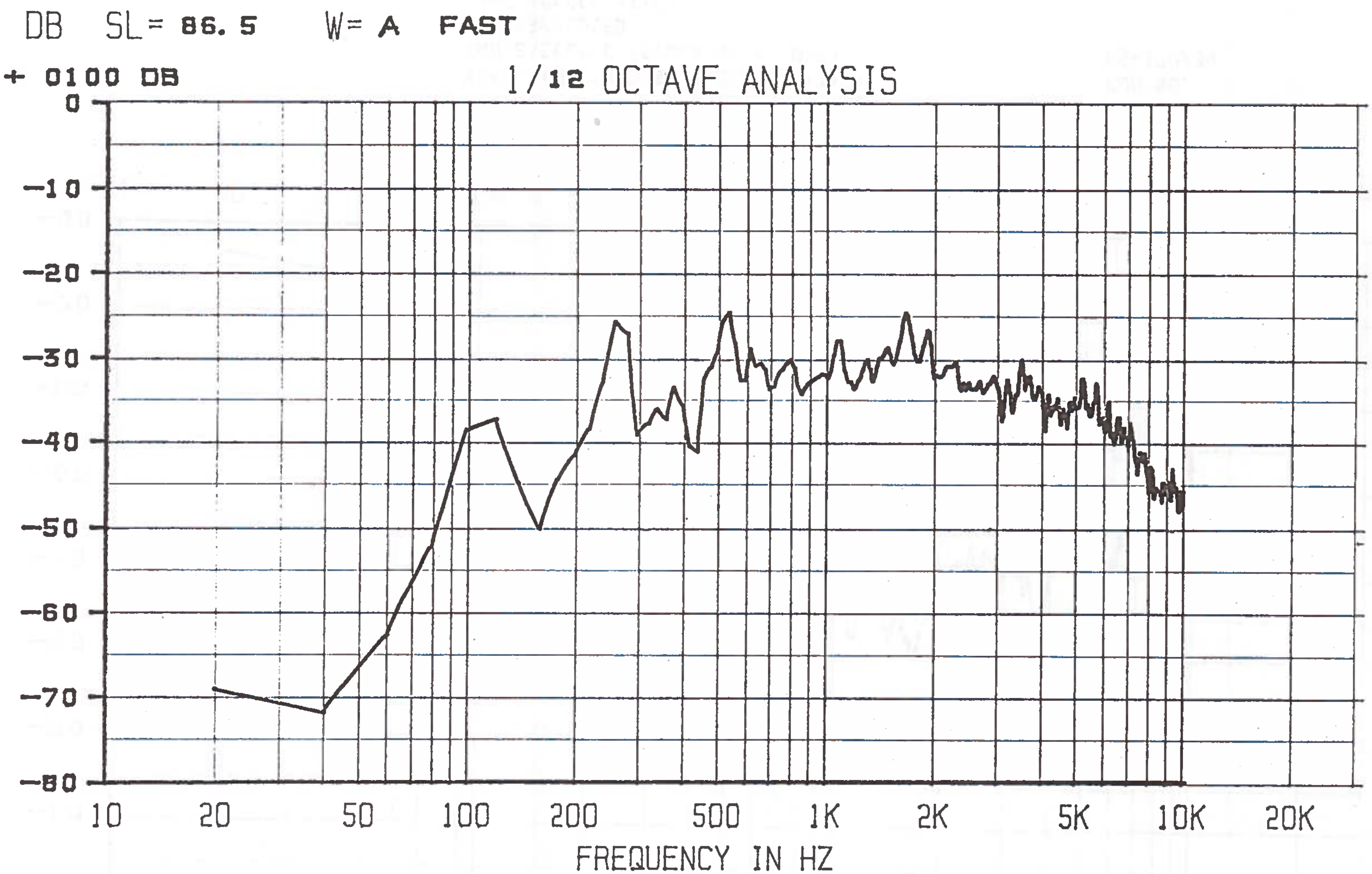
FIGURE C-15



KENWORTH SOUND SOURCE DEFINITION
FAN BASELINE (STOCK W/FAN OFF)
DRIVER/CLOSED
J366 ACCELERATION

RUN NO.
N5-100/34

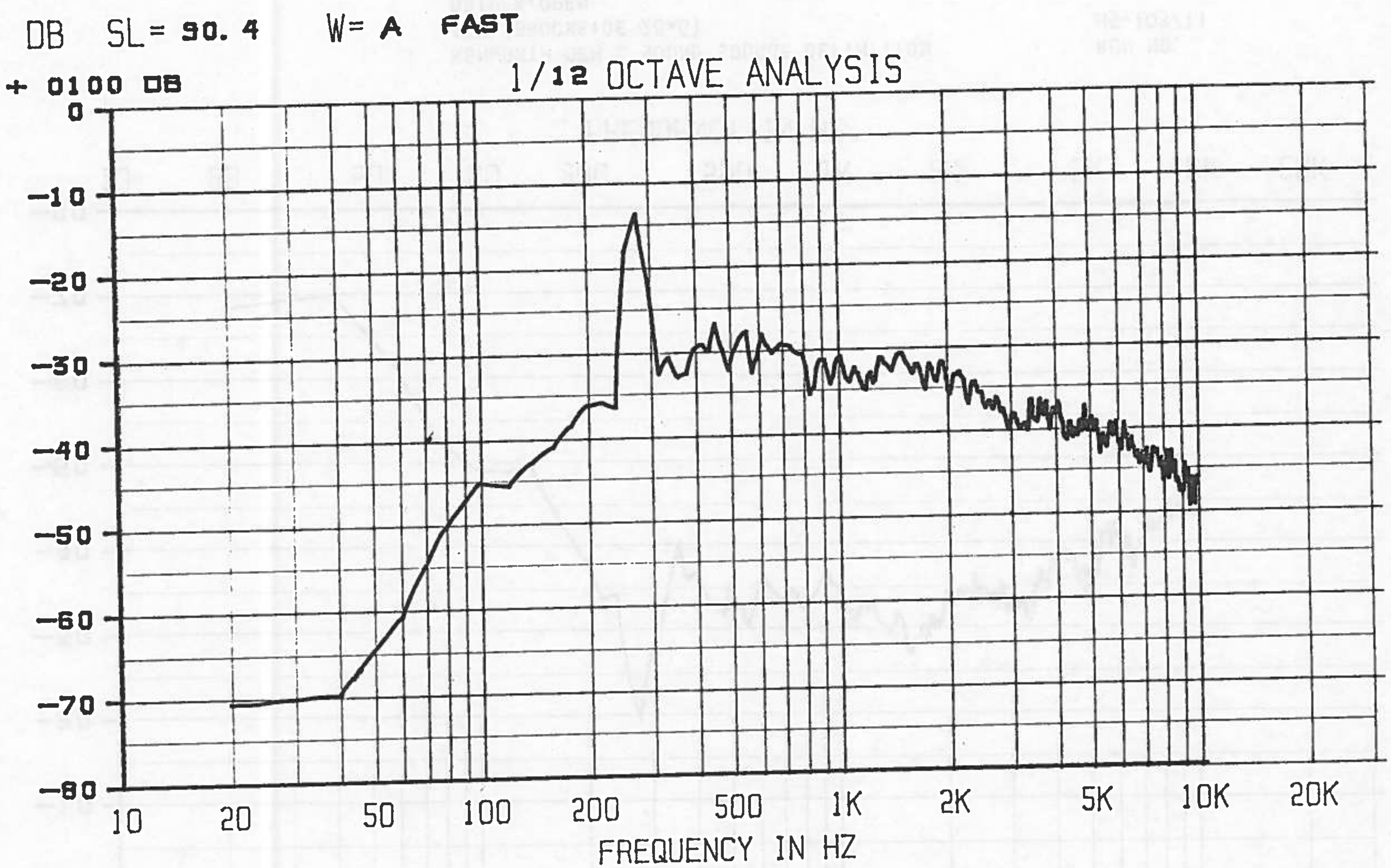
FIGURE C-16



KENWORTH OEM & SOUND SOURCE DEFINITION
FAN (BROOKSIDE 28x6)
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-103/3

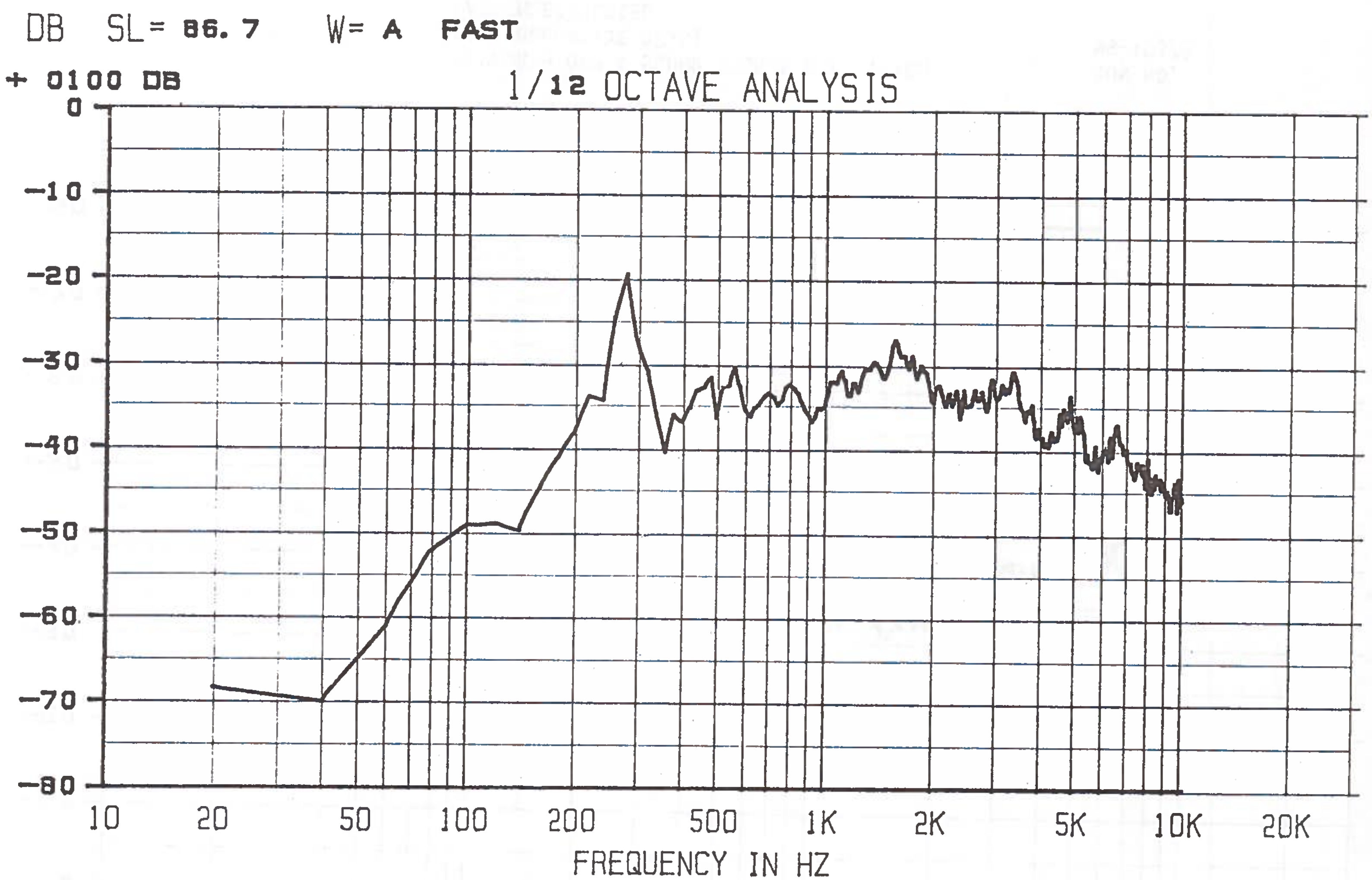
FIGURE C-17



KENWORTH OEM & SOUND SOURCE DEFINITION
FAN (BROOKSIDE 28x6)
PASSENGER/CLOSED
J366 ACCELERATION

RUN NO.
N5-103/6

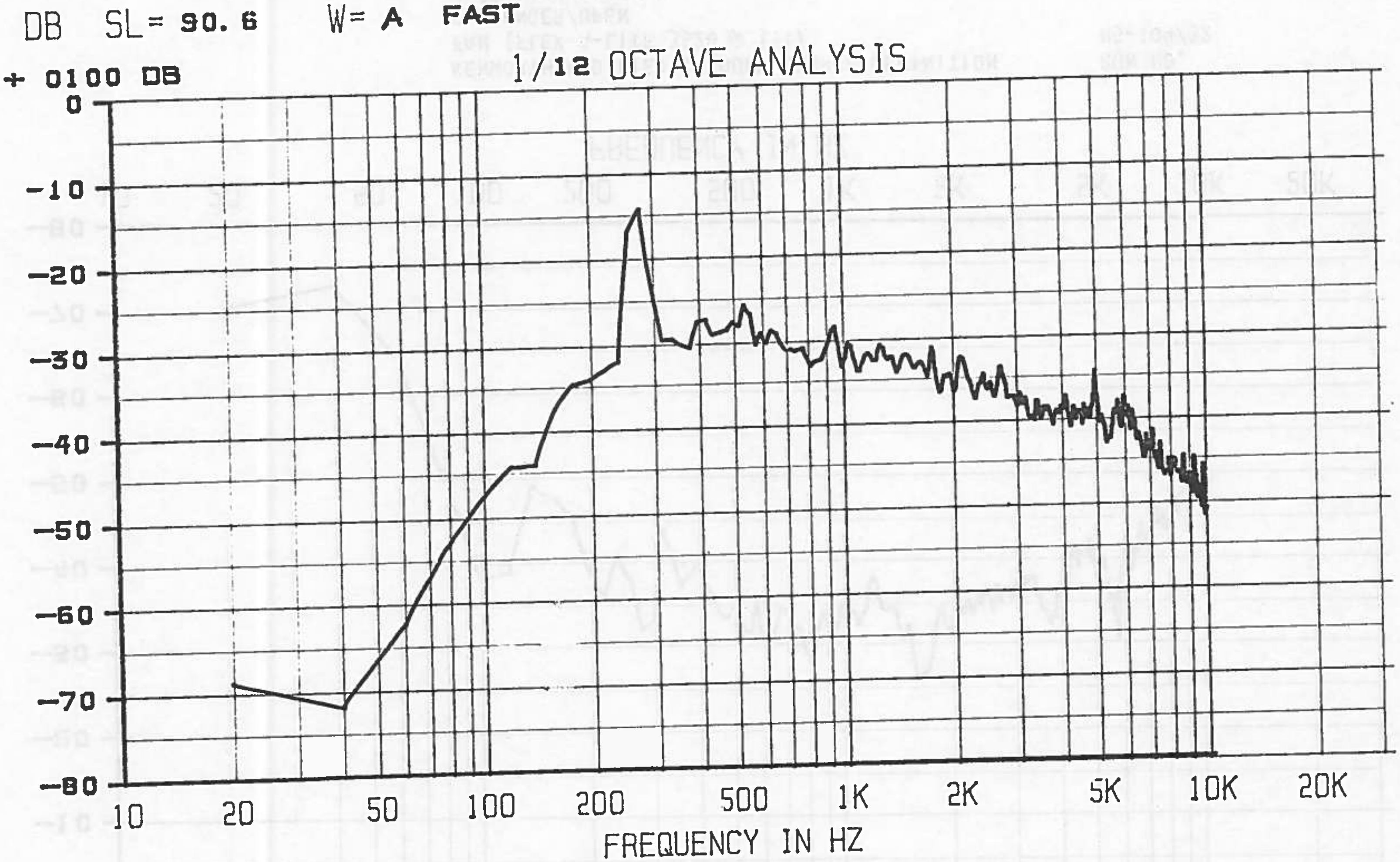
FIGURE C-18



KENWORTH OEM & SOUND SOURCE DEFINITION
FAN (BROOKSIDE 28x6)
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-103/11

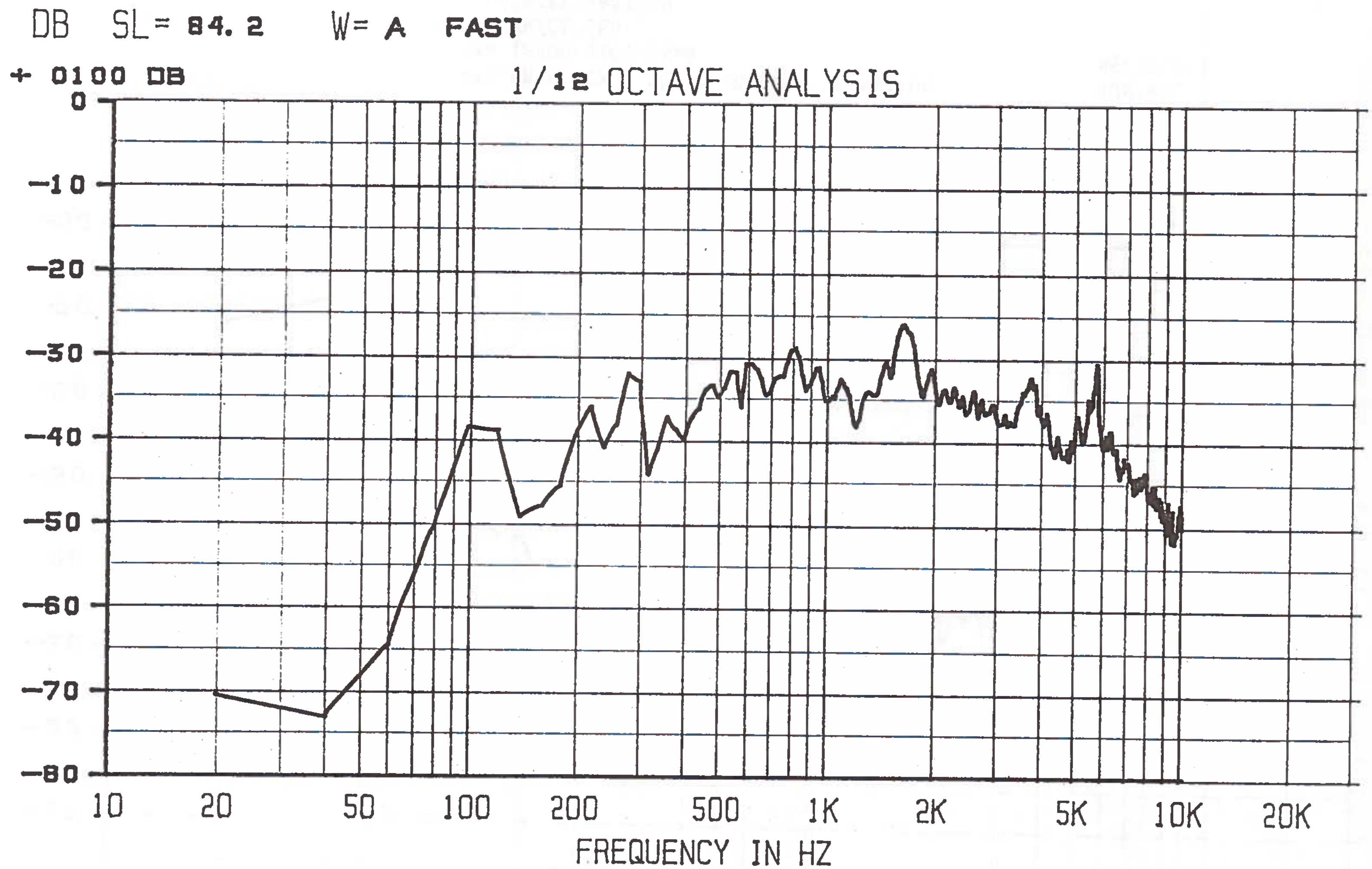
FIGURE C-19



KENWORTH OEM & SOUND SOURCE DEFINITION
FAN (BROOKSIDE 28x6)
DRIVER/CLOSED
J366 ACCELERATION

RUN NO.
N5-103/13

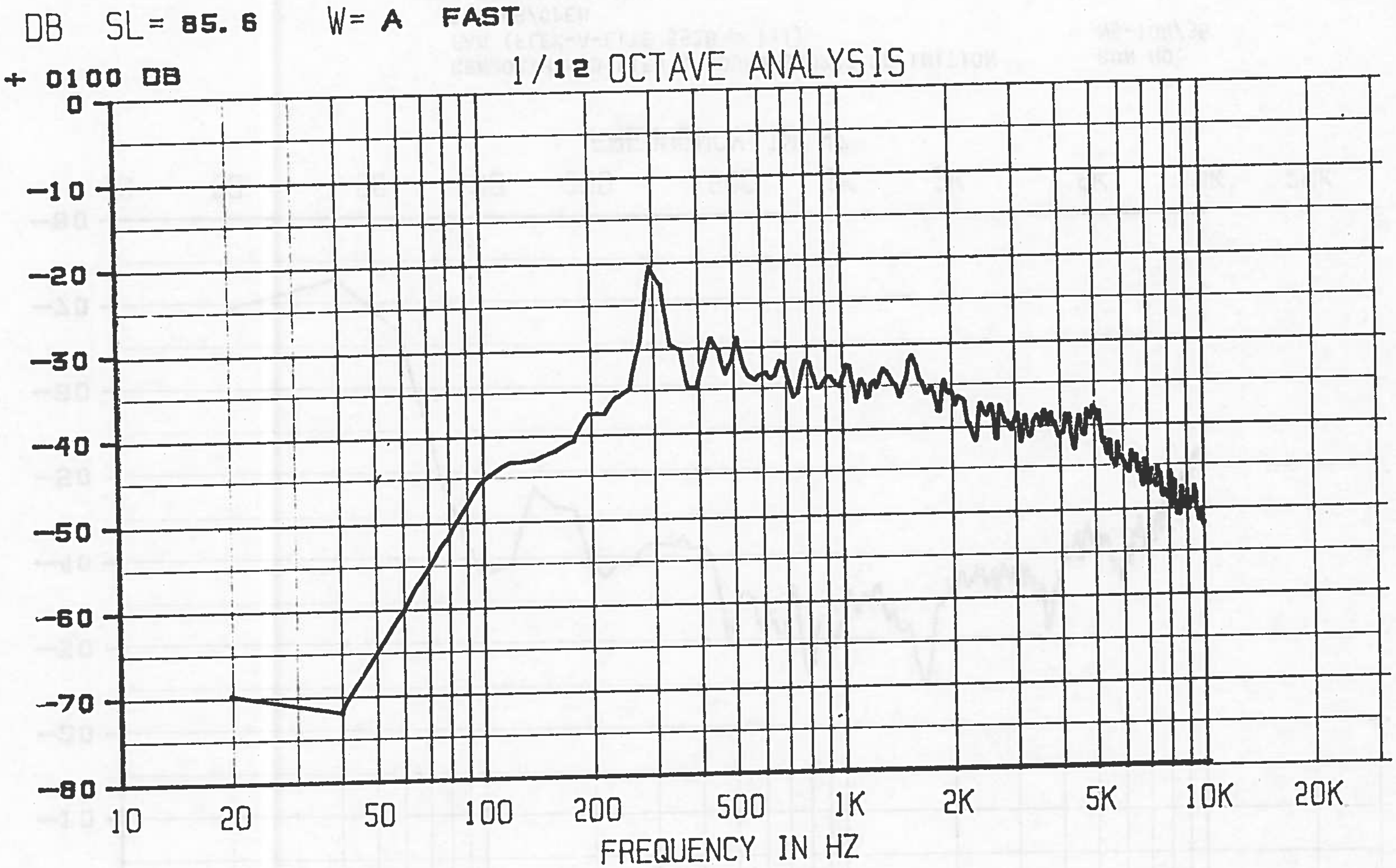
FIGURE C-20



KENWORTH MODIFIED & SOUND SOURCE DEFINITION
FAN (FLEX-A-LITE 3528 @ 1:1)
PASSENGER/OPEN
J366 ACCELERATION

RUN NO.
N5-104/32

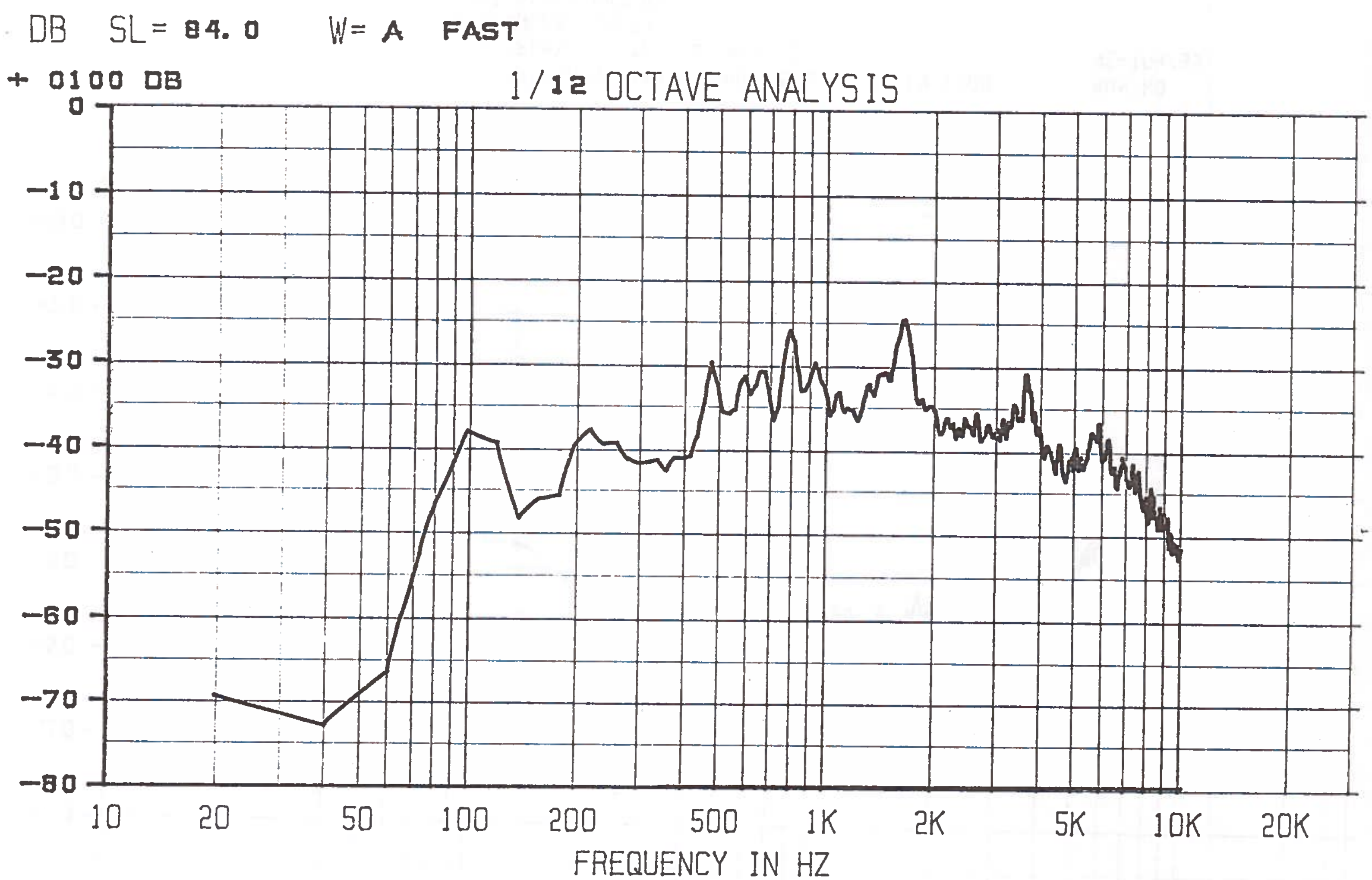
FIGURE C-21



KENWORTH MODIFIED & SOUND SOURCE DEFINITION
FAN (FLEX-A-LITE 3528 @ 1:1)
PASSENGER/CLOSED
J366 ACCELERATION

RUN NO.
N5-104/35

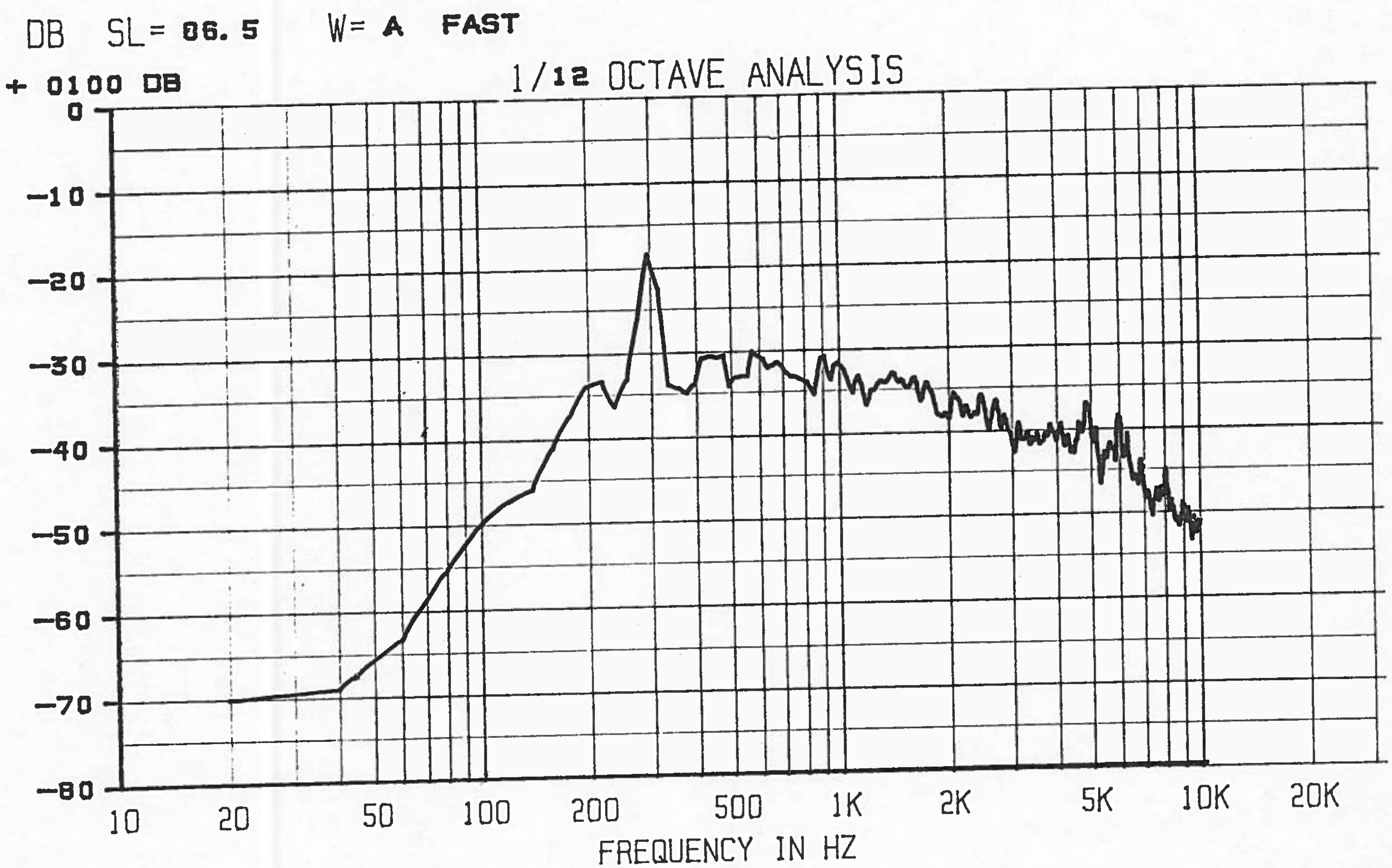
FIGURE C-22



KENWORTH MODIFIED & SOUND SOURCE DEFINITION
FAN (FLEX-A-LITE 3528 @ 1:1)
DRIVER/OPEN
J366 ACCELERATION

RUN NO.
N5-104/36

FIGURE C-23



KENWORTH MODIFIED & SOUND SOURCE DEFINITION
FAN (FLEX-A-LITE 3528 @ 1:1)
DRIVER/CLOSED
J366 ACCELERATION

RUN NO.
N5-104/41

FIGURE C-24

APPENDIX D

SOUND ANALYSIS EQUIPMENT

D.1 Spectrum-Analysis Equipment Description

Truck drive-by data requiring spectral analysis was originally acquired in the field using a Nagra Model SJ analog tape recorder. The spectral plots were generated in the laboratory using a Hewlett-Packard Model 5451B Fourier analyzer as shown in Figures 12, 13 and 14. The Fourier analyzer system is basically a Hewlett-Packard Model 2100S digital computer, with 32K of core and various peripheral devices. These peripheral devices include 48 dB per octave anti-aliasing filters, high performance ten bit analog-to-digital converter, HP Model 7900A disc drive, high speed paper tape reader and punch, teletype and special programming keyboard, CTR output display, and a HP 7210A digital X-Y plotter.

D.2 Analog-to-Digital Conversion

The first step in processing the analog tape recordings was the conversion of the original data from unweighted to A-weighted. This was accomplished by taking advantage of A-weighting frequency networks within the Nagra Model SJ analog tape recorder. The A-weighted signals from the analog tape recorder were fed through the anti-aliasing filters and to the input of the analog-to-digital converter. The ADC sampling rate was set up so that data from DC to 12 K Hz would be available from the output of the spectrum analyzer. Final data were plotted from 20 Hz to 10 K Hz. A 10-second-long record for each drive-by was stored on the computer disc drive. This 10-second record was made up of 200 50-millisecond blocks of data.

D.3 Calibration

The spectrum analyzer was calibrated using pistonphone signals recorded on the same analog tape as the original data. The RMS level for ten seconds of pistonphone data was averaged by the computer to give an absolute sound pressure calibration level. The numerical value of this sound pressure level was manually entered into the computer using the teletype. This information was used by the data system to present the final reduced data in terms of an absolute sound pressure level.

D.4 Frequency-Spectrum Generation and Averaging

Each of the 200 50-millisecond blocks of digitized data previously recorded on the disc was sequentially converted from time domain records to frequency domain, or spectral, records by Fast Fourier transform software resident within the 2100S digital computer.

By its very nature random acoustical energy, such as that originating from a diesel truck, is nonstationary. Therefore, it is necessary to give consideration to some type of time averaging of the spectral data. This is particularly the case when only 50-millisecond-long samples of data are being analyzed and is further compounded by the transient nature of the J366 truck drive-by test. In those few cases where stationary vehicle tests were performed, it was possible to average the spectral data over many seconds of time. This allowed for high resolution frequency plots with a high level of confidence in the accuracy of the sound level at each frequency.

In the case of the transient drive-by tests, it was necessary to develop a different averaging technique. It was decided that it would be desirable to emulate the averaging found in a fast sound level meter. This type of averaging made it possible to display and plot the same frequency spectrum that would cause a fast response sound level meter to indicate a maximum during a truck drive-by test. A technique involving the exponential time averaging of successive 50-millisecond frequency domain records was used. The time constant of the exponential average was empirically adjusted until the data system response duplicated the requirements of ANSI S1.4-1971 paragraph 5.3 for a fast response Type 1 sound level meter. When time histories of the overall A-weighted sound pressure level from the digital spectrum analysis system were compared with time histories generated by a conventional fast response sound level meter system, it was found that the maximum A-weighted sound pressure level generally was within $\pm$ 0.2 dB of the maximum displayed on the analog strip chart.

D.5 Percent-Bandwidth Data Presentation

A Fast Fourier transform spectrum analysis system inherently gives a constant bandwidth output. The system being discussed here generated information each 20 Hz from DC to 12 KHz. If this constant bandwidth data were presented as a final output, it would result in a data presentation which would indicate very low acoustic levels at the high end of the frequency spectrum, possibly leading to erroneous engineering decisions. Therefore, it was necessary to convert the output of the Fast Fourier transform analyzer to a constant percentage bandwidth output format, such as would be obtained from a 1/3 octave analyzer. As a result of the desire to compare data obtained previously from a 1/12 octave analyzer, it was decided that all data for this program would be presented as if it had been reduced using a 1/12 octave analyzer. This required that the original 20 Hz constant bandwidth data be multiplied, at each individual frequency, by a factor of 0.058 times that frequency. The result of this was a spectral plot of A-weighted data with 20 Hz resolution presented as if it had been analyzed with a 1/12 octave analog analyzer.

D.6 Data-Output Format

The output of the data reduction system was spectral plots of the maximum sound pressure level during the truck drive-by. These spectral plots were presented either as CRT displays or as fully labelled plots on the X-Y plotter. Examples of this output format are shown in Appendices B and C of this report. The total data analysis process was highly automated and required a minimum of operator intervention.

APPENDIX E

REPORT OF INVENTIONS

REPORT OF INVENTIONS

This document was prepared by PACCAR Inc, Bellevue, Washington. The work was done under contract DOT-TSC-708, entitled "Noise Reduction Options for Diesel Powered Trucks and Buses." PACCAR Inc does not claim to have made any innovation, discovery, improvement, or invention as a result of this work.

☆U. S. GOVERNMENT PRINTING OFFICE: 1976--700-260--29

500 copies