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Feasible Noise Limits For Construction And Maintenance Equipment And Study Of Noise Reduction Methods

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Mas M. Hatano and Earl C. Shirley

**8. PERFORMING ORGANIZATION REPORT No.**

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Sacramento, California 95819

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This report was prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

**16. ABSTRACT**

This study concerns modifications and evaluation of noise attenuating devices and methods for quieting diesel powered vehicles and construction equipment. The findings were used to develop guidelines for operation correction of noisy vehicles and equipment and specifications for construction contracts.

The major effort was directed toward modification of an existing 1964 diesel powered dump truck to build a "Quieted Truck". Changes to the exhaust system, cooling system and building a tunnel around the engine and drive train were successful in significantly reducing noise. The amount of reduction varied depending on factors such as speed and mode of operation.

As one example, an estimated reduction from 82 to 73 dBA was measured at 50 feet during an accelerated test at 50 mph.

A literature survey and synthesis on diesel powered trucks and construction equipment are a part of this report.

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Truck noise, acoustics, construction equipment noise, noise specifications

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DIVISION OF STRUCTURES AND ENGINEERING SERVICES

TRANSPORTATION LABORATORY

RESEARCH REPORT

# FEASIBLE NOISE LIMITS FOR CONSTRUCTION AND MAINTENANCE EQUIPMENT AND STUDY OF NOISE REDUCTION METHODS

FINAL REPORT

FHWA-CA-TL-7083-77-18

JULY, 1977

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

Caltrans

CALIFORNIA DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT STANDARD TITLE PAGE

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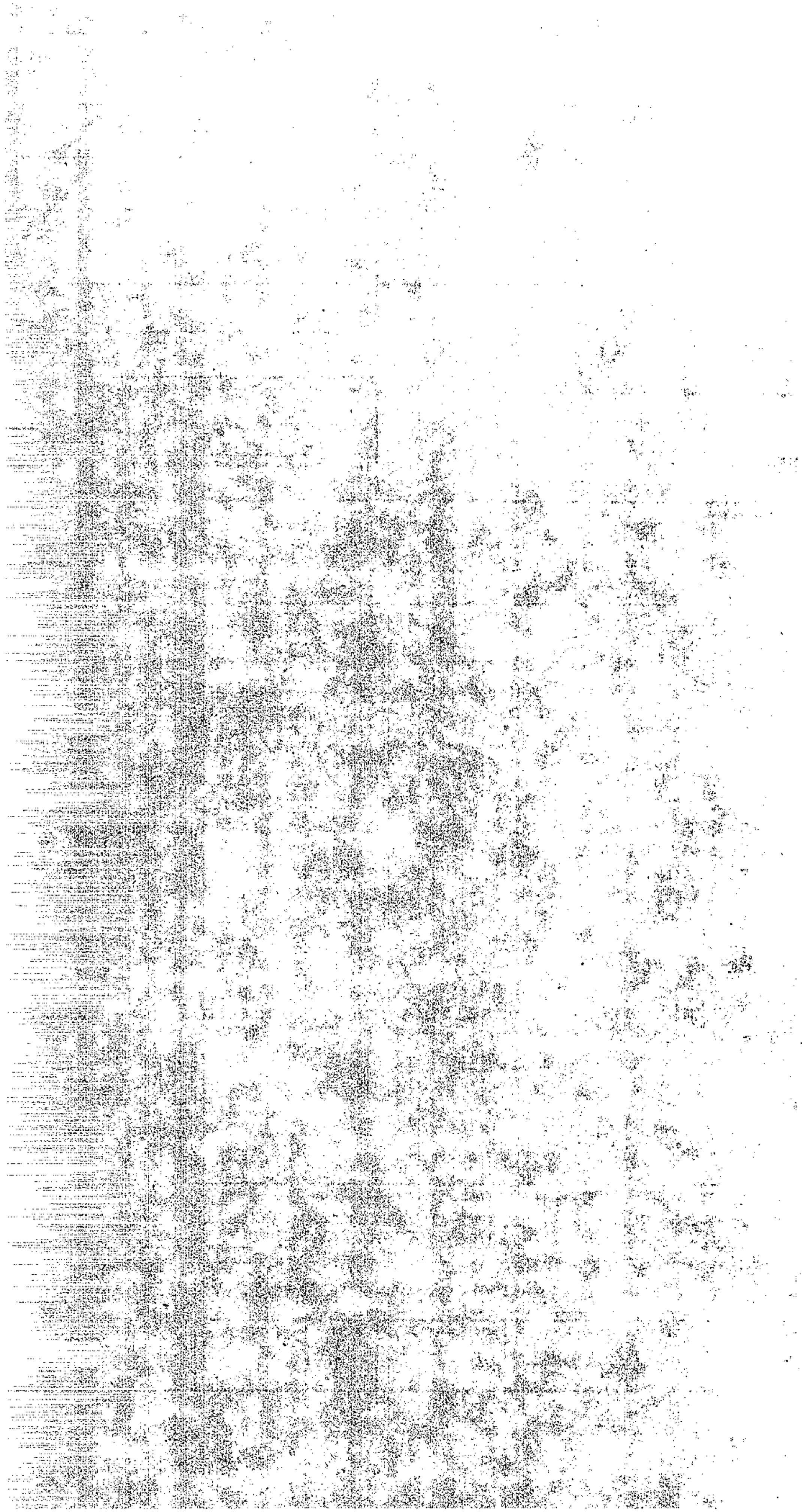


STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

July 1977

FHWA No. A-8-8
TL No. 657083

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

FEASIBLE NOISE LIMITS FOR CONSTRUCTION AND MAINTENANCE EQUIPMENT AND STUDY OF NOISE REDUCTION METHODS

Study made by . . . . . . . . . . . . . . . . Enviro-Chemical Branch and Equipment Department

Principal Investigators . . . . . . . . . . . Earl C. Shirley
Ralph Qualls

Co-Principal Investigators . . . . . . . . . Lou Bourget
Walt Winters
Bob Apperson

Report Prepared by . . . . . . . . . . . . . Mas Hatano

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

MMH:lb

## ACKNOWLEDGEMENT

The initial work was under the direction of the Equipment Department assisted by the Transportation Laboratory. Both organizations are a part of the California Department of Transportation. The Laboratory assumed responsibility for the project during the final stages to complete the study.

Due to a large turnover in personnel resulting from a department reduction in program, and technical and administrative problems, many individuals were involved in this research. The following is a partial list of the persons who participated.

| | | |
|---|---|---|
| Ralph Qualls | Principal Investigator | Equipment Department |
| Robert Apperson | Co-Principal Investigator | Equipment Department |
| Louis Bourget | Co-Principal Investigator | Transportation Laboratory |
| Walter Winter | Co-Principal Investigator | Transportation Laboratory |
| Marvin Greenstein | Noise Measurements | Transportation Laboratory |
| Pete Forte | Truck Design & Modifications | Equipment Department |
| Wyatt Harris | Truck Design & Modifications | Equipment Department |
| Shop Personnel | Truck Design & Modifications | Equipment Department |
| Gurlabh Baidwan | Data Analysis & Report Writing | Transportation Laboratory |
| Steven Kassel | Noise Measurements | Transportation Laboratory |
| David Nakao | Noise Measurements | Transportation Laboratory |
| Dilford Onodera | Noise Measurements | Transportation Laboratory |
| Earl Shirley | Principal Investigator (replaced Qualls to complete project) | Transportation Laboratory |
| Mas Hatano | Co-Principal Investigator (completed final report) | Transportation Laboratory |

This document does not endorse products or manufacturers. Trade or manufacturers' names are referenced solely because they are considered essential to the object of this report.

# PREFACE

The report on this project is divided into four parts. This format was selected because it was felt that the nature of the information presented could most easily be followed by the reader when presented in this manner.

PART I "PROJECT SUMMARY"

This part gives an overview of the report and summarizes the conclusions, recommendations and proposals for implementation. It is intended to provide upper level management personnel and others a quick but sufficiently thorough presentation of the total project without discussing the details.

PART II "SYNTHESIS OF THE LITERATURE ON QUIETING DIESEL POWERED TRUCKS"

This part summarizes the individual efforts of the Freightliner, White Motor Company, and International Harvester Corporations in analyzing and mitigating truck noise. Also, tire noise studies by the National Bureau of Standards are reported. These studies were performed under contract to the U.S. Department of Transportation.

PART III "SYNTHESIS OF THE LITERATURE ON QUIETING CONSTRUCTION EQUIPMENT"

This part covers the various publications on construction equipment noise. Federal and state laws are also discussed.

PART IV "CALIFORNIA'S WORK ON QUIETING A DIESEL POWERED TRUCK AND A DRILL RIG"

This part describes the modifications to a diesel powered truck and test results indicating the successful efforts to build a "quieted" truck. It also discusses some work done to quiet a drill rig used for construction and maintenance.

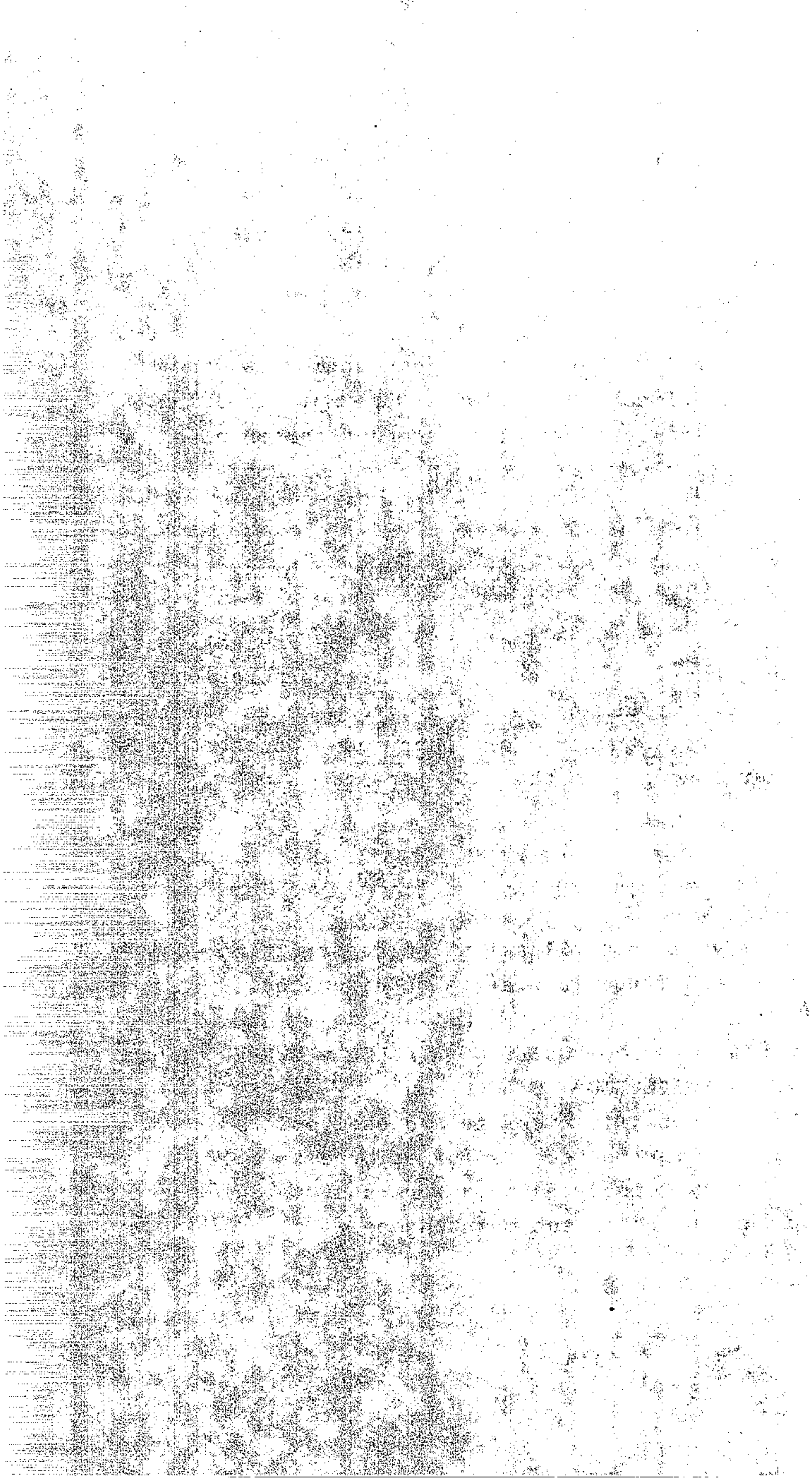


TABLE OF CONTENTS

## PART I
## PROJECT SUMMARY



## PART II
## SYNTHESIS OF THE LITERATURE ON QUIETING DIESEL POWERED TRUCKS

TABLE OF CONTENTS (con't.)

TABLE OF CONTENTS (con't.)

PART III
SYNTHESIS OF THE LITERATURE ON QUIETING CONSTRUCTION EQUIPMENT



PART IV
CALIFORNIA'S WORK ON QUIETING A DIESEL POWERED TRUCK AND A DRILL RIG

TABLE OF CONTENTS (con't.)

## LIST OF FIGURES

### PART I
### PROJECT SUMMARY



### PART II
### SYNTHESIS OF THE LITERATURE ON QUIETING DIESEL POWERED TRUCKS



### PART III
### SYNTHESIS OF THE LITERATURE ON QUIETING CONSTRUCTION EQUIPMENT

LIST OF FIGURES (con't.)

PART IV
CALIFORNIA'S WORK ON QUIETING A DIESEL POWERED TRUCK AND A DRILL RIG

LIST OF FIGURES (con't.)

LIST OF TABLES

PART II
SYNTHESIS OF THE LITERATURE ON QUIETING DIESEL POWERED TRUCKS

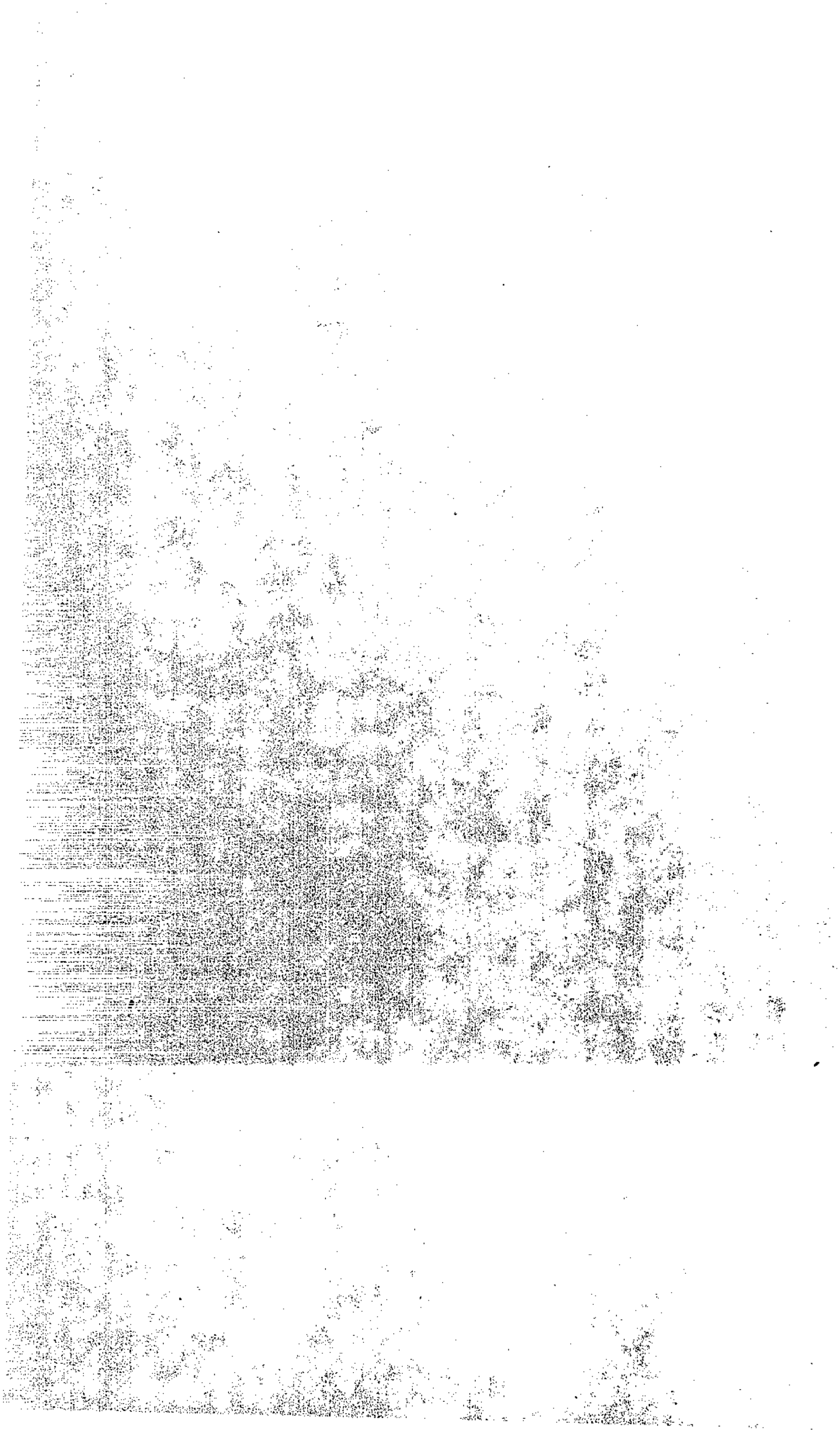


PART III
SYNTHESIS OF THE LITERATURE ON QUIETING CONSTRUCTION EQUIPMENT



PART IV
CALIFORNIA'S WORK ON QUIETING A DIESEL POWERED TRUCK AND A DRILL RIG

APPENDIX



# PART I

# PROJECT SUMMARY

# INTRODUCTION

The National Environmental Policy Act of 1969 (Public Law 91-190) declared a national policy for encouraging productive and enjoyable harmony between man and his environment. This legislation was enacted due to public concern about the extensive pollution of our environment.

Noise is one facet of this problem and is defined as unwanted sound. Noise can be annoying, interfere with various activities, and may cause physical or psychological damage. Figure I illustrates the relative scale and effect of noise on people.

Highway traffic noise is one of the largest sources of noise pollution in our society and, on highways, diesel powered trucks are the loudest noise source. Diesel and non-diesel powered construction equipment is another serious noise pollution source related to highways. Literature on these subjects is limited.

In April, 1971, the Federal Highway Administration (FHWA) approved a California Department of Transportation, Transportation Laboratory project entitled "Diesel Truck and Motorcycle Noise Baseline and Reduction Methods". The following month, the project was combined with another to eliminate redundancy and was entitled "Determine Feasible Noise Limits For Construction and Maintenance Equipment and Study of Noise Reduction Methods". Responsibility for the new combined project was given to the Equipment Department of the California Department of Transportation. The purpose of the study was to find practical methods of quieting the sources of highway related noise pollution and applying them to construction and maintenance equipment. This study was to lead to suggested specifications and guidelines for operation, purchase, and retrofitting construction and maintenance equipment to reduce noise pollution from Caltrans operations.

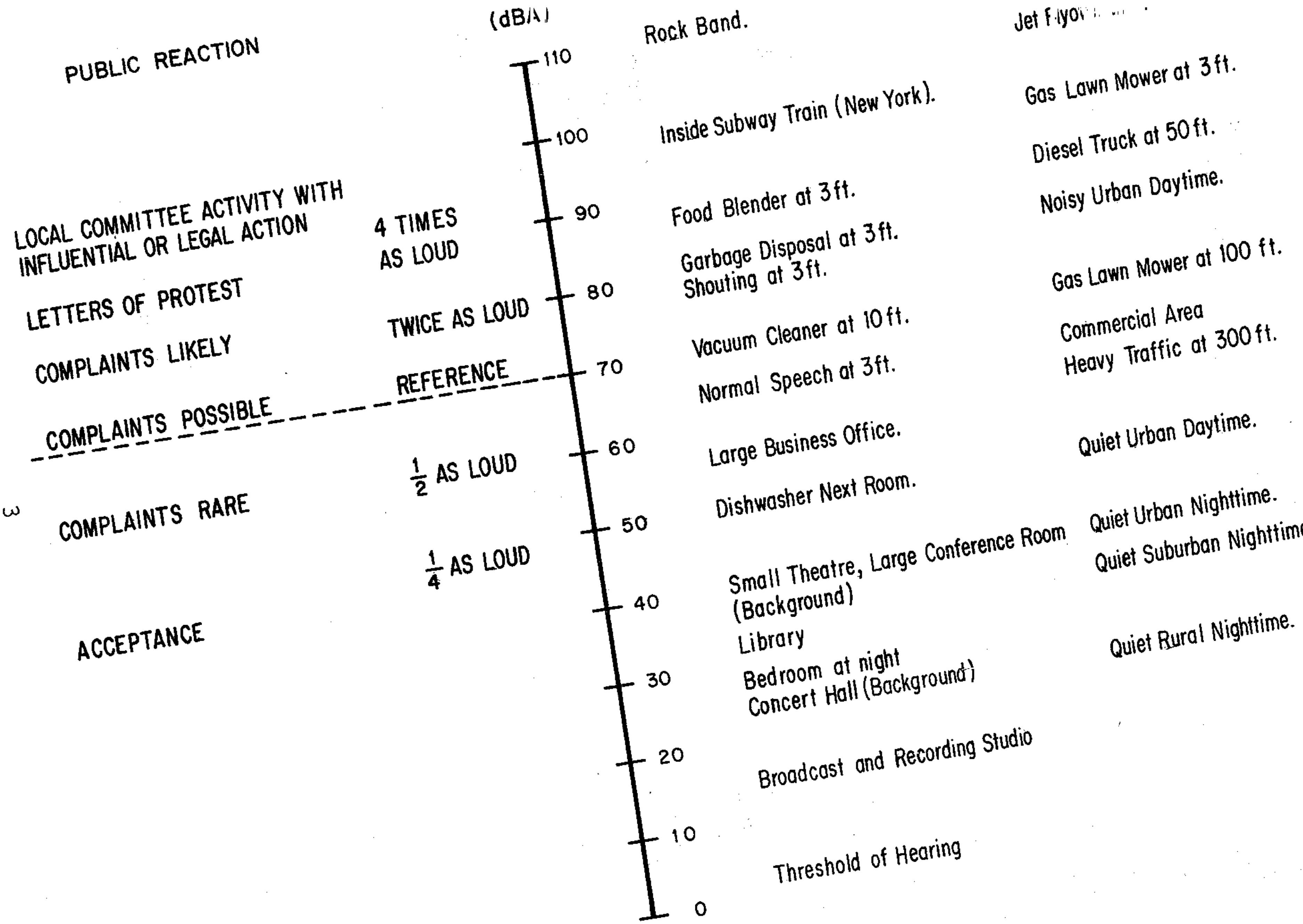

PUBLIC REACTION
LOCAL COMMITTEE ACTIVITY WITH INFLUENTIAL OR LEGAL ACTION
LETTERS OF PROTEST
COMPLAINTS LIKELY
COMPLAINTS POSSIBLE
COMPLAINTS RARE
ACCEPTANCE
4 TIMES AS LOUD
TWICE AS LOUD
REFERENCE
1/2 AS LOUD
1/4 AS LOUD
(dBA)
110
100
90
80
70
60
50
40
30
20
10
0
Rock Band.
Inside Subway Train (New York).
Food Blender at 3ft.
Garbage Disposal at 3ft.
Shouting at 3ft.
Vacuum Cleaner at 10ft.
Normal Speech at 3ft.
Large Business Office.
Dishwasher Next Room.
Small Theatre, Large Conference Room (Background)
Library
Bedroom at night
Concert Hall (Background)
Broadcast and Recording Studio
Threshold of Hearing
Gas Lawn Mower at 3ft.
Diesel Truck at 50ft.
Noisy Urban Daytime.
Gas Lawn Mower at 100 ft.
Commercial Area
Heavy Traffic at 300ft.
Quiet Urban Daytime.
Quiet Urban Nighttime.
Quiet Suburban Nighttime.
Quiet Rural Nighttime.

Figure I

The initial thrust of the project was to modify and [cut off]
a quieted diesel powered truck. Secondly, some work [cut off]
done to quiet construction equipment.

Numerous delays were caused by mechanical problems with
truck, and by technical, administrative and staffing pr[cut off]
These things also resulted in a loss of continuity in th[cut off]
Modifications to the truck were completed around February
and some testing was done that year and during the spring
1976.

In the interim, legislation at the State and Federal level[cut off]
prompted industry to study ways to reduce highway related [cut off]
Findings from various research projects were steadily being
published. As a consequence, these various factors affected
the direction and progress of the work.

Due to the manpower, and administrative and other problems
mentioned, the responsbility for this project was transferred
to the Transportation Laboratory in the latter part of 1976.
Although more work needed to be done with the quieted truck,
a decision was made to report all work completed to date and
synthesize some of the publications directly related to this
study. It was felt that the accomplishments of other researche[cut off]
had essentially covered the objectives of this study.

## OBJECTIVES

1) Synthesize the literature on quieting truck and tire noise.

2) Synthesize the literature on quieting construction equipment noise.

3) Evaluate noise attenuating devices and methods for quieting truck noise.

4) Use findings from items 1, 2 and 3 to retrofit noisy construction equipment.

5) Use findings from items 1, 2, 3 and 4 to develop specifications for construction contracts.

6) Use findings from items 1, 2, 3, 4 and 5 to develop guidelines for equipment operations to promote a quiet environment.

7) Use findings from items 1, 2, 3, 4, 5 and 6 to develop quidelines for purchase of maintenance and construction equipment.

## SUMMARY AND CONCLUSIONS

Studies performed by various investigators have demonstrated that the technology is available for quieting old diesel powered trucks. Also, new trucks can be manufactured to meet the current and proposed noise regulations. Various researchers also reported on successful ways to quiet construction related equipment.

Conclusions Part II Synthesis of the Literature on Quieting Diesel Powered Trucks

1) The major sources of noise on the White, International Harvester, and Freightliner diesel powered trucks were the cooling system, exhaust system, engine, intake and transmission, in this general order. Tire noise was not included because tests were performed at low speeds around 35 mph.

2) The total noise for the trucks studied was initially around 88 dBA and was lowered to about 78, 76 and 72 dBA for the International Harvester, White, and Freightliner Trucks, respectively, after modifications were made to quiet these trucks.

3) Use of a temperature controlled cooling fan was the most effective modification from an engine efficiency and noise reduction standpoint. Other items such as using a larger radiator, a larger fan, slowing fan speed and shrouding the fan were effective in reducing cooling system noise. The maximum noise reduction in the cooling system was achieved by International Harvester (86 down to 66 dBA).

4) Exhaust noise is generally reduced by using a large, heavy, properly designed muffler and using heavy exhaust pipes to minimize shell noise. The maximum noise reduction in the exhaust system was achieved by Freightliner (82 down to 65 dBA).

5) Engine noise was most effectively reduced by using a partial enclosure system. This method is similar to putting the engine in a tunnel with baffles at each end. The maximum noise reduction in the engine using the enclosure system was achieved by Freightliner (84 down to 72 dBA).

6) Intake system noise was generally quieted by using a silencer or using a different off-the-shelf system. Freightliner achieved the greatest reduction in the intake system noise (82 down to 72 dBA).

7) Estimated initial additional costs to the customer for a quieted truck were $1,390 (International Harvester), $1,307 (White) and $1,644 (Freightliner).

8) There were increased weight, maintenance, and operating costs but these items were not fully reported since it was difficult to differentiate between normal costs and additional costs due to the quieting modifications.

9) It was demonstrated that a quieted truck could be built to meet the California (80 dBA in 1978) and Federal (80 dBA 1982) regulations for total vehicle noise.

10) Tire noise is dominated by speed, road surface characteristics, and tread design. It becomes a major noise factor above 35 miles per hour.

11) Rib tire designs were the quietest.

12) Cross bar tire designs were the nosiest.

Summary Part III Synthesis of the Literature on Quieting Construction Equipment

Since this part of the report does not readily lend itself to specific conclusions, the pertinent information is summarized from the various publications.

1) Most construction equipment such as earth moving, processing, compaction, stationary, and impact equipment is gasoline or diesel powered and the principles for quieting these engines are discussed in parts II and IV of this report. Briefly, noise mitigation measures consist of the following:

a) Install or replace the exhaust muffler with a unit recommended by the muffler manufacturer. This is usually the first and most important step to quieting an engine.

b) Perform maintenance to keep all fastened parts tight and all moving parts well lubricated.

c) Use commercially available damping material on sheet metal surfaces.

d) Install or replace intake mufflers.

e) The more difficult measures would be the cooling fan modification and installing rubberized engine mountings.

2) a) Some pile driver noise can be minimized by muffling exhaust noise or using sound muffling encasements constructed with about a 5 mm thick rubber.

b) Vibrating pile drivers are less noisy than impact pile drivers.

c) Hydraulic pile drivers are less noisy than steam or pneumatic units.

3) Pneumatic jackhammers can be quieted by using muffling aprons and installing exhaust mufflers.

4) The most effective means of quieting a compressor is to totally enclose the unit after installing an adequate muffler.

5) Concrete mixing process noise can be reduced by using V-belt instead of chain drive, applying noise damping material to the mixing drum, and proper maintenance. Placing the mixer in a wooden shed can reduce noise as much as 15 dBA.

6) Sharp saw blades can reduce circular saw noise by as much as 5 dBA. Muffling pads and discs are helpful. Operation in a shed can reduce noise by about 10 dBA.

7) Use of electric motors instead of internal combustion engines is preferable from a noise standpoint.

8) Regulations are very effective in forcing manufacturers to design noise control into their products. They can also require retrofitting old equipment with noise control devices, maintaining, and operating equipment with noise control devices to minimize noise.

9) In some cases, scheduling of various operations, changing procedures or equipment, or limiting operating hours may reduce total noise or shift it to a time of the day when the ambient is high.

10) Stationary noisy operations should be kept as far as possible from the construction site boundary to protect the public.

<u>Conclusions Part IV</u> California's Work on Quieting a Diesel Powered Truck and a Drill Rig

A 1964 Chevrolet diesel powered dump truck was successfully quieted. Noise level reductions on the modified truck varied considerably depending on vehicle speed and operating mode.

The following conclusions generally indicate the noise reductions achieved during the various conditions of test.

1) Engine off - Cruise mode tests at 55 mph showed about 70 dBA for the modified truck and 72 for the regular truck.

2) Engine on - Cruise mode tests at 55 mph showed about 72 dBA for the modified truck and 77.5 for the regular truck.

3) Engine on - acceleration mode tests at 50 mph showed about 73 dBA for the modified truck and 82 for the regular truck.

4) SAE J366a - acceleration mode tests at 35 mph showed about 76 dBA for the modified truck and 81 for the regular truck.

5) Engine on - driveby tests for the modified truck showed noise levels slightly increasing from 63 to 66 dBA from 15 to 35 mph. The increase from 35 to 50 mph is somewhat greater ranging from 66 to 75 dBA. There was no significant difference from 50 to 55 mph. Noise levels were slightly higher when the driveby tests were performed with the muffler of the truck on the side closest to the microphone.

## RECOMMENDATIONS

1) The California Department of Transportation (Caltrans) should adopt the proposed noise control specifications shown in Appendix B for construction equipment for all transportation construction contracts.

2) The specifications shown in Appendix C should be used for purchase of new agency owned and operated construction and maintenance equipment.

3) Caltrans Equipment and Maintenance Offices at Headquarters and the Districts should undertake a program to retrofit all internal combustion engines with adequate mufflers designed to achieve the maximum reduction in noise. This would only apply in cases where no mufflers exist, where replacements are needed, or where there is an exhaust noise problem. Guidelines for maximum noise levels are shown in Appendix D. In some cases, it may not be economically feasible to accomplish the mitigation measures by retrofitting.

4) Caltrans should adopt a policy of using District Environmental personnel to assist Construction and Maintenance personnel in monitoring equipment noise so that appropiate abatement measures can be taken.

5) A further study should be made to determine whether the position and direction of the exhaust outlet might reduce the noise levels from trucks to the receiver. The data from this study suggests that the exhaust outlet configuration be modified, placed on the left side of the truck and be pointed towards the center of the highway to reduce noise to the receiver off the right of way.

## IMPLEMENTATION

Reducing noise pollution is a matter of economics. As an example, initial efforts to quiet vehicles may simply require a new muffler, but the maximum noise control may require designing an enclosure system for the engine and drive train. How much noise attenuation must be achieved for vehicles and construction equipment is controlled by various laws, guidelines, ordinances, and specifications of different public agencies.

The researchers feel that Caltrans should be a leader in this field and be guided by the provisions of the Environmental Policy Act of 1969 and the California Environmental Quality Act of 1970. Every effort should be made to incorporate the latest findings from research studies and apply them where feasible even though specific legal requirements may not exist.

## Vehicle Noise Control

Federal and California laws adequately control noise emissions from newly manufactured vehicles (Part III). However, much can be done to minimize noise from older vehicles manufactured before the laws were passed and for those vehicles whose component parts are worn and need replacement. In some cases, noise attenuating devices can be retrofitted to older vehicles.

Equipment managers and equipment maintenance personnel can take the following steps to quiet vehicle noise:

1) The first, most simple and cost effective step in quieting vehicle noise is to have an adequate muffler designed to reduce exhaust system noise. Muffler manufacturers should be consulted to ensure that the unit will be compatible with the engine and not create excessive back pressure. They will also be able to indicate the amount of noise reduction that can be expected. As an example, the Donaldson Company has a muffler attenuation rating (dBA reduction from straight stack) to describe the performance of their mufflers. It ranges from 3 to 35 with the following classifications: 3-5 minimum, 5-12 bark arrester, 12-18 moderate, 18-25 good and 25-35 hi-silencer.

Exhaust system noise should be measured before and after modifications so that effectiveness of the abatement measure can be evaluated.

The following is a list of sources which may be able to provide information on mufflers. It is not all inclusive but is intended to serve as a guide.

SOURCES FOR TRUCK AND CONSTRUCTION EQUPMENT MUFFLERS

1) Alexander-Tag Industries Inc.
395 Jacksonville Road
Warminster, PA 18974

2) AMF Beaird, Inc.
Maxim Silencers
P. O. Box 1115
Shreveport, Louisiana 71102

3) Donaldson Company, Inc.
1400 West 94th Street
Minneapolis, Minn.

4) Kittell Muffler & Engineering
1977 Blake Avenue
Los Angeles, Calif. 90039

5) Mariemont Corp.
3025 West 47th Street
Chicago, Illinois

6) Nelson Muffler Corp.
Stoughton, Wisconsin 53589

7) Reiker Mfg. Inc.
4901 Stickney Avenue
Toledo, Ohio 43612

8) Stemco Mfg. Co.
P. O. Box 1989
Longview, Texas 75601

9) Walker Mfg. Co.
1201 Michigan Boulevard
Racine, Wisconsin

2) Cooling system fan noise is often a predominant source of noise. Effective procedures are to shroud the fan, change pulley diameter to slow the fan down, and use larger fans to maintain the same volume of air flow.

A temperature controlled fan is very effective when the vehicle is used predominantly at high speeds.

The manufacturer of the engine should be consulted before any changes are made in this area so that optimum operational characteristics will be retained.

Noise reductions of 10 dBA or more may be achieved in quieting cooling system noise.

3) Other measures that may be helpful if the exhaust and cooling system noise emissions are reduced is to use commercially available intake system silencers and engine acoustic cover plates. These items can reduce noise by about 3 dBA. Information can be obtained from the engine manufacturers.

4) A final procedure for quieting vehicle noise which requires special designs and major vehicle modifications is to enclose the engine and drive train with sound attenuating material. This is a very effective but costly method that is not generally recommended for vehicles but may have some applications for construction equipment in special locations where noise control is a paramount concern.

Mitigation of Maintenance and Construction Equipment Noise

The techniques for quieting noise from equipment in this category were discussed in the summary for "Synthesis of the Literature on Quieting Construction Equipment" in this Part I. The specific details of "how to" should be obtained from the manufacturer of the particular equipment involved.

# PART II

# SYNTHESIS OF THE LITERATURE ON QUIETING DIESEL POWERED TRUCKS

## INTRODUCTION

On July 5, 1972, the U.S. Secretary of Transportation awarded research contracts to the Freightliner Corporation of Portland, Oregon; International Harvester Company of Fort Wayne, Indiana; and the White Motor Corporation of Torrance, California. This research effort was directed towards quieting truck noise but did not include tire noise. Two years earlier, the Department of Transportation (DOT), in cooperation with the National Bureau of Standards (NBS), performed research studies on automobile and truck tire noise.

Heavy duty diesel truck noise is the greatest contributor to highway noise. In 1971, more than 88,000 diesel trucks in the 33,000 pound class were delivered in the United States and 45 percent of these trucks were manufactured by the three firms under contract. Their objective was to identify and design noise reduction measures on their regular production trucks and enter them into regular commercial service. Complete costs and maintenance work were to be documented.

Freightliner, as a prime contractor, organized a team composed of Bolt, Beranek and Newman (noise control engineers); Cummins Engine Company (engine design and economics); Donaldson Company (intake and exhaust systems) and Mid American Lines (field evaluations).

White Motor Corporation, as another prime contractor, organized a team composed of Cummins Engine Company (engine design); Donaldson Company (intake and exhaust systems); Schwitzer Company (radiator fans); and the Hydrospace Challenger Corporation (instrumentation and data processing).

International Harvester, as the third prime contractor, organized a team composed of the Donaldson Company (intake and exhaust); Purdue University (acoustic consultant and engine enclosure) and International Harvester Engineering Research (cooling system).

The time schedule for the three contracts specified one year for identifying noise sources and designing a quieted truck (to July 1973); one year of regular commercial service (to July 1974) and finally to publish their findings. The last report under this series of contracts was completed by Freightliner in December 1975. The reports under the DOT contract are referenced as numbers 1 through 16.

This part of the report synthesizes the findings of the three contractors on truck noise and the NBS findings on tire noise. No effort was made to cover the details of all the experiments but the significant achievements are presented. The reader can check the references for additional information.

Work by others such as Ford and General Motors is not covered here since much of the information on their studies is proprietary. Discussion with their engineers indicated the work appeared to be similar to that performed by the three contractors. There were also other studies by Paccar and General Motors under contract to the U.S. Department of Transportation that are not reported here because the information was similar to that of the three contractors.

# DESCRIPTION OF TRUCKS

## White Motor Company

The following is a description of the White Motor Company datum vehicle used in their research (Reference 16).

1) White Model RC64T Road Commander truck tractor, cab over engine, non sleeper

2) Engine - Cummins NTC-270CT turbocharged custom torque 6 cylinder in-line four cycle diesel, 270 HP at 2,100 RPM, 855CID, 5 1/2" bore, 6" stroke.

3) Transmission - Six speed Fuller RT906

4) Rear Axle - Single speed Rockwell SQHD

| | | |
|---|---|---|
| 5) | Front Axle | White F3W-120 |
| 6) | Rear Suspension | Hendrickson R.T. 380 |
| 7) | Steering | White 7J |
| 8) | Brakes | Air-Bendix |
| 9) | Exhaust Muffler | Nelson-Horizontal |
| 10) | Air Cleaner | Donaldson 16 inch |
| 11) | Fuel Tanks | 75 Gal., R.H. and L.H. |
| 12) | Battery | Four 6V, 172 A.H. |
| 13) | Air Compressor | Cummins 13.2 CFM |
| 14) | Freon Compressor | Tecumseh HG-1000 |
| 15) | Alternator | Leece Neville 65 Amp |
| 16) | Engine Brake | Jacobs Model 258 |
| 17) | Tires | General HCR (quiet rib-type) |
| 18) | Radiator Shutters | Kysor |

Freightliner

The following is a description of the datum Freightliner Corporation vehicle used in their research (Reference 1).

| | | |
|---|---|---|
| 1) | White-Freightliner COE truck tractor model WFT8164T, cab over engine | |
| 2) | Serial Number | CA213HP067330 |
| 3) | Car Number | 52447 |
| 4) | Engine | Cummins NTC-350, 6 cylinder, in-line turbo-charged diesel with a 350 HP rating at 2100 RPM, 4 cycle, 855CID, 5 1/2 stroke, 6" bore |
| 5) | Transmission | Fuller RTO-12513 with 4.11:1 axle ratio |
| 6) | Differential | Rockwell-Standard WHD tandem (4.11:1) |
| 7) | Exhaust System | Single branch 4-in. diameter tubing. Vertical muffler on right side with stack outlet 13-1/2 ft above ground. |
| 8) | Muffler | Con Met A04-9990 |
| 9) | Cab | 81-in. sleeper cab-over-engine |
| 10) | Intake | Snorkle at rear of cab |
| 11) | Tires | 10:00 x 22 General HCR with tread pattern of five circumferential straight ribs (Rib "A"). |
| 12) | Fan | 26" dia. 3-1/4" projected width, 6 blades running at 1.2 x engine speed (SC/914043) |
| 13) | Air Conditioner | Freightliner 320D with radiator mounted condensor |
| 14) | Year Mfg. | 1972 |

## International Harvester

The following is a description of the International Harvester Company datum truck used in their research (Reference 13).

1) International Harvester model COF 4070A, cab over engine

| | | |
|---|---|---|
| 2) | Engine: | Detroit Diesel 8V-71N (N-65 Injectors) equipped with rapid warm-up cooling, rated at 318 HP at 2100 RPM, 8 cylinders, 2 cycle, 518 CID, 4-1/2" bore, 5" stroke. |
| 3) | Transmission: | Fuller RT-910 (10-Speed) |
| 4) | Exhaust System: | Dual 9" Diameter Mufflers, 3-1/2" In and Out, Donaldson No. MSM09-0157. Vertical Mufflers with Vertical Tailpipe. |
| 5) | Induction System: | Primary Dry Air Cleaner, Donaldson No. FWA16-0107, mounted on right side behind cab. Vertical intake pipe with offset metal rain cap. |
| 6) | Cooling System: | Radiator - 4 staggered rows, 11 fins per inch (louvered plate fin type); 38" high, 26.3" wide, 2.33" thick. (1000 $In.^2$ frontal area).<br><br>Fan -- 26" diameter, 2.42" projected width, 6-blades, operating 1.2 times engine speed. |
| 7) | Tires: | Goodyear, Custom Hi Miler, 11.00 x 24.5, rib tread. |

## TEST PROCEDURES

The procedures used by various researchers to measure truck noise generally conformed to the SAE J366a Recommended Practice (Appendix A). This is a full power acceleration test where the truck passes 50 feet from a microphone at an initial approach speed of 35 miles per hour. The vehicle produces maximum noise under these conditions and, because of the low operational speeds, tire noise is minimized.

In order to set a standard for comparison purposes the SAE J366a procedure was used by all researchers.

Tests for tire noise were performed with the engine off and the vehicle coasting by the test area at various speeds.

## IDENTIFYING SOURCES OF NOISE

The primary sources of information on quieting trucks were reported by the International Harvester Company, Freightliner Corporation, and the White Motor Company. They were under contract to the Department of Transportation to perform research to demonstrate diesel truck noise reduction technology.

Initially, the suspected sources of noise were identified as the exhaust system, cooling system, intake system, engine, transmission, drive train, and other component parts. Various techniques were used to isolate and measure the sound level of the sources. Tire noise was not considered because all testing was performed using the J366a test.

International Harvester and the White Motor Corporation used the technique of isolating the various source components except the one being studied. As an example, when the exhaust system was to be studied, the intake system, engine, transmission and rear axles were covered with about four inches of fiberglass or lead faced polyurethane foam to minimize the noise from these items. The cooling fan was disconnected. Each source was uncovered individually and tested. Coast-by tests with the engine off were used to evaluate the tire effect and transmission noise. All tests were performed in the field according to the SAE J366a procedure.

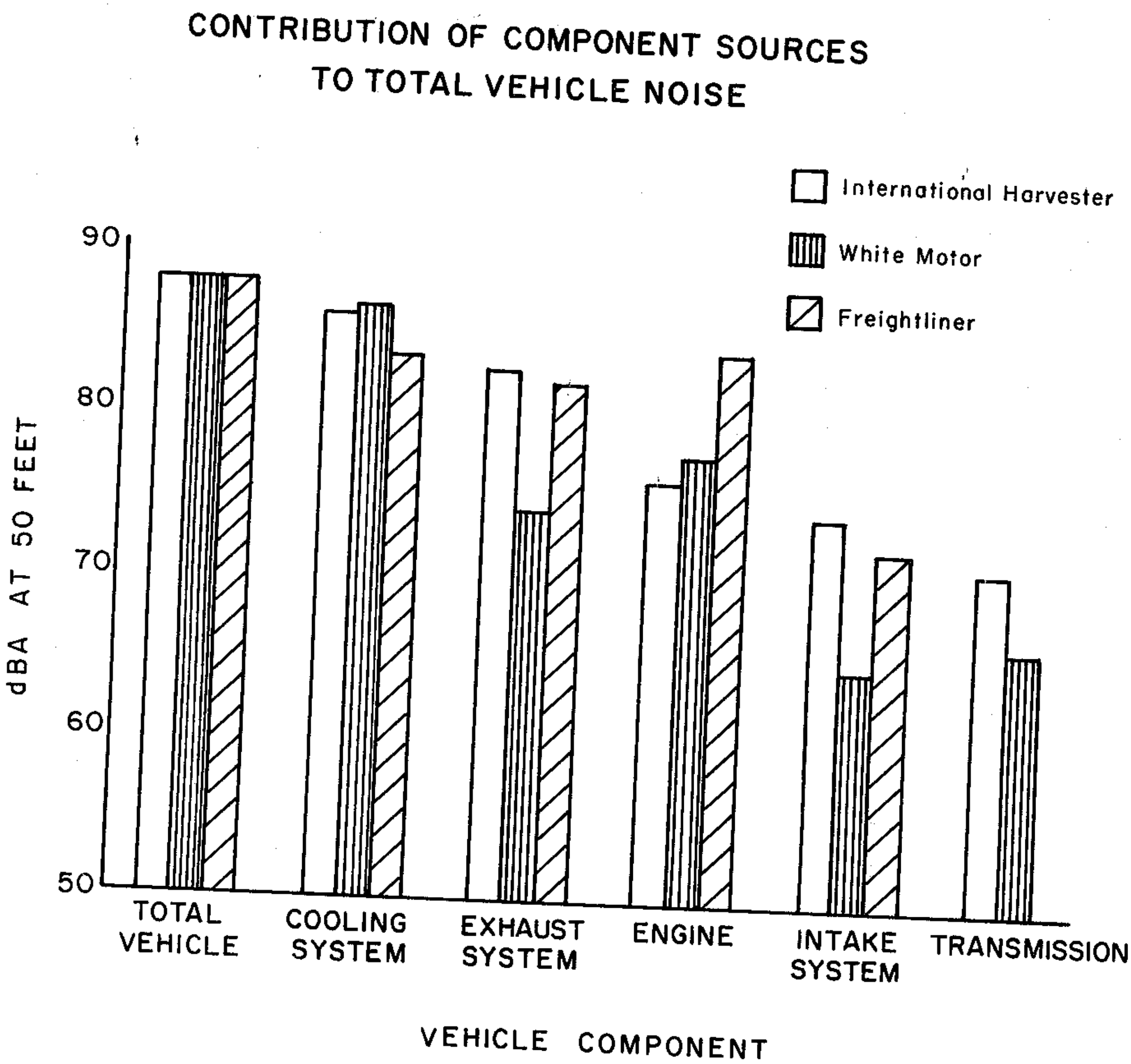
The Freightliner Corporation used their dynamometer testing facility which was modified with insulating material to somewhat simulate an anechoic room. They also used insulating material to minimize tire and dynamometer noise. Tests were performed to simulate the SAE J366a procedures and data were extrapolated to 50 feet. Noise measurements were made by placing the microphone near the specific component being evaluated. Figure II shows the comparative test data for the three type of trucks tested.

## REDUCTION OF COOLING SYSTEM NOISE

The cooling system was the noisiest component in the datum vehicle for the Freightliner, White, and International Harvester trucks (Figure III). Basically, the function of the cooling system is to maintain an optimum operating temperature at all times to maximize the life and efficiency of the engine. This is accomplished by controlling the flow of air and coolant in and around the engine.

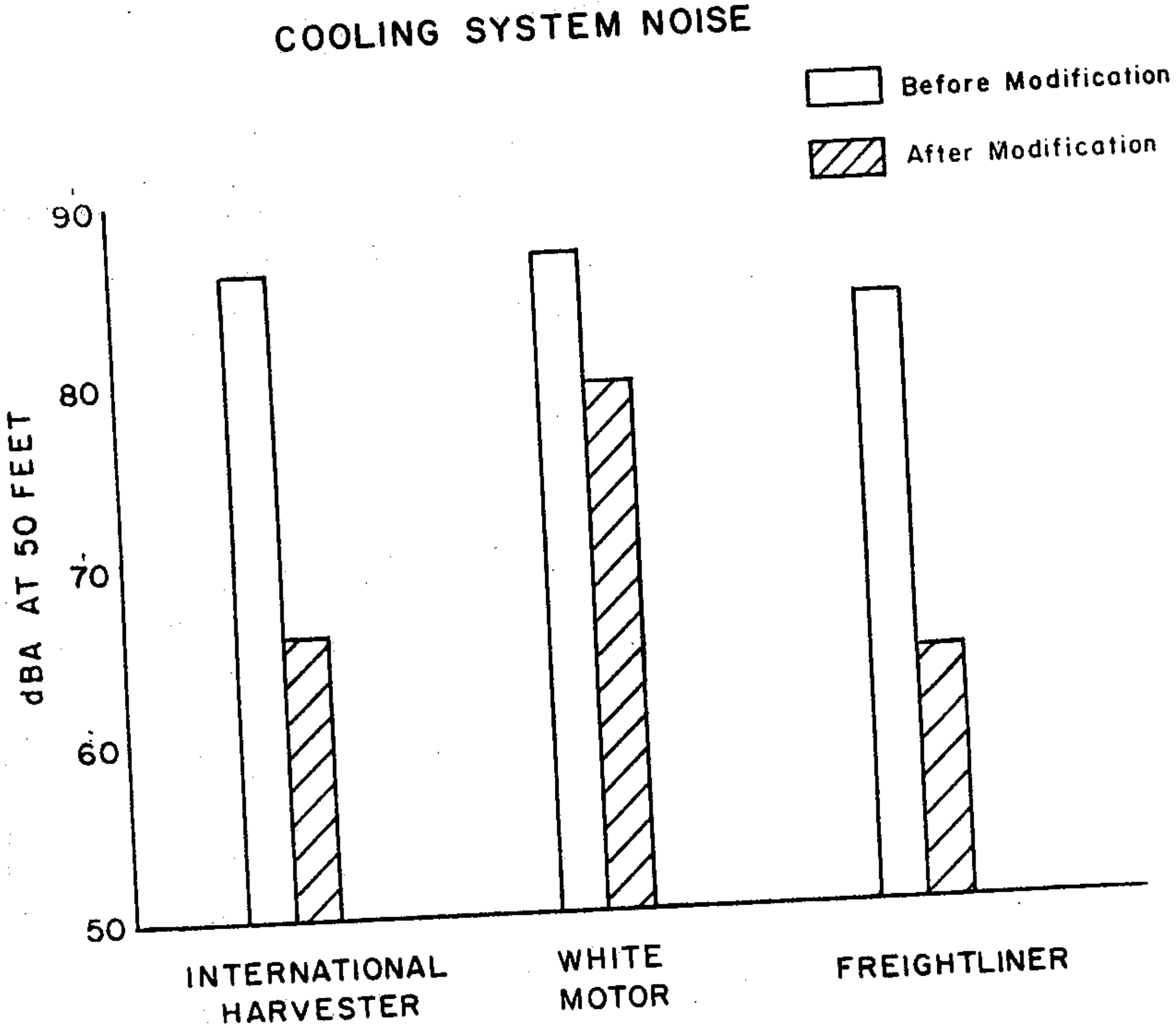
Noise associated with the cooling system comes from the fan. Redesigning the fan helps to reduce noise but the major reduction comes from reducing fan rotational speed while maintaining its cooling capabilities. In order to quiet the fan, it is necessary to modify the cooling system components such as the shroud, the radiator, and the fan-to-radiator clearance or the shutters.

Figure II




From References 1, 9, 16

Figure III




From References 5, 11, 16

White Motor Company

White Motor experimented with 10 various types of fan and shroud combinations. The best performer was a Flex-A-Lite, Model TF 1328-3 with 6 evenly spaced 30 inch diameter blades having tip to shroud clearance of one inch. Test results indicated a 6 to 8 dBA noise reduction and 5.5 less horsepower to operate. This fan was also 9 pounds lighter than the fan on the production model.

## International Harvester

International Harvester conducted their studies in the laboratory and in the field. They found that minor noise reductions were achieved by changing fan design. Major reductions were realized by sealing the shroud to the radiator and using a contoured shroud with reduced fan tip clearance. Other modifications that were helpful included optimizing radiator heat transfer surface, optimizing fan to radiator distance and the elimination of shutters. Clutches which controlled fan operations only when needed eliminated fan noise for a large portion of the time and resulted in a savings of horsepower and fuel.

Modifications to the cooling system resulted in a decrease in noise level from about 86 to 66 dBA.

## Freightliner

Freightliner's effort to quiet cooling system noise was concentrated on the fan, radiator and shrouding. They had developed a 2,000 square inch radiator which was much larger than their 1200 square inch radiator used in the datum truck.

Because of the larger radiator, a larger Schwitzer 7 bladed, 31 inch diameter, staggered blade fan was used on the quieted truck as compared to the 6 bladed, 28 inch diameter fan on the datum truck. The researchers concluded that the staggered fan did not reduce noise but did make the noise less tonal and therefore, less intrusive.

A shroud was designed for this system with a 1/2 inch clearance at the top and bottom and 1 inch on the sides. The combination of radiator, fan and shroud allowed a reduction in the rotational speed of the fan and still maintained comparable cooling capacity. These factors reduced the cooling system noise from about 84 to 64 dBA.

Freightliner also used a "Thermatic" fan drive which permitted the fan to be disengaged for over 99% of the truck's operating time. This results in considerable fuel savings since the fan needs 10 or more horsepower to operate. This savings would not be found if the truck operated at slow speeds in warm weather.

## REDUCTION OF EXHAUST SYSTEM NOISE

Exhaust noise is created by the high velocity gas flowing through the ports of the engine. This noise is also radiated from the manifold, the walls of the exhaust pipes, and the muffler, as well as being transmitted directly from the open end of the exhaust system.

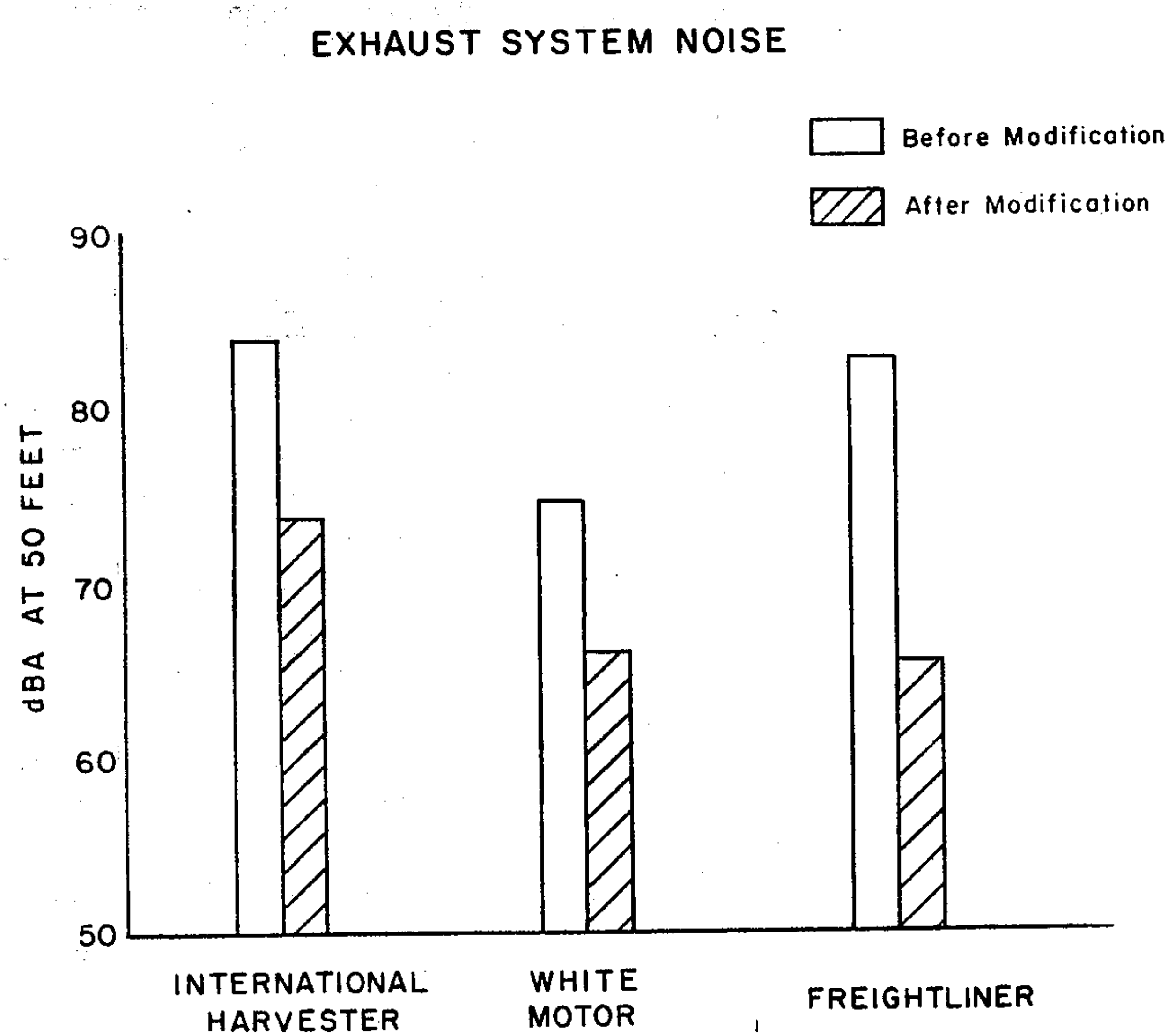
The three basic types of mufflers are the absorptive, which absorbs the noise in a porous packing material; the reactive, which reflects the noise back down the pipe towards the engine; and the dispersive, which creates a pressure drop in an expansion chamber. All three types attenuate noise in varying degrees depending on the size of the device and where it is placed in the exhaust system.

Other considerations in exhaust system noise control are limitations on exhaust back pressure, leaks in the system, which are common, and the mounting of the system.

In all cases, no attempt was made to redesign the engine in order to reduce noise levels.

The comparative data for the exhaust system for the three manufacturers are shown on Figure IV.

Figure IV




From References 3, 12, 16

## International Harvester

The International Harvester Company was the prime contractor on this study and the Donaldson Company, a well known muffler manufacturer, was the subcontractor. Modification experiments on the exhaust system were performed in the laboratory by Donaldson and in the field by International Harvester.

Various combinations of primary mufflers, resonators, and absorptive tailpipe were investigated. Five different systems were studied and the final system adopted consisted of dual exhausts with a single muffler per bank. The mufflers were a combination of reactive, dispersive and absorptive devices (Donaldson 5135D47).

The mufflers were 23% longer, 18 percent greater in diameter and 65 pounds heavier (each) than the baseline mufflers. Pipe shell noise was still a major unsolved problem which made further exhaust noise reduction doubtful.

Exhaust system noise was reduced from about 83 to 73 dBA.

## White Motor Company

The White Motor Company was the prime contractor on this study and the Donaldson Company, was the subcontractor. Modification experiments were performed in the laboratory by Donaldson and in the field by White.

Dual and single exhaust stack systems were developed for study. Each system had resonators, exhaust mufflers, and a super stack (smaller muffler). The studies indicated one muffler did an adequate job of reducing noise. Elimination of one system, the resonator, and super stacks resulted in an increase of 2 to 3 dBA in exhaust noise. This was not a significant contribution when the added cost and weight were considered. The single exhaust system equaled 75% of the dual system volume.

Noise reduction from the datum truck to the quieted truck for the single exhaust system was about 74 to 66 dBA. The probable reason for the White exhaust system being quieter than the International Harvester and Freightliner is the smaller horsepower engine in the White truck.

Freightliner Corporation

The Freightliner Corporation was the prime contractor on this study and the Donaldson Company was the subcontractor. Modification studies on the exhaust system were performed in the laboratory by Donaldson and in the field by Freightliner.

A multiple muffling approach of identifying and mitigating noise from the various components in the exhaust system was used.

Initially a three chamber exhaust manifold muffler was designed and it helped reduce back pressure and low frequency noise. Next an Expand-O-Flex exhaust pipe coupling was used to minimize exhaust leaks and provide some isolation of high frequency vibration.

After various mufflers were studied, a Donaldson 9 inch diameter, venturi choke muffler (model MPM09-0141) was placed on each of the dual stacks. Donaldson muffler wraps were used to protect personnel from muffler burns and also helped to reduce noise.

Finally, a pair of stock silencers (Donaldson AEM-00-1207) replaced the muffler tailpipes. The silencers consist of a perforated inner tube of the same diameter as the exhaust pipe surrounded by an asbestos blanket within a 6 inch diameter outer cylinder.

The overall reduction in exhaust system noise over the datum vehicle was 17 dBA (82 to 65).

## REDUCTION OF ENGINE NOISE

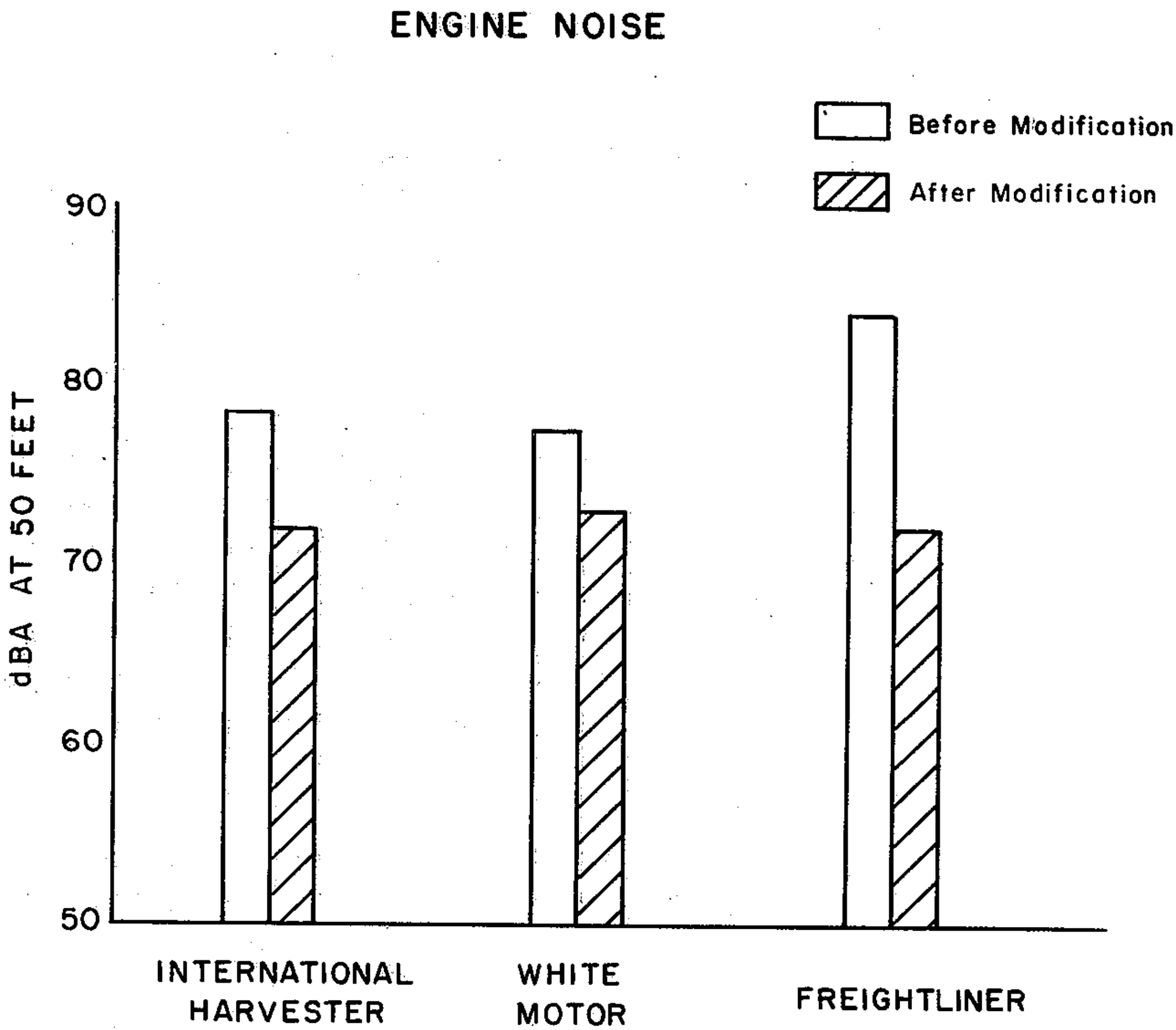
Engine noise is not a major contributor to total truck noise. However, noise reduction in other systems could result in engine noise becoming a major factor in total truck noise control.

A significant amount of structural vibrations come from things such as piston slap, timing gears, valves, injector and pump forces, and bearing clearances. Combustion was another engine component noise source. Structural response is the transmission of noise from the internal members of the engine to the external non-load carrying surfaces. No effort was made to control noise in these areas because the research did not provide for major modifications to the engine.

The major thrust of all the engine noise studies by International Harvester, White and Freightliner was directed towards shielding parts of the engine or partially enclosing the engine. The noise data are shown on Figure V.

It is interesting to note that the noise level of the Cummins NTC 350 (84 dBA) was higher than the Cummins NTC 270 (78 dBA) or the Detroit 8V-71N (76 dBA). An examination of the engine specifications suggests that the greater horsepower of the Cummins NTC 350 was the reason.

Figure V




From References 3,13,16

## International Harvester

International Harvester's first experiments involved shielding the engine by attaching close fitting covers and panels. A coated oil pan, block, manifold, valve and blower covers that were insulated and mounted with rubber grommets were designed for the engine. Three successive trial sets were tested and the third set decreased engine noise by 2.5 dBA.

Another 1.5 dBA noise reduction was achieved by using a modified alternator cooling fan with asymmetrically spaced blades instead of the usual symmetrical unit.

The Detroit Diesel engine (8V-71) can be purchased with several different oil pans, approximately 20 different exhaust manifolds, and optional accessory drives. Modifications to quiet this engine with one set of optional equipment may not be successful with another set of optional equipment. Other considerations are accessibility to the engine for maintenance, weight, fire hazards, and sealing considerations.

Purdue University was the subcontractor for developing a partial enclosure around the engine. Some of the factors involved in designing the enclosure were the mass of the walls, the use of acoustical absorbing material, and the enclosure configuration (walls should not be parallel to the engine and the enclosure volume should be as large as possible).

The basic enclosure consisted of a tunnel around the engine with acoustically treated inlet and outlet openings. It was constructed of 22 gauge sheet metal around a steel framework and lined with one inch of acoustical foam having a mylar facing. The cab served as the top of the enclosure. Noise was reduced about 7 dBA by the enclosure. The weight of the vehicle was increased by 400 pounds.

The total engine noise on the prototype vehicle was reduced from about 78.5 to 72 dBA.

## White Motor Company

Initially, the White Motor Company evaluated the application of panels to quiet the engine. The Cummins Engine Company had previously developed panels for their engines. These panels were sheet metal lined with fiberglass and mounted with rubber isolation grommets to the engine. All panels were abandoned when the partial enclosure system was adopted.

The research involved in the enclosure design considered things such as ease of manufacture, amenability to experimental change, accessibility, durability, maintenance, and air flow capacity.

A partial engine enclosure was accomplished by using sheet metal lined with urethane foam sound absorption material encased in plastic to protect the material from water and oil. The vehicle cab served as the top of the enclosure.

Noise was reduced on the prototype vehicle from 77.5 to 73 dBA.

## Freightliner

The Freightliner baseline truck used a Cummins engine. A quiet kit was offered by Cummins which consisted of damped valve covers, intake manifold isolation, side covers, and oil pan covers. The parts were constructed of steel and aluminum lined with fiberglass and a rubber compound. About 2 to 3 dBA noise reduction was achieved by this modification.

Laboratory experiments were performed using a partial and fully enclosed engine system which reduced noise levels from 77 to 74 dBA. A partial enclosure system was finally adopted due to less cooling problems, easier maintenance, and lower costs.

The enclosure system consisted of 0.080 inches thick aluminum panels covered with 2 inch thick Owens Corning fiber glass pads. The fiber glass lined truck cab was the top of the enclosure. Basically, the system was a lined tunnel surrounding the engine and transmission except for essential openings.

Noise on the quieted truck was about 72 dBA as compared to 84 on the baseline vehicle.

## INTAKE SYSTEM

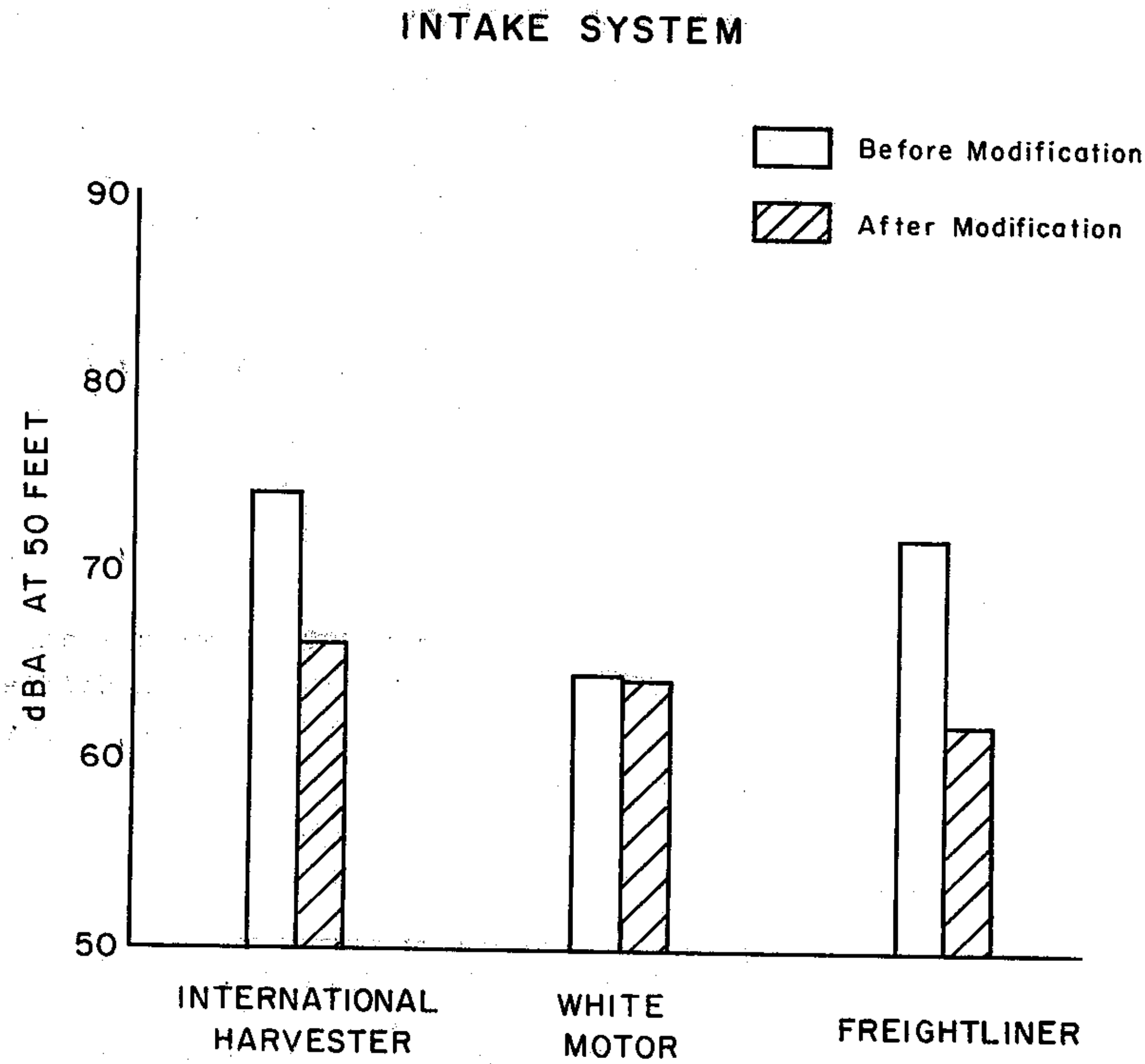
The intake system was not noisy as compared to the other systems (fan, exhaust, engine) when noise levels were initially identified (Figure VI). In general, no major modifications were made to the intake system by the three manufacturers.

### International Harvester

The intake system was relatively quiet and only minor changes were made. A Donaldson in-line silencer was added between the air cleaner and engine. This change made it necessary to change some of the piping. A plastic raincap was also used.

Noise was reduced from 74 to 66 dBA by these changes. Although the intake system was not a dominant noise source, the 8 dBA reduction was significant and should be remembered because this does become very important as the total truck noise is decreased.

Figure VI




From References 3, 12, 16

## White Motor Company

The baseline truck intake system noise was very low when compared to the overall vehicle noise. Because of the low noise, studies were performed to determine if a smaller 15 inch diameter air cleaner could be used instead of the 16 inch on the quiet truck in order to provide more space behind the cab. The data indicated the noise level stayed around 65 dBA.

## Freightliner

No design modifications were made except using a production Frontal-Aire intake system with a Farr Dynacell air cleaner. This was quieter than the snorkel system on the datum truck because the entrance noise tended to be beamed straight forward rather than generally broadcast. The entire system on the quiet truck was in the engine enclosure.

There was a reduction in intake noise from 82 to 72 dBA.

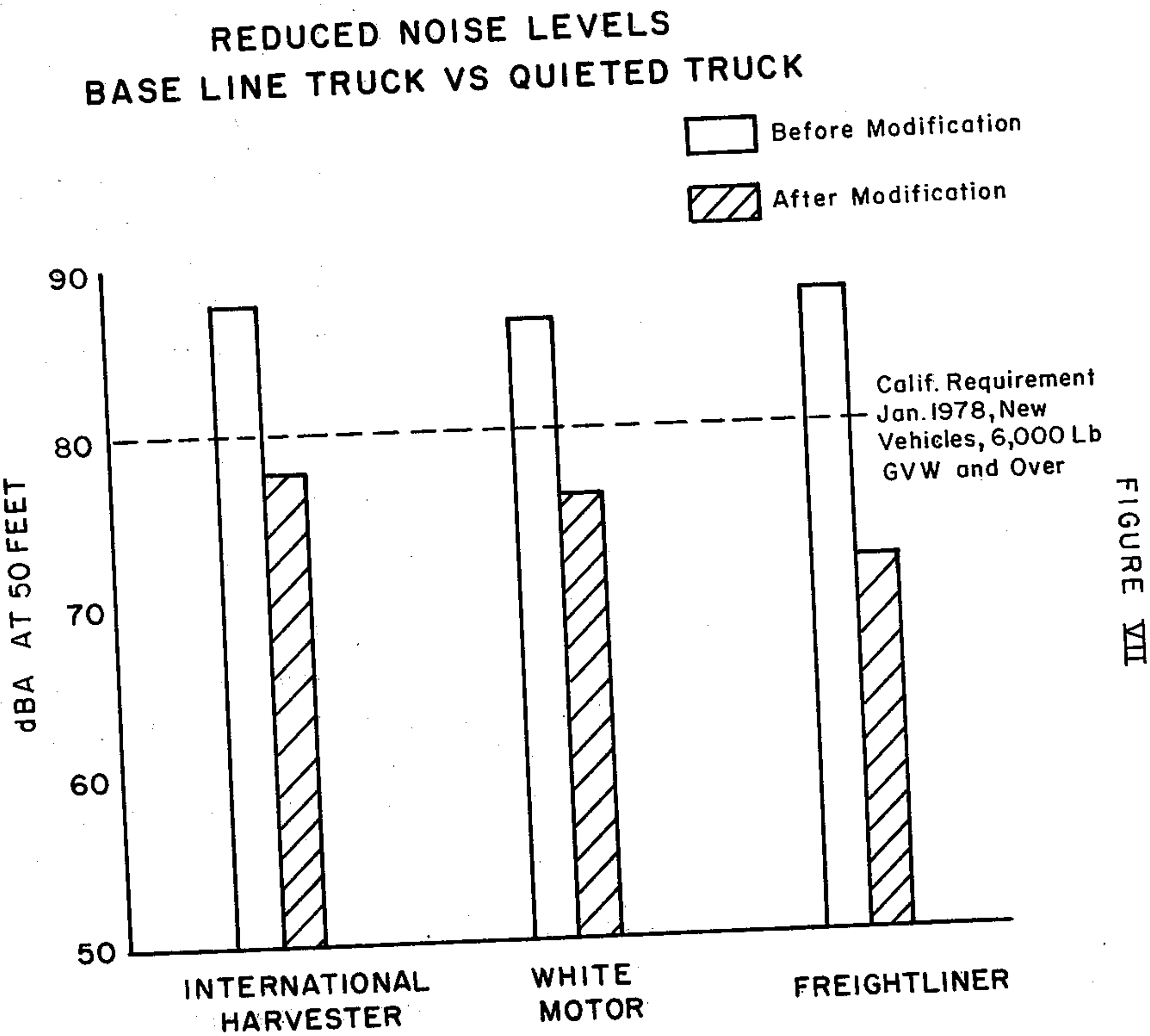
# TRANSMISSION NOISE

No separate discussion on the transmission system is presented because the noise level from this component was generally low. Noise was reduced in all cases when the transmission was partially enclosed during the efforts to quiet the engine.

# QUIETED TRUCKS

Figure VII shows comparative noise levels before and after modifications on the International Harvester, White and Freightliner trucks. The total truck noise was originally

Figure VII




From References 8, 9, 16

around 88 dBA for all three manufacturers and was reduced below 80 dBA in all cases after modifications. These trucks would meet the State of California (80 dBA) and Federal (83 dBA) noise requirements for newly manufactured trucks which becomes effective in January 1978.

## ECONOMICS

### International Harvester

Modifications on the quieted International Harvester truck resulted in an initial estimated cost to the user of $1,390. The major costs were from the engine enclosure, cooling, and exhaust systems. Increased maintenance costs were estimated at $174 for the first 150,000 miles and $1,058 for the first 450,000 miles. The increased weight due to the modification was 580 pounds.

Due to the improved cooling system, there was a savings in fuel cost estimated to be $199 over 450,000 miles.

The initial cost of reducing truck noise from 88 to 80 dBA was approximately $70 per dBA and $550 per dBA below 80 dBA. All of the costs shown are based on 1972 prices.

Efforts for future reduction in noise level on the International Harvester truck must be concentrated in the engine since this became one of the dominant noise sources on the quieted truck. Engine modifications will require extensive research and initial costs are expected to be high.

Maintenance cost comparisons were made between the unmodified and quieted trucks but the costs were not reliable. There was a wide range of costs on the unmodified truck from 1.2 to 2.4

cents per mile, which was based on a different year than the costs for the quieted truck. The quieted truck was in an accident which required repairing the cooling system and there was an unrelated rear axle problem that had to be corrected.

Because of the problems cited, International Harvester reported that the noise reduction modifications will probably result in some increased maintenance costs but that the increases should be modest at low vehicle mileage and should not be excessive the first year.

White Motor Company

Modifications to build the White Motor Company quiet truck resulted in an initial estimated cost to the user of $1,307. The major costs were from the engine enclosure.

The cost of reducing noise from 86.6 to 79.2 dBA was $37 per dBA and $137 per dBA from 79.2 to 76.3 dBA. There was an added 355 pounds in weight to the quieting modifications.

No operational or maintenance costs were reported.

Freightliner Corporation

The added cost to the customer for noise control on the Freightliner truck was estimated to be $1,644. The major costs were from the enclosure of the engine followed by the exhaust and cooling system. An estimated total weight of 771 pounds was added due to the quieting components. Over 50 percent of that weight was due to the engine enclosure system.

Freightliner estimated it would increase truck price by 1.87 percent to reduce noise from 88 to 83 dBA, 3.43 percent to to from 83 to 80 dBA and 4.92 percent to go from 80 to 75 dBA.

Changes in estimated annual operating costs varied considerably depending on the particular noise control treatment used. Freightliner showed 19 different options with savings from $879 to increased cost of $607. As an example, full engine enclosure increased operating cost $583 and the exhaust outlet $61. There was a considerable operating cost savings of $897 by using a demand actuated drive cooling fan and a $17 savings for the intake system.

After about one year of field trials, maintenance records indicated a total expenditure of $3,630, of which $245 was spent on noise control hardware maintenance. The report suggested that the total maintenance cost was excessive and could have been due to inexperience in operating and maintaining a quieted truck.

## TIRE NOISE

### Truck Tire Noise

There are no truck tire noise regulations at the present time. Tire noise is not a significant factor because other vehicle component noise dominates when the SAE J366a test procedure is used. However, as the engine, exhaust, fan, and other sources are quieted, the tire noise may become a significant factor and this may have implications on design of noise mitigation measures for highways.

There have been a number of studies on truck tire noise which have been reported. This discussion is a synthesis of six studies performed by the National Bureau of Standards for the U.S. Department of Transportation on truck tire noise (17, 18, 19, 20, 21, 22). All studies were performed on portland cement concrete (PCC) and asphalt concrete (AC), test sections.

Nine tire tread designs consisting of three rib, three cross-bar and three retread patterns were used. The retread patterns included a rib, cross-bar and pocket design. These designs were representative of 70 to 80 percent of the total truck tire population in use. The rib designs were the most common type. Figure VIII shows the various types of tire designs used.

The tires were mounted on four different trucks. Two trucks were the International Model 1890 chassis equipped with a 20 foot stake body. One of these was loaded to a gross vehicle weight of 25,640 pounds while the second similar truck was unloaded with a gross vehicle weight of 10,800 pounds. A third vehicle was a Ford tandem tractor model TL-9000 loaded to a gross vehicle weight of 65,080 pounds. The fourth vehicle was a White Freightliner tandem tractor model WFT-8164T with a gross vehicle weight of 67,200 pounds. All tests were performed with the engine off.

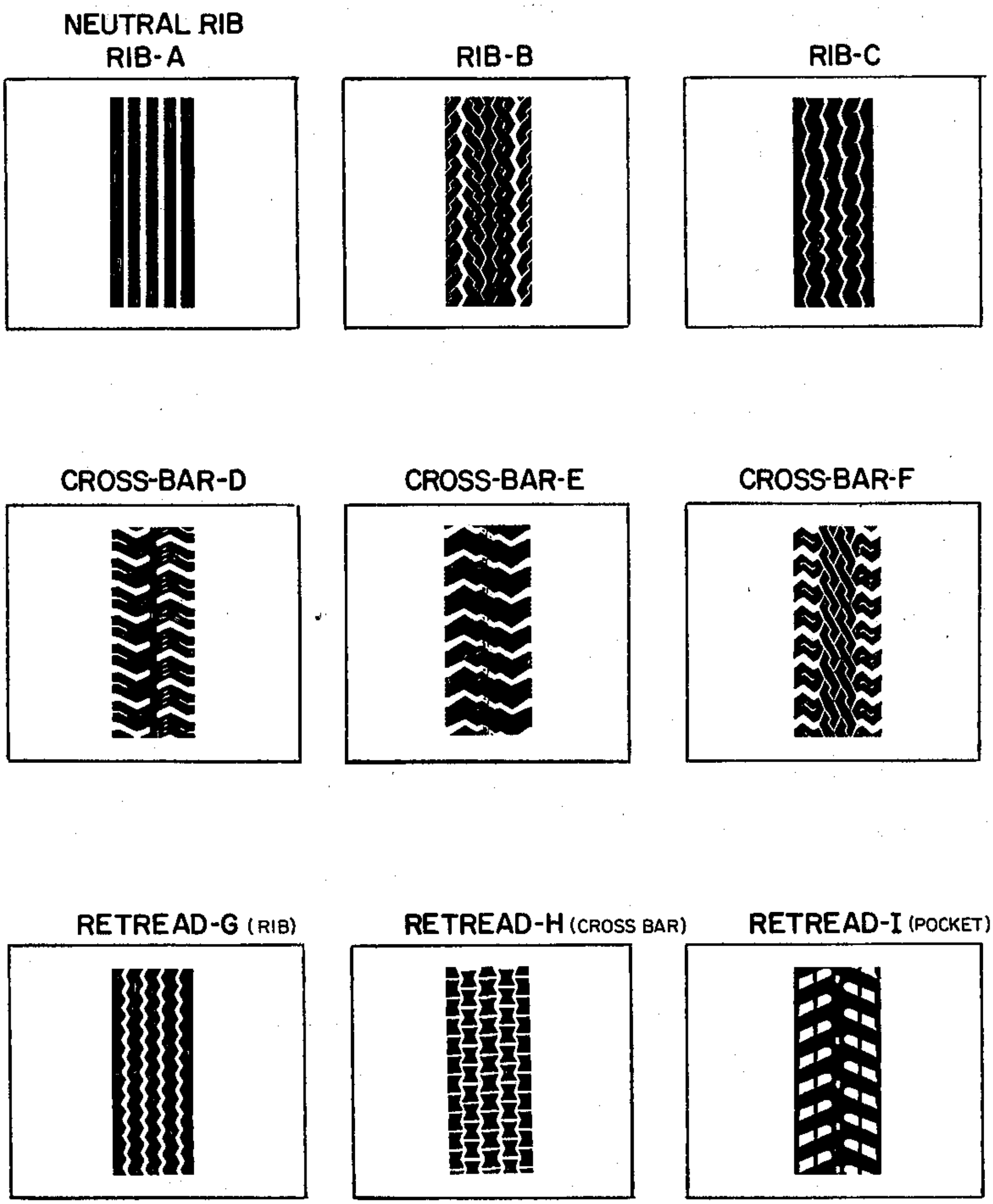
Figure IX shows a plot of speed versus peak sound level for the various tire designs, for new tires, on concrete pavement, on loaded vehicles with the noise measured at 50 feet. The graph indicates the rib tires are the quietest ($\bar{X}$ 72 dBA at 45 mph) and the pocket retread the noisiest (91 dBA at 45 mph) with the cross bar tires in between ($\bar{X}$ 79 dBA at 45 mph). An increase in speed increases the noise (about 8 dBA from 30 to 50 mph) for all types of tire designs.

Other data plotted in the same manner as Figure IX consistently indicated the rib tires were quietest followed by the cross-bar and pocket retread tire designs. Speed also remained a significant factor and appeared to show a direct correlation with noise.

Other variables such as tire wear, increased loading, type of pavement and tire location showed some difference depending on the combination of variables tested. In general, the half worn

Figure VIII

## TIRE TREAD DESIGN

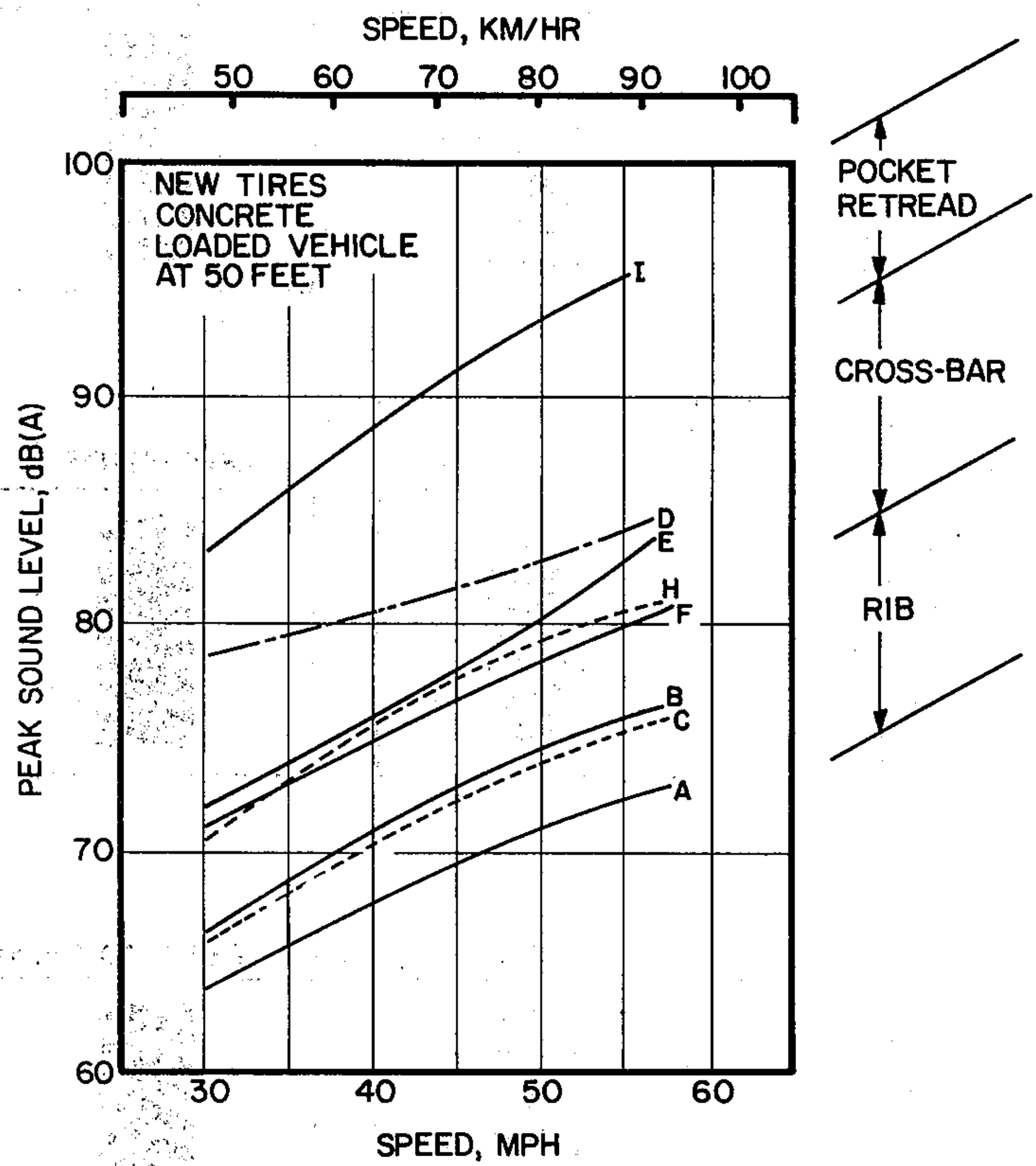



Test tire tread designs. These exact tread patterns represent 70-80% of the total truck tire population in use on the road today. Scale-1:16.

From Reference 19

Figure IX

## SPEED VERSUS NOISE FOR VARIOUS TIRE DESIGNS




Peak A-weighted sound level, as measured at 50 feet, versus speed for a loaded single-chassis vehicle running on a concrete surface. Various types of new tires were mounted on the drive axle. Letter designations for each curve correspond to the tire types shown in figure E-1.

**From Reference 19**

tires were slightly noisier than the new tires whereas the fully worn tires were slightly quieter than the new tires. An increase in load (11,600 pounds/axle) for the rib tires showed a small increase in noise (0-4 dBA) and the increase for the cross-bar and pocket retread was significant (4-8 dBA). This was constant whether the pavement surface was asphalt or concrete. The pavement type contribution to noise depended a great deal on the tire design, wear condition and surface roughness. As an example, tests with the pocket tread tire showed a range of 10-20 dBA for the surfaces tested as compared to the rib or cross-bar tires which showed a range of 4-6 dBA at any one particular speed.

Up to a certain pavement macrotexture, the generated noise appears to be tire dependent, while above this value, the pavement macrotexture appears to be a controlling factor. It was extremely difficult to evaluate all of the variables independently because different combinations resulted in different noise levels. The influence of some of these variables is very complex and, due to limited knowledge of the mechanisms of tire noise generation, many of these phenomena are not fully explainable at this time.

Automobiles

Literature on tire noise related to automobiles was very limited. Table 1 shows test data from a study entitled "Automobile Tire Noise: Results of a Pilot Study and Review of the Open Literature" (17). These data were obtained from testing a full sized 1973 Plymouth Fury loaded to a gross vehicle weight of 5,000 pounds. Tests were performed at 25 and 50 feet at speeds of 50, 60, and 70 miles per hour over jointed concrete, asphalt concrete, and continuously reinforced concrete pavements. Eight different types of new and half worn tires were used.

Table 1 suggests that an analysis of variance could be used to extract information on several factors. It would indicate if wrong factors were being studied, whether major contributors are considered in the basic design, and would allow conclusions based on a minimum number of tests. However, in this case, there were data missing which made it impractical to perform the analysis of variance. Instead, some simple averages and ranges were calculated which substantiated the authors conclusions.

A plot of the data is shown on Figures X, XI and XII

The data indicated the following conclusions:

1) Tire noise levels ranged from an average low of 66.4 dBA at 50 mph (New Bias Ply Rib Retread and Radial Ply Rib Retread) to a high of 83.4 dBA (at 70 mph (Half Worn Bias Ply Studded Snow). Tire noise increases as speed goes from 50 to 60, to 70 mph. The average increase is about 2 to 3 dBA for a 10 mph increase.

2) Tire noise was about +4 dBA greater over the Continuous Poured Reinforced Pavement as compared to the Asphalt Concrete and Jointed Concrete Pavements.

3) The half worn tires showed slightly greater noise levels than the new tires, but the difference did not appear to be significant.

4) The snow tires showed higher noise levels (3 to 5 dBA) than the rib tires over the Jointed Concrete and Asphalt Concrete Pavement. However, both type tires showed generally about the same noise levels over the Continuous Poured Reinforced Concrete.

Table 1

TABULATION OF SPEED, NOISE, TIRE DESIGN AND TYPE OF PAVEMENTS
(5,000 lb. Automobile)

| Tire Tread Design | | Jointed Concrete | | | Asphalt | | | Continuous Poured Reinforced Concrete | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 50 | 60 | 70 | 50 | 60 | 70 | 50 | 60 | 70 |
| 1. Bias Ply Rib | New | 67.2 | 70.4 | 73.5 | 69.2 | 71.1 | 74.6 | 75.0 | 77.4 | 78.8 |
| | Half Worn | 67.2 | 70.3 | 72.7 | 70.3 | 72.4 | 74.4 | 73.7 | 76.4 | 80.2 |
| 2. Bias Belted Rib | New | 67.2 | 69.9 | 72.6 | 67.8 | 70.4 | 73.2 | 74.1 | 76.1 | 79.9 |
| | Half Worn | 67.9 | 70.7 | 72.7 | 68.7 | 71.5 | 73.5 | 73.5 | 76.7 | 78.6 |
| 3. Radial Rib | New | 68.9 | 69.8 | 71.8 | 67.6 | 71.1 | 73.3 | 74.2 | 77.0 | 79.3 |
| | Half Worn | 68.0 | 70.9 | 72.5 | 68.6 | 71.2 | 73.6 | 74.9 | 76.6 | 79.9 |
| 4. Radial Snow | New | 73.7 | 76.7 | 76.8 | 71.8 | 74.5 | 76.7 | 73.7 | 76.3 | 79.3 |
| | Half Worn | 74.5 | 77.6 | 80.2 | 71.3 | 73.1 | 76.0 | 74.7 | 78.5 | 80.6 |
| 5. Bias Ply Snow | New | 72.0 | 73.9 | 77.3 | 71.1 | 74.1 | - | 73.1 | 77.4 | 81.0 |
| | Half Worn | 73.7 | 76.4 | 76.3 | 72.6 | 74.7 | - | 76.1 | 79.1 | 81.1 |
| 6 Bias Ply Studded Snow | New | 74.6 | 76.6 | 80.4 | 74.4 | 77.2 | 79.3 | 74.6 | 78.0 | 81.3 |
| | Half Worn | 75.7 | 80.7 | 83.4 | 75.1 | 77.6 | 81.2 | 75.2 | 79.0 | 82.7 |
| 7. Bias Ply Rib Retread | New | 66.4 | 71.2 | 72.0 | 68.3 | 71.2 | 73.3 | 73.4 | 76.8 | 79.3 |
| 8. Radial Ply Rib Retread | New | 67.4 | 69.9 | 71.9 | 66.4 | 69.9 | 72.5 | 72.4 | 76.0 | 76.7 |

Figure X

# TESTS ON VARIOUS SURFACINGS TO EVALUATE TIRE NOISE
## PASSENGER CAR

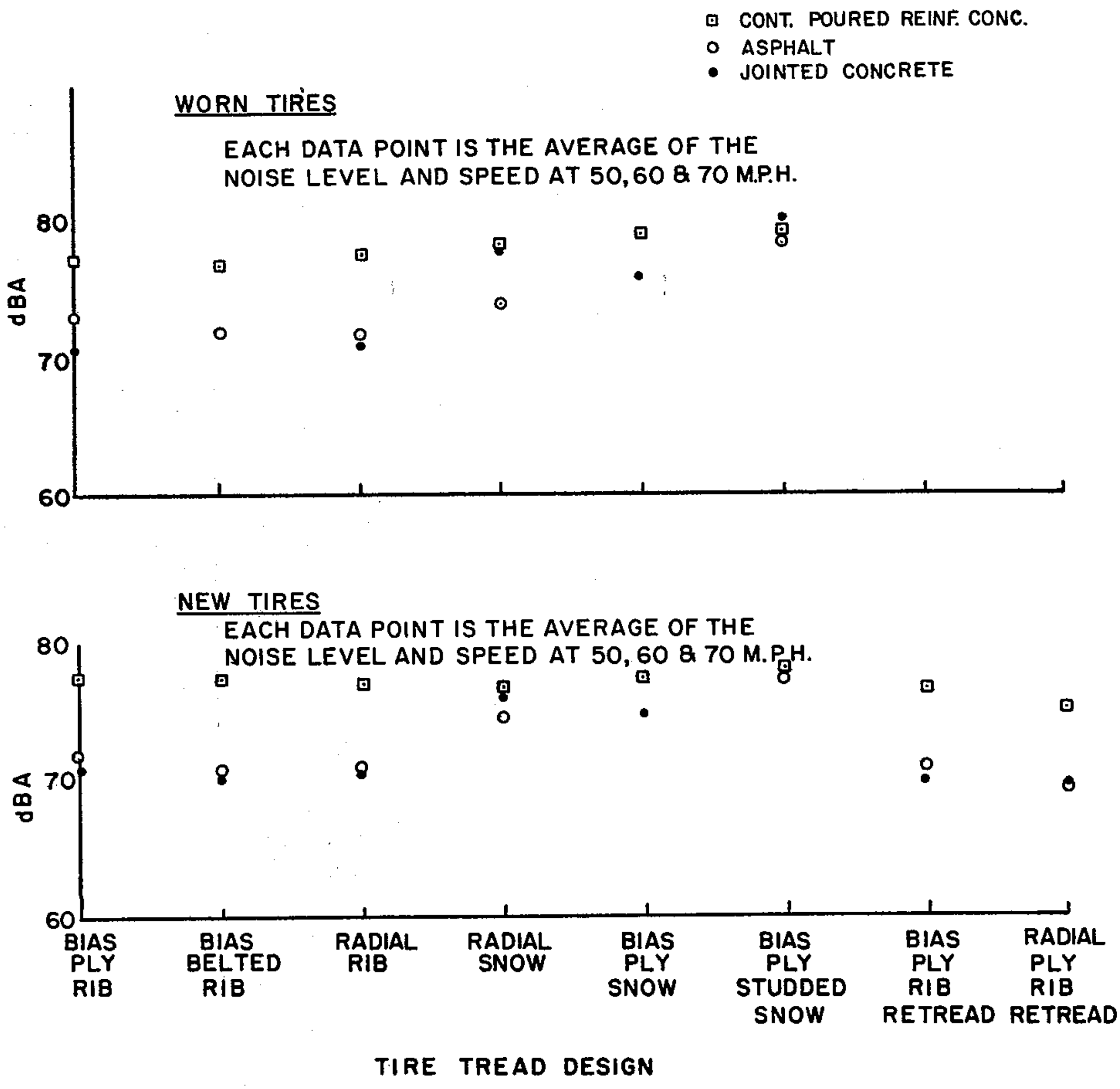
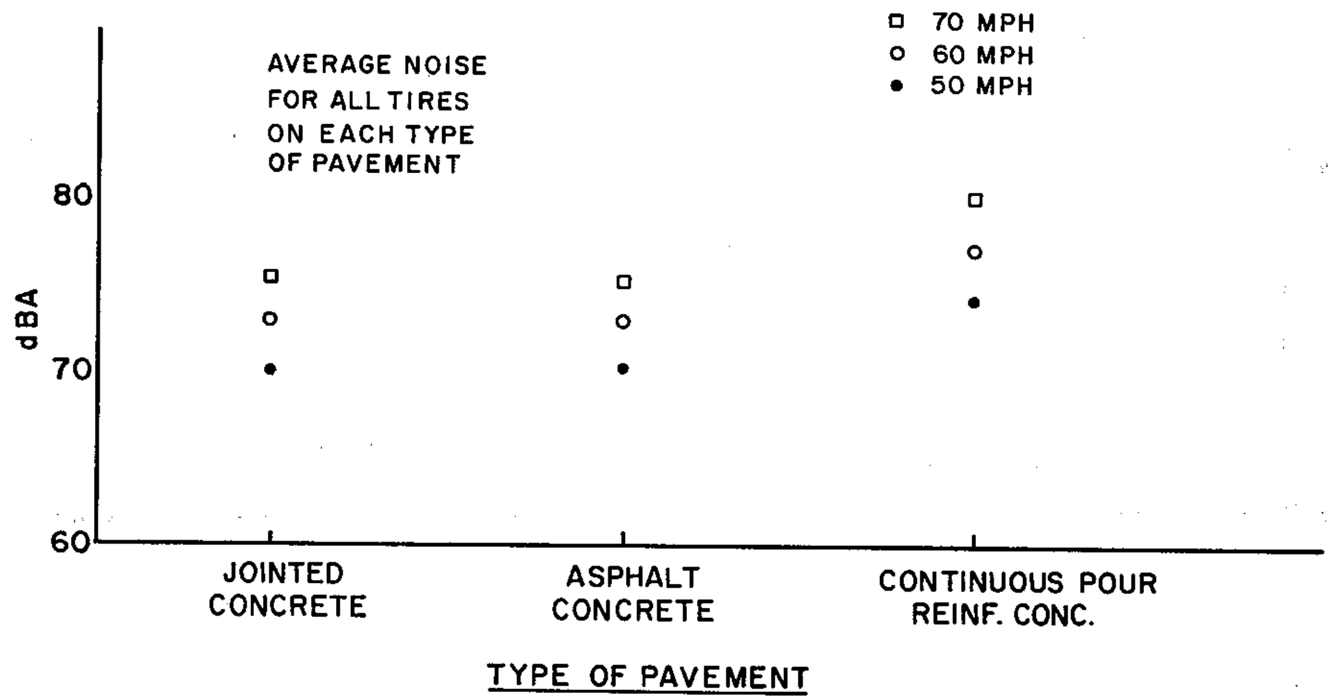


Figure XI

## TESTS TO EVALUATE TIRE NOISE
PASSENGER CAR



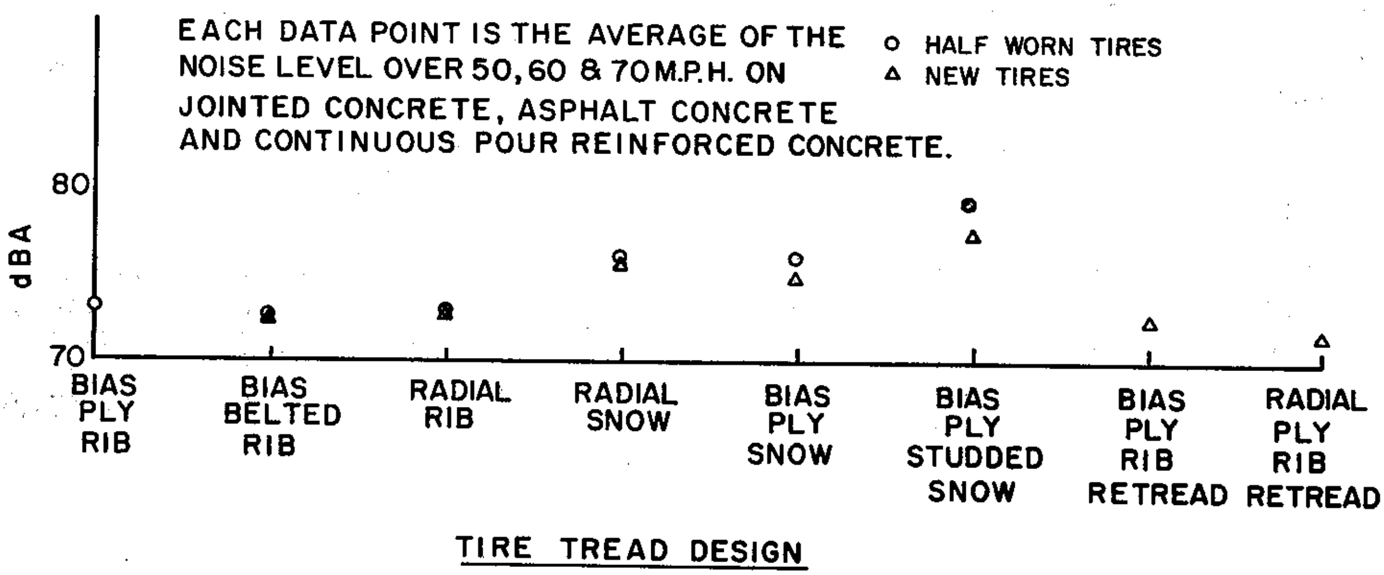
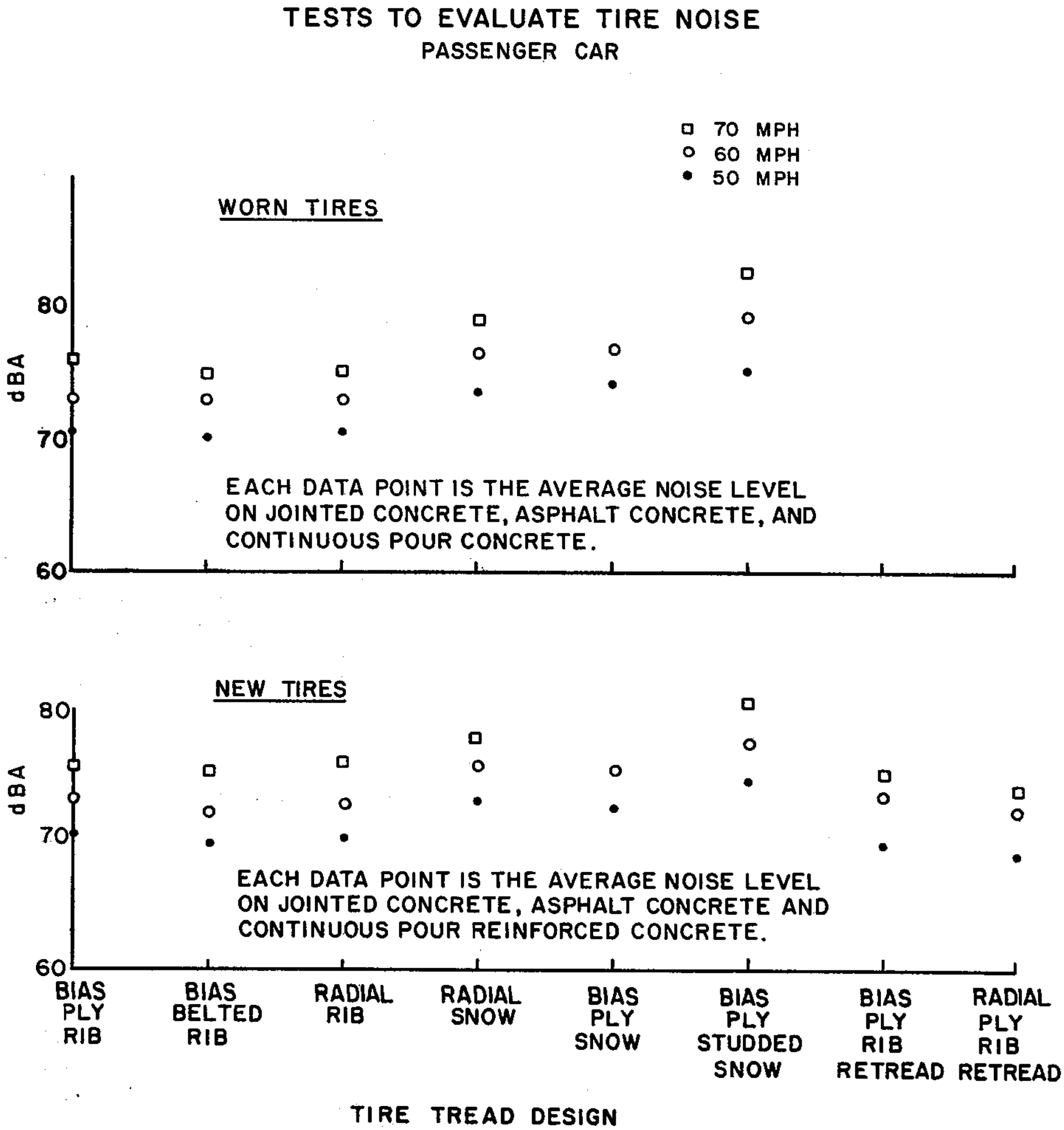



Figure XII


TESTS TO EVALUATE TIRE NOISE
PASSENGER CAR
70 MPH
60 MPH
50 MPH
WORN TIRES
dBA
80
70
60
EACH DATA POINT IS THE AVERAGE NOISE LEVEL ON JOINTED CONCRETE, ASPHALT CONCRETE, AND CONTINUOUS POUR CONCRETE.
NEW TIRES
dBA
80
70
60
EACH DATA POINT IS THE AVERAGE NOISE LEVEL ON JOINTED CONCRETE, ASPHALT CONCRETE AND CONTINUOUS POUR REINFORCED CONCRETE.
BIAS PLY RIB
BIAS BELTED RIB
RADIAL RIB
RADIAL SNOW
BIAS PLY SNOW
BIAS PLY STUDDED SNOW
BIAS PLY RIB RETREAD
RADIAL PLY RIB RETREAD
TIRE TREAD DESIGN

A second study entitled "Roadway Surface Noise" involved the relationship between tire noise and skid resistant open graded asphaltic friction courses, asphalt coated dense graded, portland cement concrete, and chip seal pavements. A 1973 Plymouth Station Wagon weighing approximately 4,600 pounds was equipped with standard rib tires for the initial tests. Subsequent tests were performed using radial rib recaps then mud and snow tires.

Tests at various speeds using the three types of tires over the open graded pavement indicated an increase in skid resistance and a slight decrease in tire noise as compared to the other two types of pavement. The mud and snow tires were about 4 dBA noisier than the standard and radial rib tires.

## SUMMARY

The literature indicated vehicle tire noise becomes a significant noise factor at speeds above 35 miles per hour. The exact speed at which tire noise begins to dominate is dependent on many variables. Speed, road surface characteristics, and tread design are major factors involving tire noise.

In general, the variables contributing to tire noise are the same for automobiles and trucks. However, road surface appears to affect automobile tire noise more than truck tire noise. Load and wear, which were significant noise factors for truck tires in some cases, did not affect automobile tires as much. Rib tire designs were the quietest.

# PART III

# SYNTHESIS OF THE LITERATURE ON QUIETING CONSTRUCTION EQUIPMENT

## INTRODUCTION

The construction and maintenance of the facilities for vehicular travel are serious contributors to the noise problem. This part of the report is a literature survey that covers the current state of the art in this area.

The Environmental Protection Agency (EPA), under the Noise Control Act of 1972, was authorized to promulgate noise standards for any products identified as being major noise sources. These standards apply to products distributed in commerce. One category under this section is construction equipment.

By December 1976, the EPA had published noise regulations for portable air compressors, medium and heavy trucks; had mandated regulations for wheel and track loaders and wheel and track dozers, and were conducting a number of other studies that will lead to noise regulations for other products.

The basic principles involved in quieting equipment are proper design, use of proper mufflers, and shielding or enclosing the source of noise.

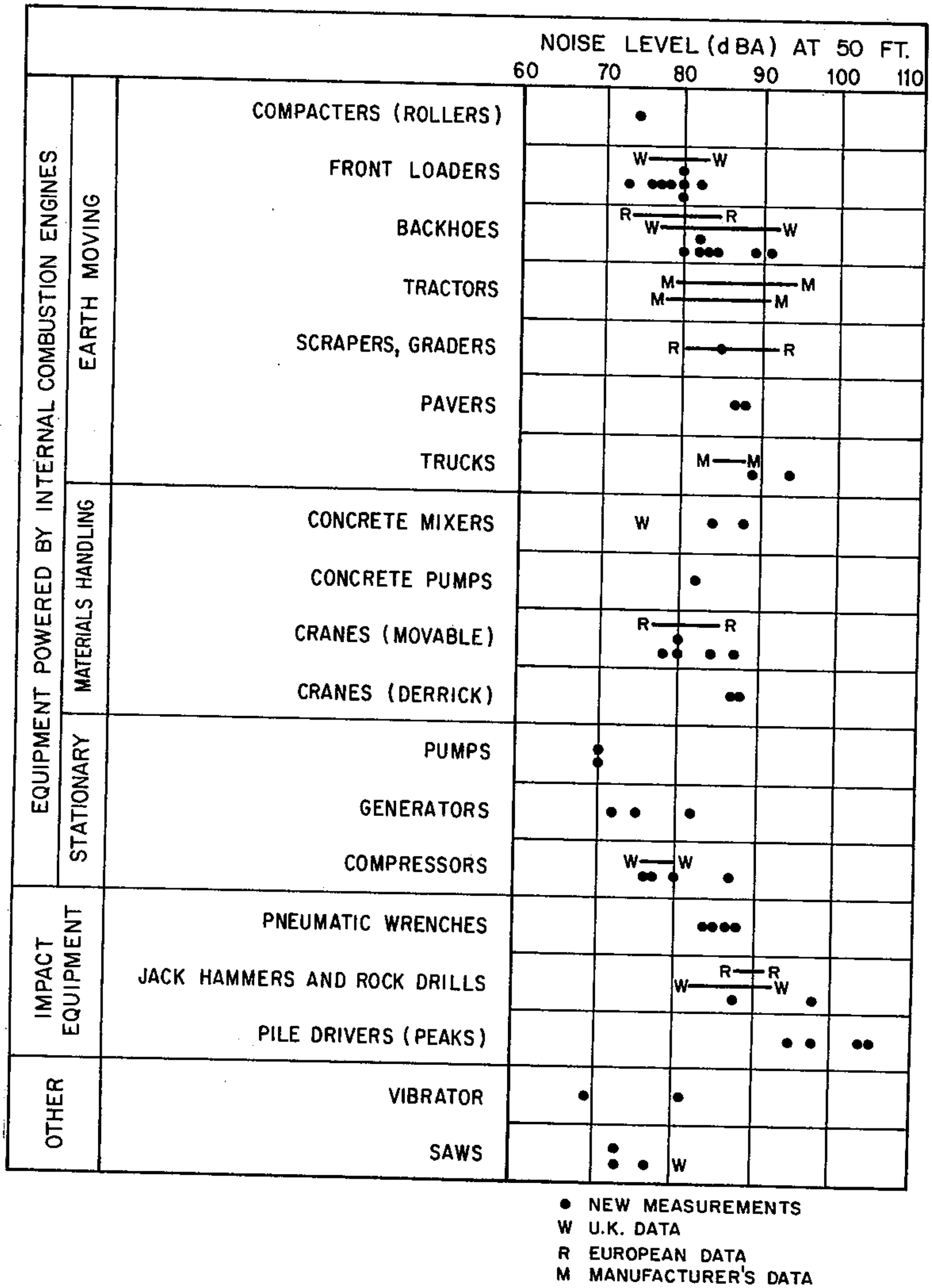
## DISCUSSION

### Construction Noise - General

In a 1972 publication, E. K. Bender (23) showed construction equipment noise ranges (Figure XIII). Data were obtained from various sources and indicated noise levels ranging from about 70 dBA to over 100 dBA for pile drivers. The report suggested that industry efforts to quiet products are usually motivated by market place demand and government regulations.

Figure XIII

## CONSTRUCTION EQUIPMENT NOISE RANGES




From Reference 23

Despite the variety in construction equipment, the basic power source is generally a diesel or gasoline fueled reciprocating engine. Noise sources are the engine, exhaust, cooling fan, and mechanical and hydraulic components. Many of the basic principles discussed in Part II of this report are applicable to quieting construction equipment. Bender indicates noise reductions of 5 to 10 dBA are achievable without great difficulty.

The impact of a hammer or tool bit against the work is the dominant component if noise is from impact equipment. Noise levels from impact equipment are hard to measure or standardize. Their peak levels are usually 100 dBA or greater. Reduction of impact noise is generally difficult and usually requires shielding or enclosing the work area These mitigation measures may reduce noise 3 to 10 dBA.

The Bender report indicated the following means can be used to reduce noise at the construction site:

1) Replace individual operations and techniques by less noisy ones, i.e.; use welding instead of riveting, mix concrete offsite instead of onsite and use prefabricated items instead of construction onsite.

2) Select the quietest equipment, i.e.; electric instead of diesel powered equipment, hydraulic instead of pneumatic impact tools.

3) Schedule noisiest equipment operations when ambient noise levels are high. Keep noise levels relatively uniform and turn off idling engines.

4) Keep noisy operations as far as possible from site boundaries.

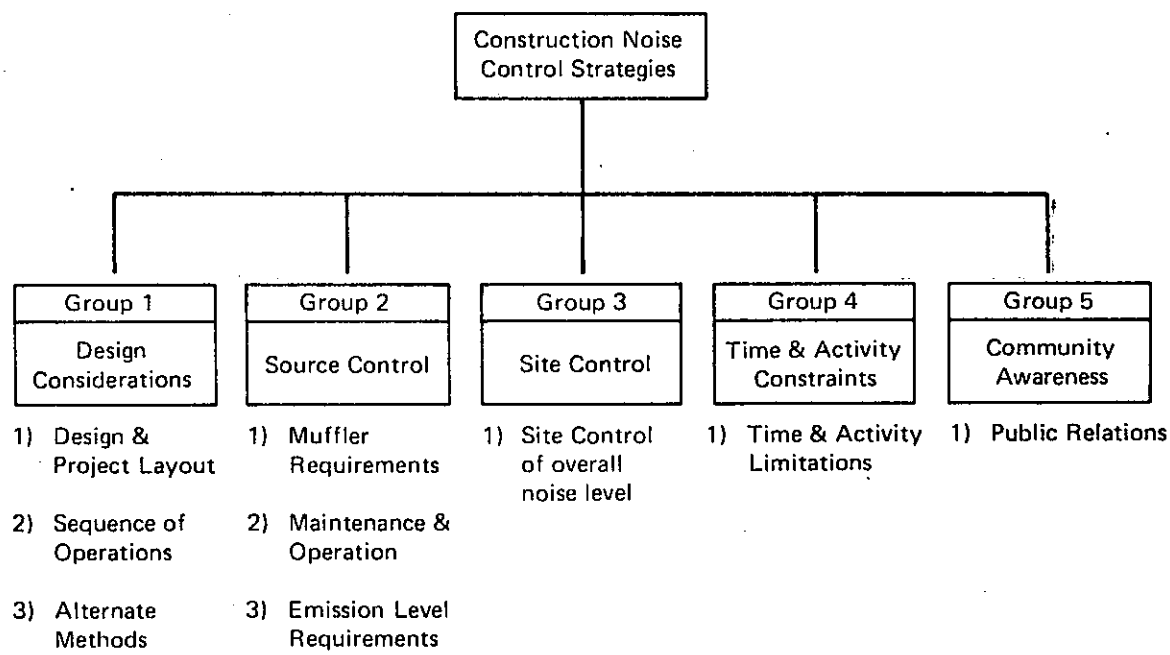
5) Use noise barriers and quiet noisy equipment.

State of the Art Report

The Federal Highway Administration (FHWA) released a report entitled "Highway Construction Noise: Measurement, Prediction and Mitigation" in May 1977 (24). It was a state of the art review outlining procedures for measurement and prediction of construction operation noise levels, mitigation measures, and example specifications.

The report indicated noise measurement and prediction procedures for construction appeared to be workable but would require additional personnel to implement. Insufficient data and experience with various equipment and operation noise levels and the practicality or feasibility of the different example specifications would preclude adoption per se at the present time.

The following table shows "Construction Noise Control Strategies" from the FHWA report. It gives a good illustration of the factors involved in construction noise mitigation.



## Air Compressors

EPA recognized the portable air compressor as one major source of noise and developed noise emission standards for this equipment (25). It stated that, effective January 1, 1978, portable air compressors with a maximum rated capacity between 75 and 250 cfm shall not produce an average sound of over 76 dBA at 7 meters. For compressors with a rated capacity of over 250 cfm, the 76 dBA shall not apply until July 1, 1978.

New York City has a very severe standard which specified no more than 70 dBA at one meter after December 1975 for air compressors (26).

Due to various governmental regulations, Martin Hirschorn (27) reported on a permanent total noise control enclosure system, developed by the Industrial Acoustics Company, for portable air compressors. The unit was designed to have adequate air flow, be within portable trailer design specifications, and be constructed of non-combustible materials.

A 1200 CFM Gardner Denver air compressor was quieted using the enclosure unit. The average noise level was dropped from an average 106 to 82 dBA measured at four locations around the compressor at a distance of one meter and a height of one and one half meters above the ground. The enclosure system appears to be a feasible method for quieting old air compressors but is often inconvenient. It was felt that other design measures applied to the enclosure and the compressor itself could further lower the noise level.

Ingersoll Rand advertises that their "whisperized" compressors, rated from 85 to 5,000 CFM, emit no more than 85 dBA at one meter.

Hydraulic Powered Equipment

There are many design approaches for the various type of pumps to minimize noise. However, this discussion, based on a Sperry Vickers publication (28), will be primarily directed towards measures that could be taken to mitigate noise on existing systems.

(A) Noise Sources

Hydraulic pumps for construction equipment are compact and, because of their relatively small size, are poor radiators of noise. However, pump induced vibrations or pulsations are radiated through the reservoirs, piping, and other interconnected parts causing the entire system to be noisy.

Valves are another source of noise but are generally not significant at this time. As quieter pumps are designed and built, valve noise may become an important factor.

Cavitation, or release of dissolved air, could be controlled through design and maintenance.

(B) Mitigation Measures to Minimize Noise

Airborne noise can be minimized by reinforcing any large flat metal panels which may be a part of the equipment. If possible, the panels should be broken down to smaller sized triangles. Damping or sound absorptive lining on the panels is helpful.

Simply moving the source away from the receiver is good practice where this is feasible.

Partial or total enclosures lined with sound absorptive material are very effective but should be carefully engineered. Details such as mechanically isolating enclosures from hydraulic lines or other parts by using resilient grommets need to be followed. Vibration mounts should be used for both the pump and motor units. Avoid sharp bends in the line.

Line isolation is accomplished by using a flexible hose at the ends of the line and a rigid section in the middle. All flexible lines or all rigid lines are not desireable. Commercially available combination barrier material and fiberglass or foam can be used to wrap the lines to minimize airborne noise. Use resilient line supports to isolate one line from another and from the rest of the machine.

Maintenance for the hydraulic system is an important part of noise control. Things such as maintaining the correct fluid level, keeping the fittings tight so there are no air leaks, replacing worn resilient fittings, and keeping all bearings properly lubricated are important in controlling noise.

## Track Mounted Drills

Figure XIV shows an Ingersoll Rand tractor mounted drill with an acoustical drill tower enclosure. Noise levels were measured at 7 meters and estimated to be 85 dBA. Figure XV shows the noise levels for the various noise mitigation measures used on the drill.

## Jackhammers

Air operated jackhammer noise comes from the high energy release of the exhaust air and the impact of the piston or hammer on the

Figure XIV

# FROM INGERSOLL RAND

**Exclusive I-R muffled drill tower keeps noise down to 85 dBA at 7 meters.**

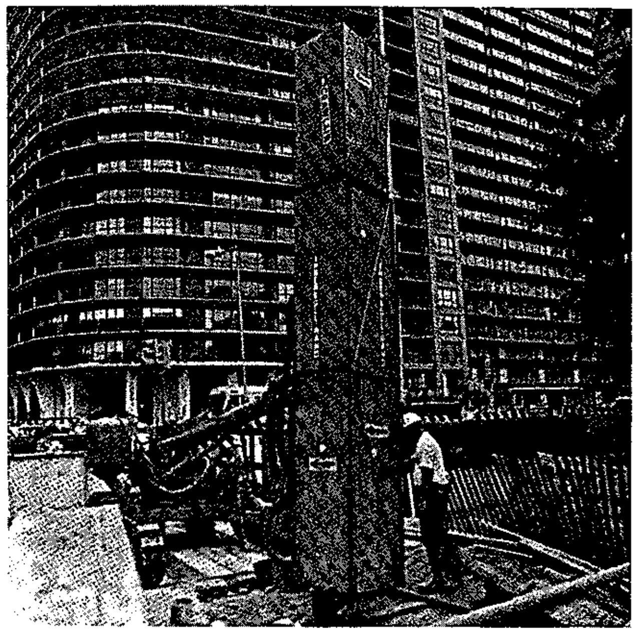
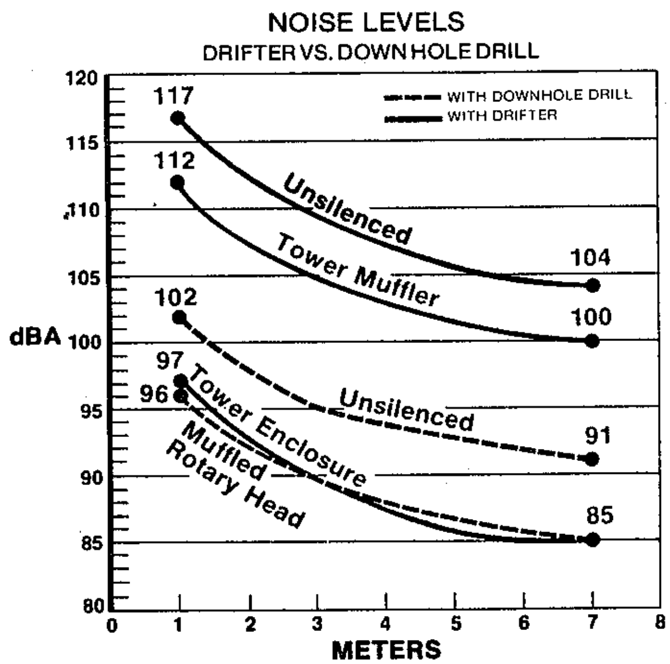


Figure XV

# FROM INGERSOLL RAND



steel. This does not include the impact noise from the jackhammer working against concrete or other material.

About 90 percent of the jackhammer noise comes from the exhaust. Care must be taken so that excessive back pressure is not created when reducing exhaust noise. Back pressure severely restricts the work output.

Figure XVI shows a strap-on muffler developed by the Ingersoll Rand Corporation for their jackhammers. It reduced noise about 7 dBA on their 80 lb. breaker at a distance of one meter. Newer models have built-in muffling.

A Norwegian publication authored by Dirdal and Gjaevenes (29) indicated jackhammer noise is generally in the 89 to 94 dBA range at 7 meters. There did not appear to be any significant difference between new and old or small and large ones. The authors indicated noise levels could be reduced about 14 dBA by using sound insulating mantles that are commercially available. However, the operation of the jackhammer against different materials will reduce the benefits from the mantle.

The following Table 2 shows noise measurements of a jackhammer operating on different materials. Measurements were made at 7 meters.

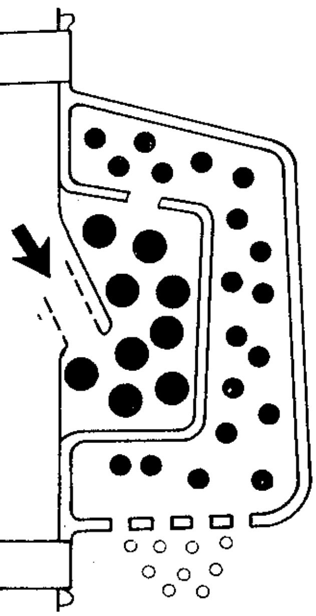
Table 2

| Material | dBA |
|---|---|
| Compressed Soil | 94 |
| Asphalt | 95 |
| Gravel | 96 |
| Concrete | 99 |
| Clay Slate | 101 |
| Granite | 103 |

Figure XVI

## FROM INGERSOLL RAND

## STRAP ON MUFFLER
## FOR JACK HAMMER



Dirdal and Gjaevenes also proposed criteria which limited construction noise to various levels during the day and night near various receptors such as schools, hospitals, residences and industrial zones.

## REGULATORY LAWS

The first major Federal Law aimed directly at noise control was Public Law 92-574 ("Noise Control Act of 1972"). This Act was to provide coordination of Federal research and activities in noise control and establish standards for products distributed in commerce. Regulations for new medium and heavy trucks, portable air compressors, railroad emission standards and motor carrier noise emission standards have been adopted and others are being considered.

Various other laws, ordinances, specifications, citizen complaints, and threats of law suit have forced the construction industry to manufacture quiet equipment. Standard off-the-shelf parts and techniques are being utilized to retrofit older equipment.

Following is a general list of regulations that apply to this subject. Comprehensive details of the regulations should be obtained from the sources listed. Numerous other State and Municipal Noise Control Acitivities are listed in an EPA publication (30).

### Federal

Federal Register, April 13, 1976, EPA, Noise Emission Standards for Transportation Equipment - Medium and Heavy Trucks.

The regulation sets noise emission levels for January 1978, January 1982, and January 1895 as 83 dBA, 80 dBA, and "to be determined" for new trucks with a gross vehicle weight rating equal to or greater than 10,000 pounds. It also provides for EPA testing procedures and an enforcement program.

Federal Register, September 12, 1975, DOT-FHWA, Interstate Motor Carrier Noise Emission Standards.

These regulations set maximum permissible sound level readings under various conditions for new and in-use fleet trucks with a gross vehicle weight rating equal to or greater than 10,000 pounds. These regulations became effective on October 15, 1975.

1. 90 dBA at 50 feet at speeds greater than 35 mph.
2. 86 dBA at 50 feet at speeds of less than 35 mph.
3. 88 dBA at 50 feet under a prescribed stationary run-up test.
4. Visual exhaust system inspection.
5. Visual tire inspection.

Federal Register January 14, 1976, EPA, Portable Air Compressors.

The regulation sets January 1, 1978, as the date on which portable air compressors with maximum rated capacities between 75 and 250 CFM shall not exceed 76 dBA at 7 meters. The same regulations apply to portable air compressors with maximum capacities greater than 250 CFM after July 1, 1978.

OSHA

Federal Register, October 24, 1974, Department of Labor Occupational Noise Exposure.

The proposed regulations set a permissible 16 hour exposure level starting at 85 dBA with monitoring and audiometric testing. Exposure levels decrease as the noise increases (i.e. 8 hours at 90 dBA). Engineering and/or administrative procedures need to be taken when the steady state noise is greater than 90 dBA.

Although the OSHA Regulations are designed to protect the working person, they have a definite direct effect on promoting design of quiet equipment and machines.

General Services Administration (GSA)

The Federal GSA specifications regulate the construction equipment noise on all Federal construction contracts. The following Table 3 shows maximum noise levels (dBA) allowed for equipment measured at 15 meters using the SAE J952 or equivalent test.

Table 3

| EQUIPMENT (dB(A)measured at 15m) | GSA 1JUL73 | 1JAN75 |
|---|---|---|
| EARTHMOVING EQUIPMENT | | |
| Frontloader | 79 | 75 |
| Backhoes | 85 | 75 |
| Dozers | 80 | 75 |
| Tractors | 80 | 75 |
| Scrapers | 88 | 80 |
| Graders | 85 | 75 |
| Trucks | 91 | 75 |
| Pavers | 89 | 80 |
| MATERIALS HANDLING EQUIPMENT | | |
| Concrete Mixer | 85 | 75 |
| Concrete Pumps | 82 | 75 |
| Crane | 83 | 75 |
| Derrick | 88 | 75 |
| STATIONARY EQUIPMENT | | |
| Pumps | 76 | 75 |
| Generators | 78 | 75 |
| Compressors | 81 | 75 |
| IMPACT EQUIPMENT | | |
| Pile Drivers | 101 | 95 |
| Jack Hammers | 88 | 75 |
| Rock Drills | 98 | 80 |
| Pneumatic Tools | 86 | 80 |
| OTHER EQUIPMENT | | |
| Saws | 78 | 75 |
| Vibrator | 76 | 75 |

State

State of California Vehicle Codes apply to vehicles subject to registration.

27204 Gross vehicle weight rating of 6,000 pounds or more manufactured

| | | |
|---|---|---|
| 1. | After 1967 and before 1973 | 88 dBA |
| 2. | " 1972 " " 1975 | 86 |
| 3. | " 1974 " " 1978 | 83 |
| 4. | " 1977 " " 1988 | 80 |
| 5. | " 1987 | 70 |

Noise measured at 50 feet

22205 All other vehicles manufactured

| | | |
|---|---|---|
| 1. | After 1967 and before 1973 | 86 dBA |
| 2. | " 1972 " " 1975 | 84 |
| 3. | " 1974 | 80 |

Noise measured at 50 feet

23130 No person shall operate a motor vehicle in such a manner as to exceed the following statutory noise limits:

| | | | |
|---|---|---|---|
| (1) | Heavy trucks, 6,000 GVW or more: | 86 dB(A)<br>90 dB(A) | in speed zones 35 mph or less,<br>in speed zones over 35 mph. |
| (2) | Motorcycles, 15 GBH or more: | 82 dB(A)<br>86 dB(A) | in speed zones 35 mph or less,<br>in speed zones over 35 mph. |
| (3) | All other motor vehicles: | 76 dB(A)<br>82 dB(A) | in speed zones 35 mph or less,<br>in speed zones over 35 mph. |

23130.5 Within speed zones of 35 miles per hour or less on level streets (grade not exceeding plus or minus one percent) no person shall operate a motor vehicle in such a manner as to exceed the following statutory noise limits:

| | | |
|---|---|---|
| (1) | Heavy trucks, 6,000 GVW or more: | 82 dB(A) |
| (2) | Motorcycles, 15 GBH or more: | 77 dB(A) |
| (3) | All other motor vehicles: | 74 dB(A) |

Measurements are only made when the vehicular flow is at a constant rate of speed, and are not made within 200 feet of any intersection controlled by an official traffic control device or any grade exceeding plus or minus one percent.

27150 Every motor vehicle shall be equipped with an adequate muffler which is properly maintained and prevents the emission of excessive and unusual noise. No muffler or exhaust system shall be equipped with a cutout, bypass, or similar device.

27151 No person shall modify, repair or replace the exhaust system of a motor vehicle in a manner which will amplify or increase the noise emitted to a level above that emitted by the original exhaust system of that vehicle. No person shall operate a motor vehicle with an exhaust system so modified.

27160 No person shall <u>sell a new motor vehicle</u> which produces noise in excess of the limits in this section of the code.

24004 No person shall operate a vehicle after notice by a traffic officer that the vehicle is not equipped as required by this code, except as may be necessary to return the vehicle to the residence or place of business of the owner or driver or to a garage, until the vehicle and its equipment have been made to conform with the requirements of this code.

24005 It is unlawful for any person to knowingly sell, install or replace either for himself or as the agent or employee of another, any muffler or exhaust part that is not in conformity with this code or regulations made thereunder.

24007 No dealer or person holding a retail seller's permit shall sell a new or used motor vehicle for use upon the highway which is not in compliance with this code. A vehicle with a defective exhaust system which emits excessive noise is not in compliance. A vehicle with a modified exhaust system which emits more noise than the original equipment system is not in compliance.

The following is a summary of vehicle and equipment regulations previously mentioned. Noise levels are indicated in dBA.

| | | Year | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 88 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Federal** | | | | | | | | | | | |
| New Truck Sales _ 10,000 lbs GVW | | | | | | 83 | | | | 80 | |
| New or in use Truck Operation _ 10,000 lbs GVW, | Speeds | 35 mph | 90 | | | | | | | | |
| | Speeds | 35 mph | 86 | | | | | | | | |
| | Runup Test | | 88 | | | | | | | | |
| Portable Air Compressor 75-250 CFM | | | | | | 76 | | | | | |
| **State of California** | | | | | | | | | | | |
| New Truck Sales _ 6,000 lbs GVW | | | 83 | | | 80 | | | | | 70 |
| New Car Sales | | | 80 | | | | | | | | |
| All vehicles other than cars or trucks | | | 80 | | | | | | | | |
| *Truck Operation _ 6,000 lbs GVW | Speeds | 35 mph | 90 | | | | | | | | |
| | Speeds | 35 mph | 86 | | | | | | | | |
| *All other vehicles, Operation | Speeds | 35 mph | 82 | | | | | | | | |
| | Speeds | 35 mph | 76 | | | | | | | | |

*Enacted before 1975.

California Department of Transportation, Standard Specifications, January 1975.

7-1.01N SOUND CONTROL REQUIREMENTS.--The Contractor shall comply with all local sound control and noise level rules, regulations and ordinances which apply to any work performed pursuant to the contract.

Each internal combustion engine, used for any purpose on the job or related to the job, shall be equipped with a muffler of a type recommended by the manufacturer. No internal combustion engine shall be operated on the project without said muffler.

42-1.02 CONSTRUCTION -- The noise level created by the combined grooving operation shall not exceed 86 dBA at a distance of 50 feet at right angles to the direction of travel.

42-2.02 CONSTRUCTION -- The noise level created by the combined grinding operation shall not exceed 86 dBA at a distance of 50 feet at right angles to the direction of travel.

California Department of Transportation, Standard Special Provisions, January 1976.

5-1.__ SOUND CONTROL REQUIREMENTS -- Sound control shall conform to the provisions in Section 7-1.01N, "Sound Control Requirements," of the Standard Specifications and these special provisions.

The noise level from the Contractor's operations, between the hours of 9:00 p.m. and 6:00 a.m., shall not exceed 86 dBA at a distance of 50 feet. This requirement in no way relieves the Contractor from responsibility for complying with local ordinances regulating noise level.

Said noise level requirement shall apply to all equipment on the job or related to the job, including but not limited to trucks, transit mixers or transient equipment that may or may not be owned by the Contractor. The use of loud sound signals shall be avoided in favor of light warnings except those required by safety laws for the protection of personnel.

Full compensation for conforming to the requirements of this section shall be considered as included in the prices paid for the various contract items of work involved and no additional compensation will be allowed therefor.

## HEALTH EFFECTS

Noise is defined as unwanted sound and can be either annoying or an actual health hazard. This part of the report discusses the effect of noise on man and is referenced to an Environmental Protection Agency (EPA) publication entitled "Effects of Noise on People" (31).

Clear evidence is available that prolonged exposure to noises above 80 dBA can contribute to inner ear damage and eventually lead to hearing handicap. The EPA feels that the 85 dBA level set by OSHA as the minimum allowable 16 hour exposure level is too high.

A small loss of hearing from exposure to noise may not be significant when one is middle aged, but might become significant when combined with other natural losses to hearing because of old age.

Hearing loss and ear damage due to noise can be eliminated by reducing noise to sufficiently low levels, holding exposure to short duration or allowing exposure to occur only rarely.

Protection from noise can be accomplished using carefully selected ear plugs and ear muffs. They must also be properly used. However, the best solution is to quiet the noise at the source.

The specifications and guidelines in Appendix B, C, and D were prepared after carefully considering the items regarding potential hearing damage. Existing and proposed laws as well as economic considerations were evaluated before the final noise levels were set.

# PART IV

# CALIFORNIA'S WORK ON QUIETING A DIESEL POWERED TRUCK AND A DRILL RIG

# INTRODUCTION

The initial efforts of this study were directed towards construction of a "quieted truck" otherwise referred to as the "modified truck". These two terms are used interchangeably throughout this report. It was intended to use off-the-shelf items where possible and make other modifications where necessary to demonstrate the potential for noise reduction on a truck powered with a diesel engine. The findings from this work along with information gleaned from the literature were to provide guidelines for quieting maintenance and construction equipment by retrofitting. They would also lead to specifications for purchase of equipment and for control of construction noise.

A 1964, Chevrolet Low Cab-Forward Dump Truck with a Detroit 6V-53 diesel engine was chosen because it was readily available from the Caltrans Equipment Department and was typical of construction and maintenance vehicles. It had been in service for approximately 9 years as a Caltrans maintenance truck and was well maintained during this period. In general, diesel engines are about 7 dBA noisier than gasoline engines (32). This type engine was also one of the most challenging for noise reduction and it differed from those used in other studies (Part II) as shown on the following Table 4.

Table 4

| | Cylinders | Cycles | HP-RPM | Bore-Stroke | CID | Wt | Type |
|---|---|---|---|---|---|---|---|
| Cummins NTC-270 (White) | 6 | 4 | 270-2100 | 5 1/2 x 6 | 855 | 2750 | inline |
| Cummins NTC-350 (Freightliner) | 6 | 4 | 350-2100 | 5 1/2 x 6 | 855 | 2795 | inline |
| Detroit Diesel 8V-75N (International Harvester) | 8 | 2 | 318-2100 | 4 1/2 x 5 | 418 | 2215 | V |
| Detroit Diesel 6V-53N (California) | 6 | 2 | 170-2200 | 3 7/8x 4 1/2 | 318 | 1540 | V |

A similar truck, referred to as the "regular truck", was acquired at the same time. It was approximately 6 years old. The purpose of this truck was to provide a baseline for comparative purposes.

Detailed noise reduction methods vary for different engines and vehicles but it was felt that the quieting principles involved could be demonstrated and generally applied to other gasoline and diesel powered maintenance and construction equipment. Literature studies indicated the principle sources of vehicle noise to be exhaust, cooling fan, intake system, engine, transmission and tires (reference 1 thru 13).

Concurrent with the modification of the truck, sound measuring equipment was ordered and an existing dynamometer facility was partially enclosed so that it could be used for this study. Preliminary tests indicated that background and dynamometer noise was high enough to invalidate measurements on the modified truck. Due to costs involved, no further work was done on the dynamometer and evaluation of the modified truck was made in the field using drive-by tests.

Modifications to the truck were made by the Equipment Department and their approach, in general, was to make the total system as quiet as possible rather than to isolate and evaluate each major noise source. No records of noise measurements on any specific component were available. Therefore, no analysis or discussion of the component noise is made. However, these were adequately covered in Part II of this report.

## DESCRIPTION OF THE UNMODIFIED TEST TRUCK

The following is a description of the truck before it was modified to reduce noise.

1) 1964 Chevrolet Low Cab-Forward Dump Truck Ser: 4E833P102563

2) Engine, Detroit 6V-53N Diesel rated 170 HP at 2200 RPM
6 cylinder, 2 cycle, 318 CID, 3 7/8 bore, 4 1/2 stroke

3) Transmission, 5 speed Spicer S5756B

4) Muffler, Std. dual system (mfg. not known)

5) Cooling fan, Std. 5 blade belt driven (mfg. not known)

6) Radiator, Std. flow (mfg. not known)

7) Differential, 2 speed Eaton, Ratios 5.57-7.60

8) Chassis, 2 axle, 25,000 lb. GVW, 145" wheel base

9) Intake System, Std. G.M. gear driven blower.

## DESCRIPTION OF MODIFICATIONS

The major sources of truck noise were identified from the literature (Part II). Modifications to the components of the modified truck contributing to the truck noise are described in this section. Figure XVII shows a photograph of the regular truck which was similar to the modified truck.

### Engine and Enclosure System

No direct modifications were made to the engine. In order to quiet the engine, power and drive trains, a tunnel was built around this system utilizing aluminum sheets and fiberglass.

Modifications to the chassis were minimal and were made only to secure adequate space for the installation of insulating materials. These modifications included installing a three-inch thick spacer between the front axle and the front springs, installing an intermediate frame between the truck frame and the dump body hoist frame, and the relocation of the truck cab 18 1/2 inches to the rear. These changes are illustrated by the photographic record made of the placement of the insulating materials (Figures XVIII, XIX),

The basic noise insulation materials used were four layers of 1-inch thick fiber glass "Aero-flex" between an inner panel of .050-inch thick aluminum sheet with 1/4-inch perforations and an outer panel of .125-thick aluminum sheet which is coated on the inner side with automotive underseal material. This combination of materials is used to completely enclose the entire power and drive train in a tunnel. Polyfoam sheet 1-inch thick and latex foam rubber sheet 3 inches thick are used where required to obtain flexibility combined with a tight seal such as at the outer ends of the rear axle. Borg Warner No. 31-2172 small engine rubber motor mounts are used to isolate the framework supporting the insulation from the outer aluminum panel and from the truck frame. A schematic of the enclosure system is shown on Figure XX.

Exhaust System

The exhaust system was modified to use a single vertical Riker muffler No. 9xD 405 and a Riker "Y" connector No. LT3540. These changes were based on the manufacturer's recommendations as optimum for quieting exhaust noise on this particular engine. The exhaust pipes were insulated with three layers of fiber glass wrapped with steam pipe tape and the "Y" connector was

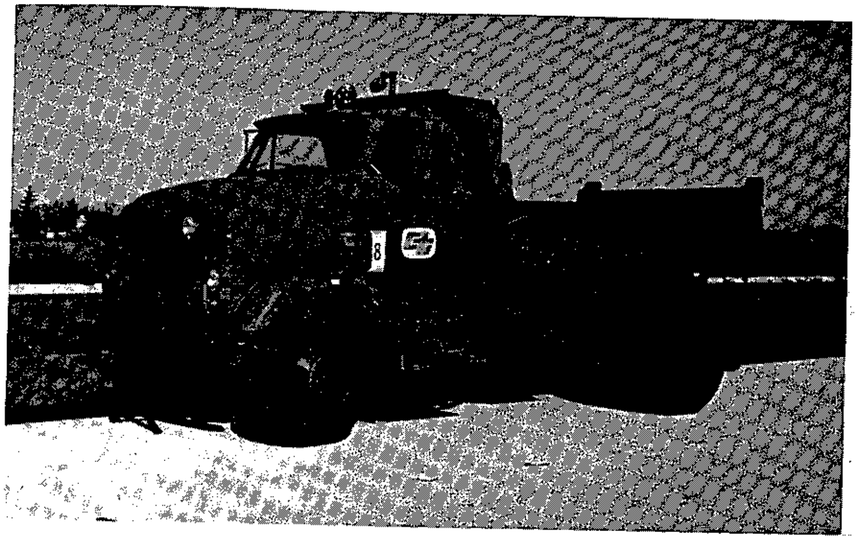


Figure XVII
Regular Truck

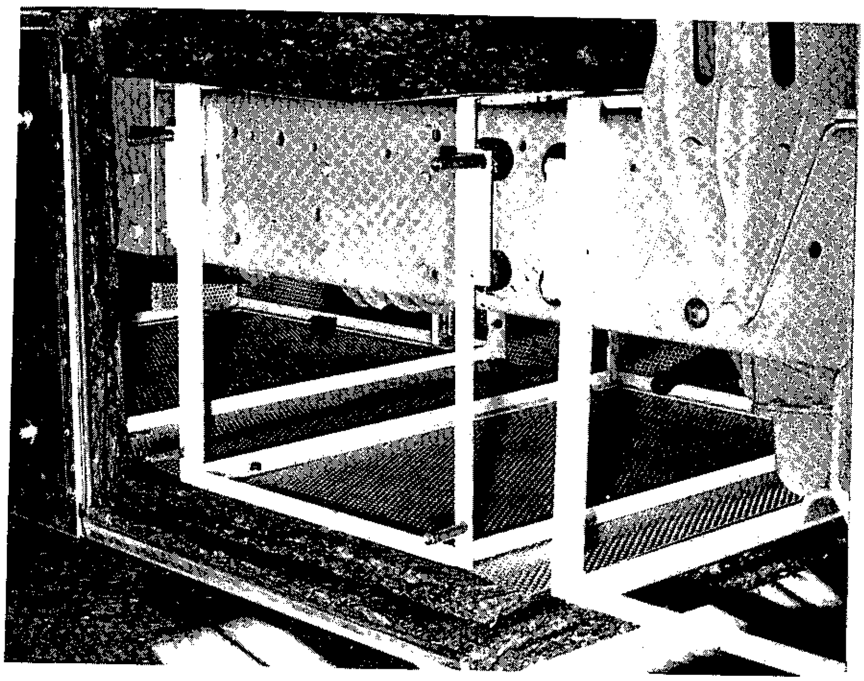


Figure XVIII
Enclosure System and Insulation on the Modified Truck

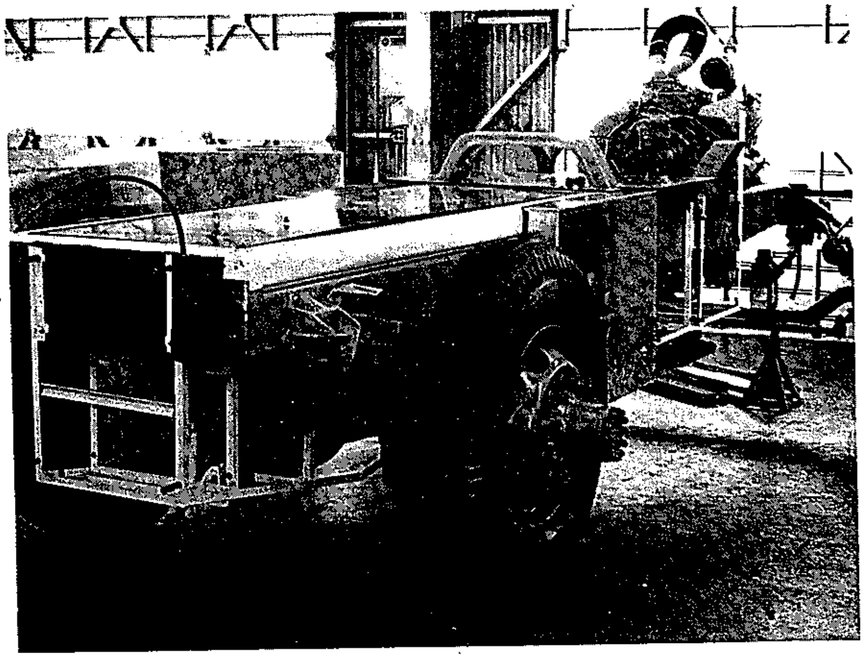
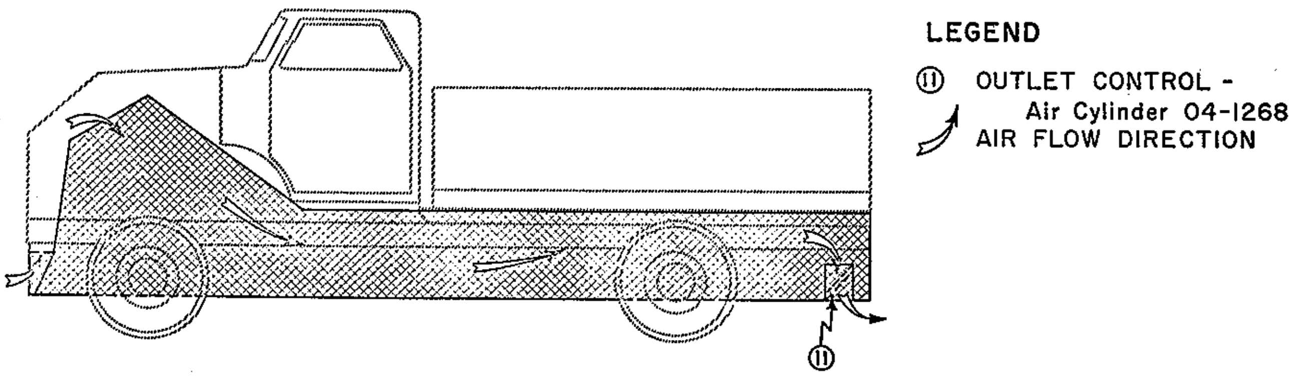


Figure XIX
Enclosure System

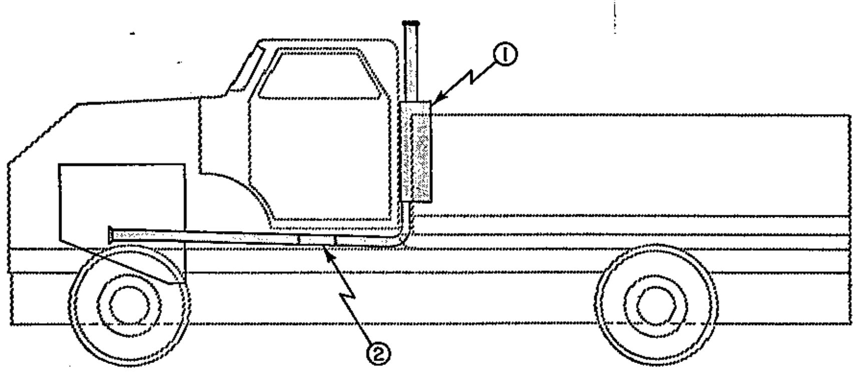
FIGURE XX




AIR FLOW TUNNEL

Figure XX
Schematic of Enclosure System

FIGURE XXI




LEGEND

① MUFFLER - Riker 9XD 405

② Y CONNECTOR - Riker LT 3540 (Insulated)

EXHAUST SYSTEM

Figure XXI

Schematic of Exhaust System

insulated with woven asbestos and a sheet metal jacket. In addition, the muffler was insulated by being located in a fiber glass lined enclosure built into the corner of the dump body. Insulation was added to minimize vibration noise from the component parts of the exhaust system. A schematic is shown on Figure XXI.

## Cooling System

The cooling system was modified so that the air passing through the radiator would not be restricted by having to pass through the power train enclosure. It was mounted in the truck bed. Plessey (33) in England reported such a system which included a temperature controlled hydraulic fan drive. A schematic of the system is shown in the following Figure XXII.

The component parts used in the modified truck are listed below:

1) A Young HC-11D2 radiator was mounted in the dump body to expedite the project into the test phase.

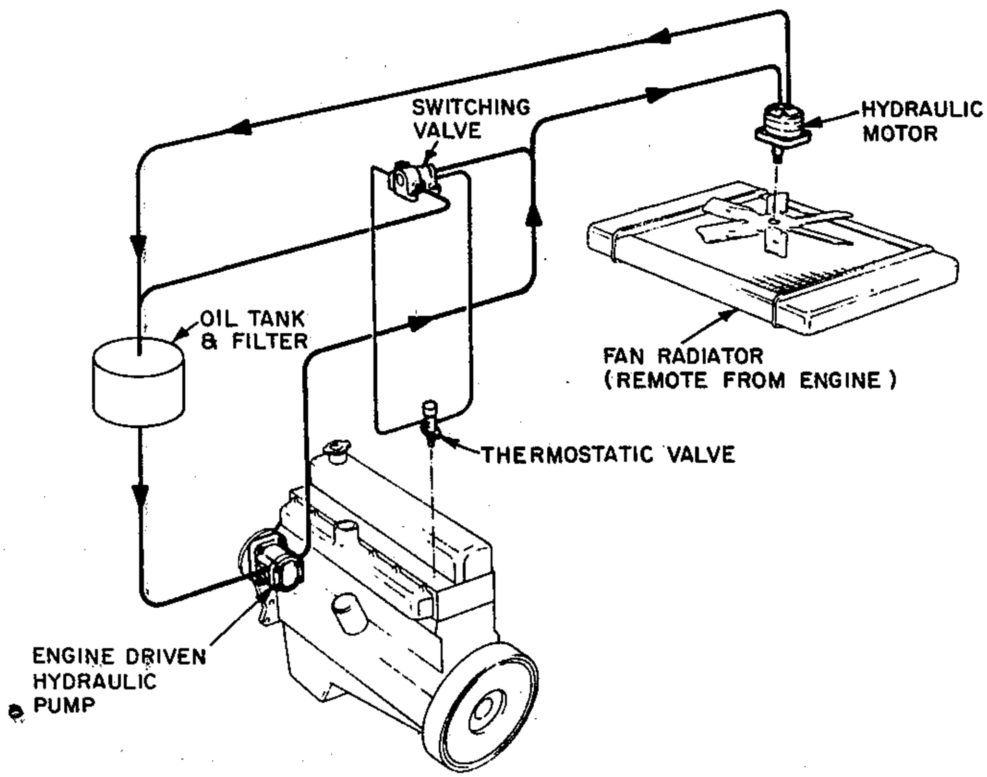
2) A cast aluminum fan with air foil type blades.

3) Fan controlled at various speeds by a Brand No. FC-51 flow control valve driven by a Charlynn II-A hydraulic motor and a Sunstrand PV-21 pump to a maximum speed of 12,000 RPM.

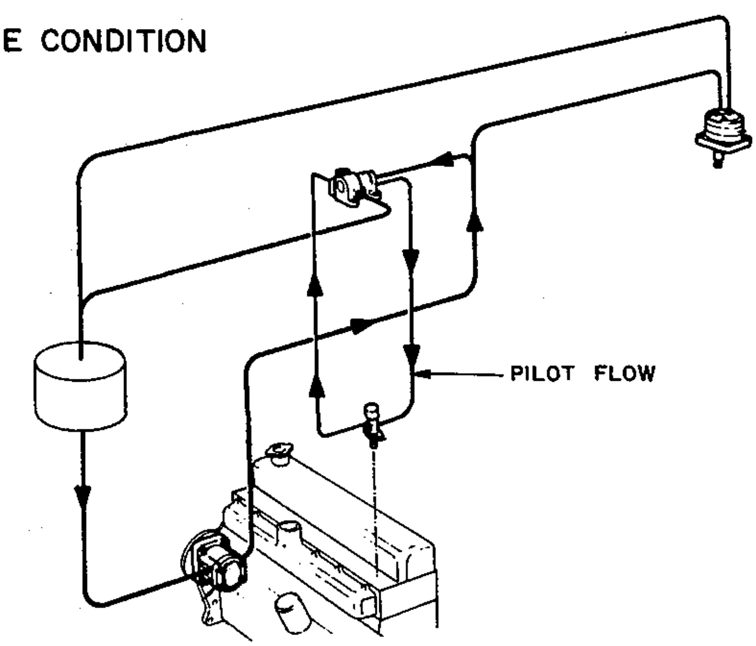
4) A Dayton 2C888 Centrifugal fan was mounted inside the enclosure to move air past the engine and power train (Figure XXIII). This fan was controlled with a Brand No. FC-51 flow control valve and driven by a Lamina No. A50F hydraulic motor and an accessory drive mounted Vickers power steering pump.

Figure XXII

# DIAGRAMS SHOW OIL FLOW WITH ENGINE IN HOT AND COLD CONDITIONS




FAN ON, HOT ENGINE CONDITION




FAN OFF, COLD ENGINE CONDITION

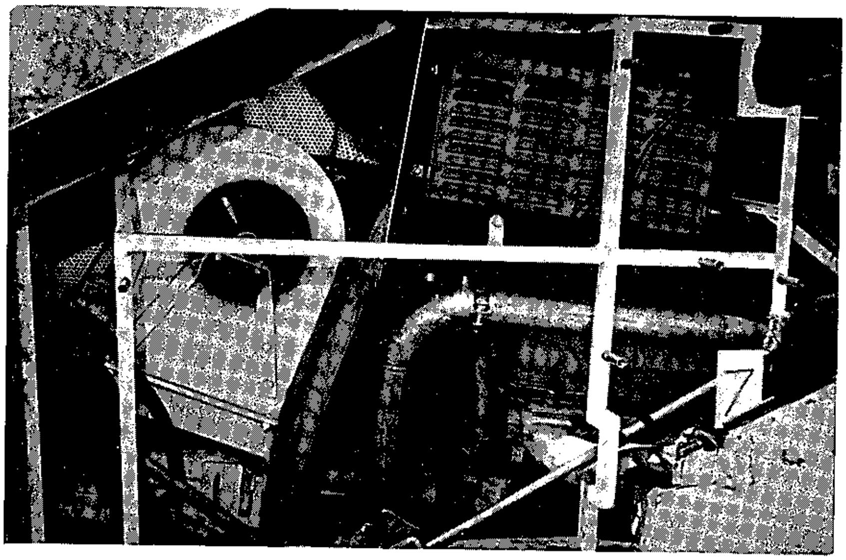


Figure XXIII

Centrifugal Fan to
Supply Engine Inlet Air

The enclosure is designed with baffles at both ends so that sounds coming through these openings must make 90-degree turns around insulated panels and the rear opening is fitted with an air operated door controlled from the cab. A schematic of the cooling system is shown on Figure XXIV.

Table 5 shows the horsepower rating of the 6V53N Detroit Diesel engine used in the modified truck for the following conditions.

1. Manufacturer's horsepower rating of the engine only, before mounting in a vehicle. These data are obtained on the dynamometer under specified conditions of testing.

2. Manufacturer's horsepower rating of engine installed in the truck used in this study before modification. This is a calculated value based on a mathematical model and is shown as a basis of comparison because no actual tests were performed.

3. Dynamometer tests performed by the Equipment Department on the truck used in this study after modification.

Table 5

| | RPM | 1,800 | 2,000 | 2,200 | 2,500 | 2,800 |
|---|---|---|---|---|---|---|
| 1. | Mfg. Rated Brake Horsepower | 145 | 158 | 170 | 186 | 197 |
| 2. | Mfg. Calculated Horsepower Before Modification | 137 | 148 | 158 | 170 | 178 |
| 3. | Equipment Department Tests After Modification Horsepower | - | 116 | 120 | 124 | 130 |

The estimated horsepower loss due to the cooling modifications was about 28 hoursepower at 2,000 RPM. This appears reasonable when compared to the data in Table 5.

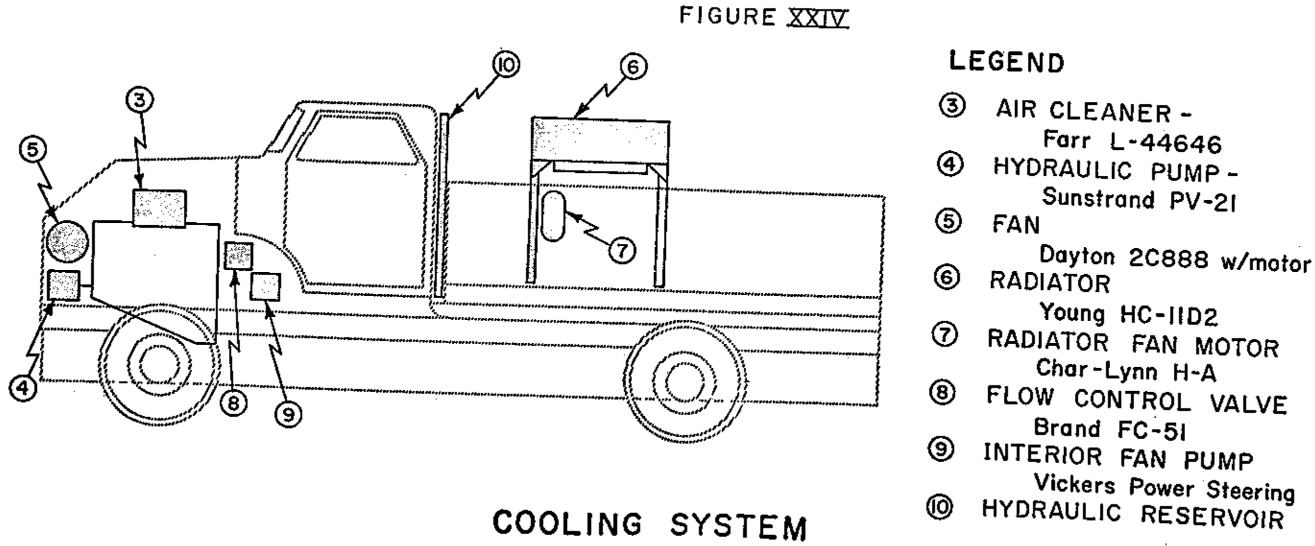



Figure XXIV
Schematic of Cooling System

The cooling modifications appeared to have resulted in a substantial decrease in horsepower. In addition, the weight added by the modifications further decreased available horsepower for transporting cargo. In summary, these particular modifications to the cooling system did not appear to be feasible. However, a properly designed enclosure system was demonstrated by others (Part II) and use of a temperature controlled fan resulted in cost savings in fuel as well as effectively quieting the truck.

Intake System

The sound generated in the engine air inlet was reduced by locating the Farr No. L-44646 air cleaner inside the insulated power train enclosure.

Tires

Tires were selected for maximum open rib type tread design. The front tires are Goodyear High Miler SxT and the rear tires are Bandag Rib Tread Caps with radial siping (narrow cuts in tread pattern) for increased traction (Figure XXV). The tires for the sister truck are shown on Figure XXVI.

Other Quieting Modifications

Diesel engine motor mounts GM No. 3888479 are used to isolate the dump body frame from the truck frame so that sound transmission through the steel frame will be minimized. Extruded Rubber Craft No. 265-X rubber edge insulation is used on the edges of the exterior aluminum panels so that random sound will not be generated at the points of contact between adjacent panels. Furnace duct tape is used to seal and fasten the insulation where required.

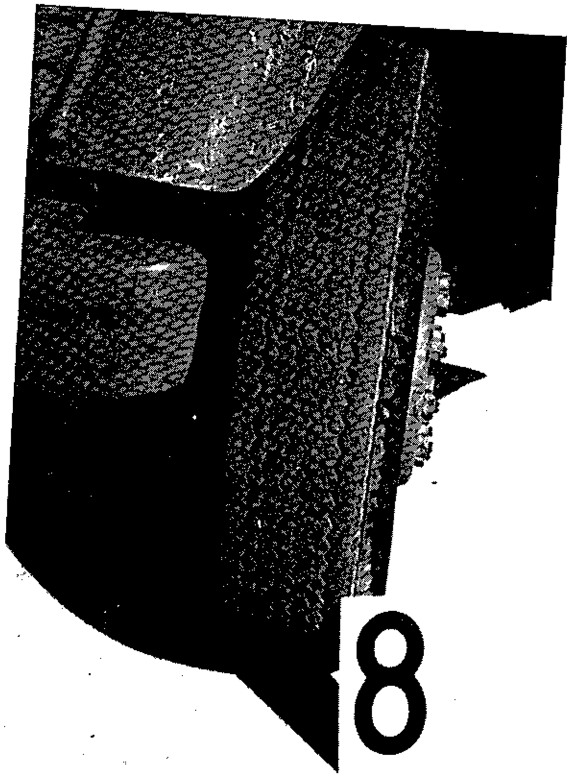
Figures XXVII and XXVIII show the completed modifications on the Quieted Truck.



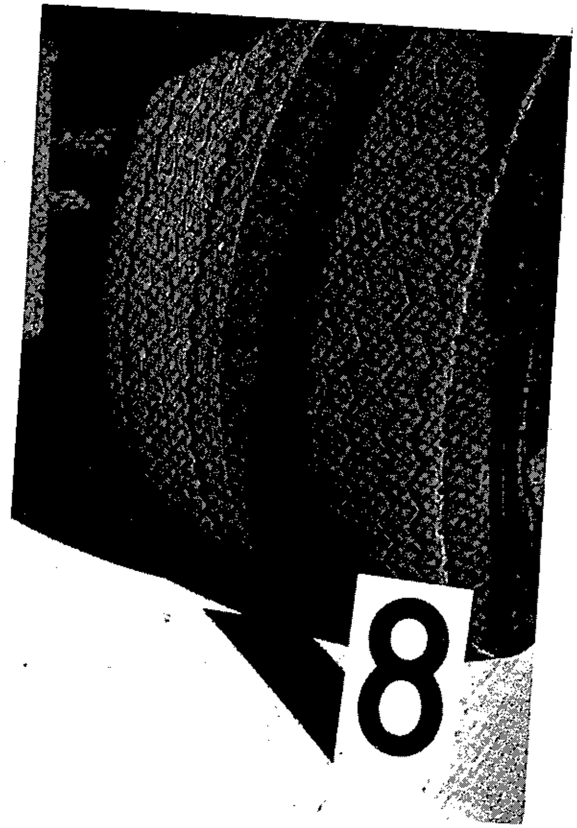
Front Tire Modified Truck

Back Tires Modified Truck

Figures XXV

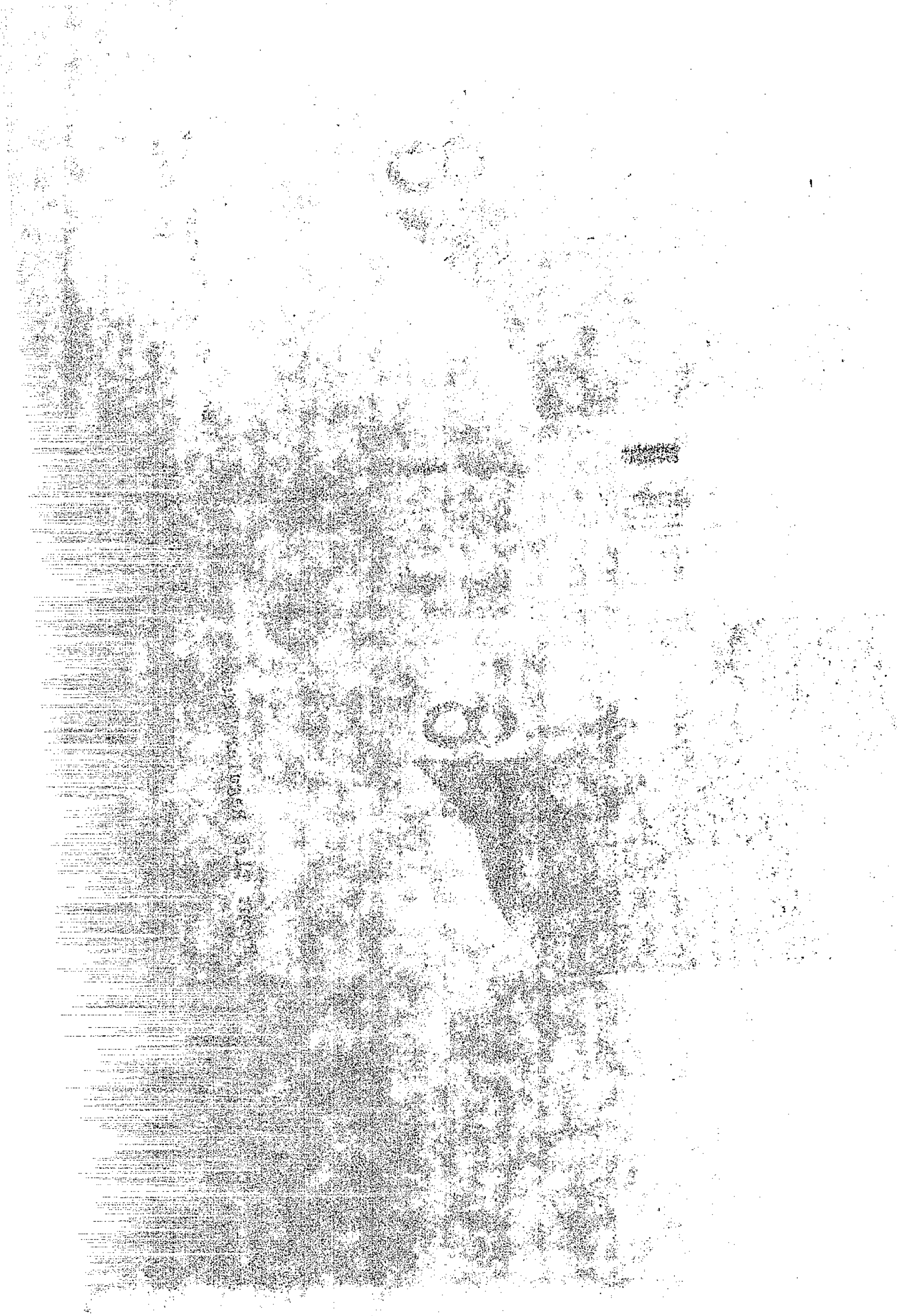



Front Tire Regular Truck




Back Tires Regular Truck

Figure XXVI



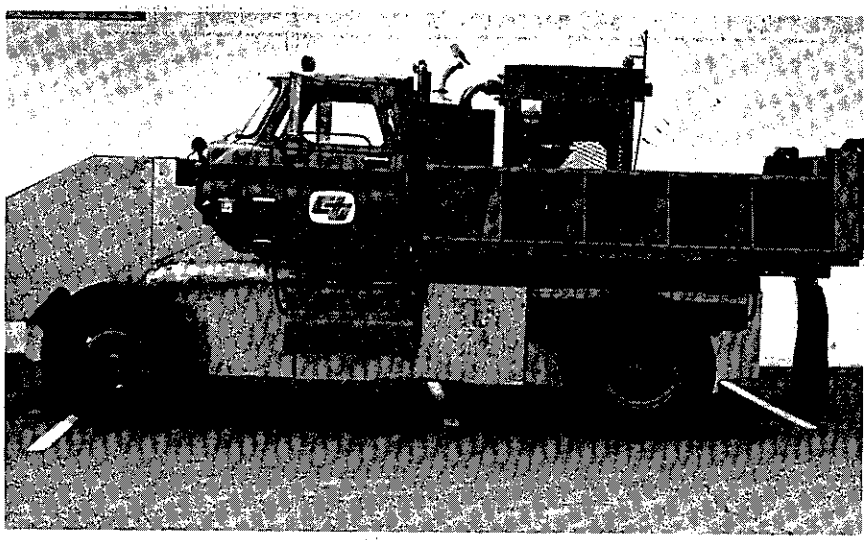


Figure XXVII
Completed Modified Truck Showing Cooling Fan Mounted in Truck Bed

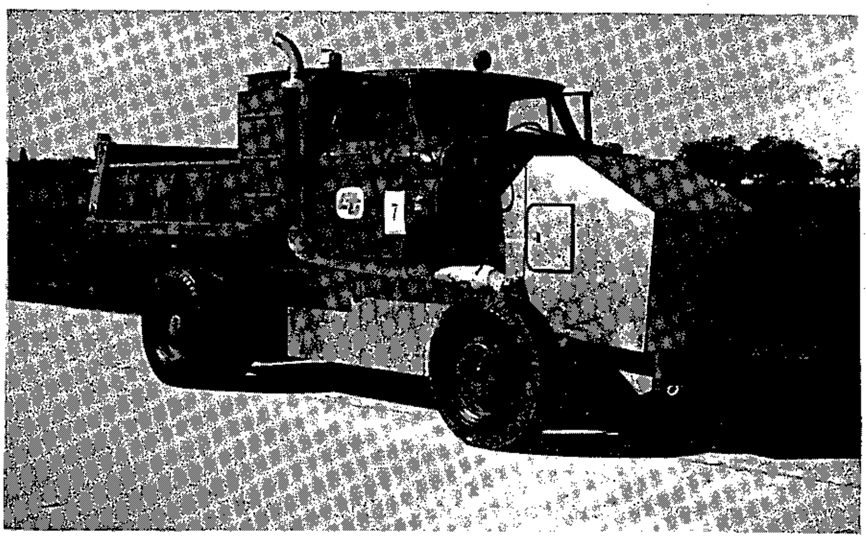


Figure XXVIII
Completed Modified Truck Showing Exhaust Position

## SUMMARY OF MATERIALS AND EQUIPMENT USED

### Materials

Engine configuration
- 6V-53 w/low sac style injectors

Truck configuration
- Low cab forward w/4-ton dump body, 1964 Chevrolet front axle spaced down 3 inches and cab relocated to the rear 18-1/2 inches for insulation clearance.

Insulation materials
- Fiber glass 1-inch thick "Aero Flex"
- Poly foam 1-inch thick
- Latex rubber 3-inch thick
- Aluminum sheet .050-inch thick w/1/4-inch perforation
- Aluminum sheet .125-inch thick
- Rubber edge insulation No. 2650X Rubber Craft
- Rubber mounts No 31-2172 Borg Warner
- Dump body mounts GM No. 3888479
- Duct tape - 4-inch

Tires
- Front - Goodyear Hi Miler SxT
- Rear - Bandag Rib tread, siped

Exhaust System
- Muffler - Riker No. 9xD 405
- Y connector - Riker LT 3540 - insulated

Inlet System
- Air cleaner - Farr L-44646

Cooling System
- Radiator - Young HC-11D2
- Fan - Young (cast aluminum air foil type)
- Hydraulic pump - Sunstrand PV-21
- Radiator fan motor - Orbit - Char-Lynn H-A
- Interior fan pump - Vickers power steering
- Interior fan motor - Lamina A50F
- Interior fan Dayton No. 2C888, 10-3/4-inch
- Outlet control air cylinder 04-1268
- Flow control valve - Brand FC-51

Instruments Used For Noise Measurements

| | |
|---|---|
| B & K Precision Sound Level Meter | Model 2206 (Type I) |
| B & K Sound Level Calibrator | Model 4230 |
| B & K Pistonphon Calibrator | Model 4220 |
| B & K Graphic Level Recorder | Model 2306 |
| G. R. Sound Level Meter | Model 1551 (Type II) |
| G. R. Sound Level Calibrator | Model 1562A |
| Nagra IV-SJ Tape Recorder | |

## TEST PROCEDURES AND FACILITY

The standard generally recognized for evaluating truck noise is the Society of Automotive Engineers (SAE) J366a procedure (Appendix A). Briefly, this method requires a level open space within 100 ft. of either the vehicle path or microphone which is placed 50 ft. from the roadway. Driveby tests start at 35 mph and accelerate to a maximum rated engine speed within the 100 ft. test zone.

A test site conforming to the requirements of SAE J366a was located at the California Highway Patrol (CHP) Academy in West Sacramento (Figure XXIX, XXX). Another site temporarily used was located on an unopened section of I-5 south of Sacramento (Figure XXXI, XXXII, XXXIII, XXXIV). Availability was the reason for using the I-5 site before moving to the CHP site.

Figure XXIX
California Highway Patrol Academy Test Site

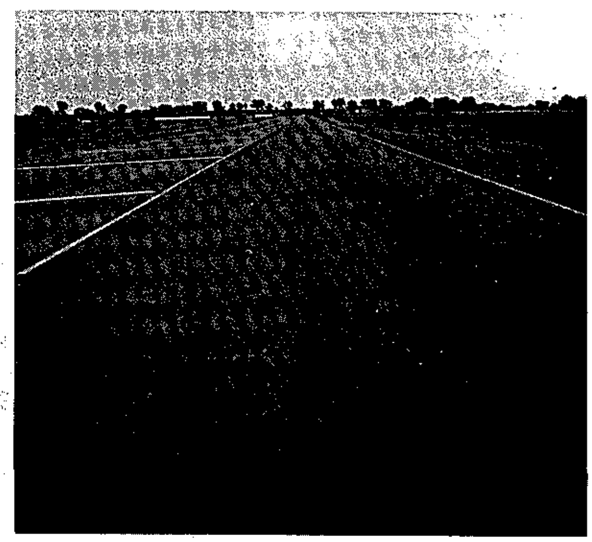


Figure XXX
California Highway Patrol Academy Test Site

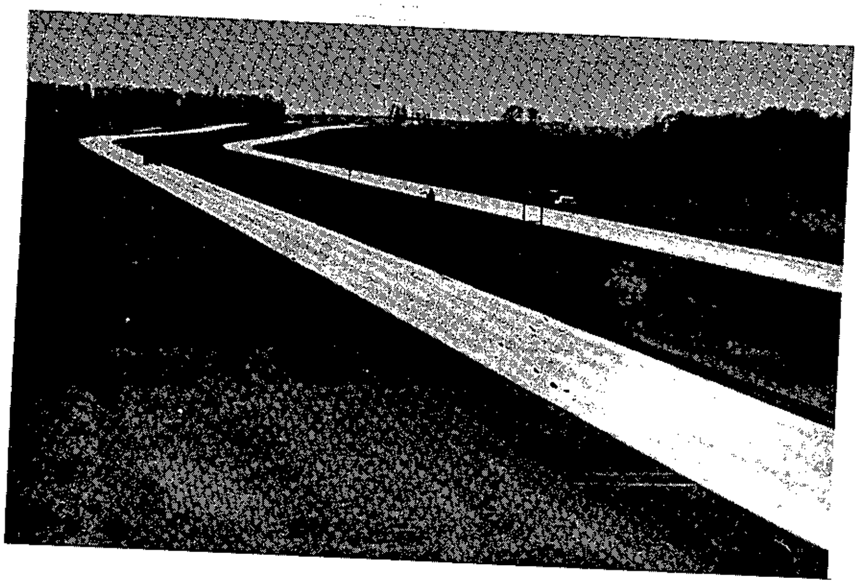


Figure XXXI
Test Site on I-5

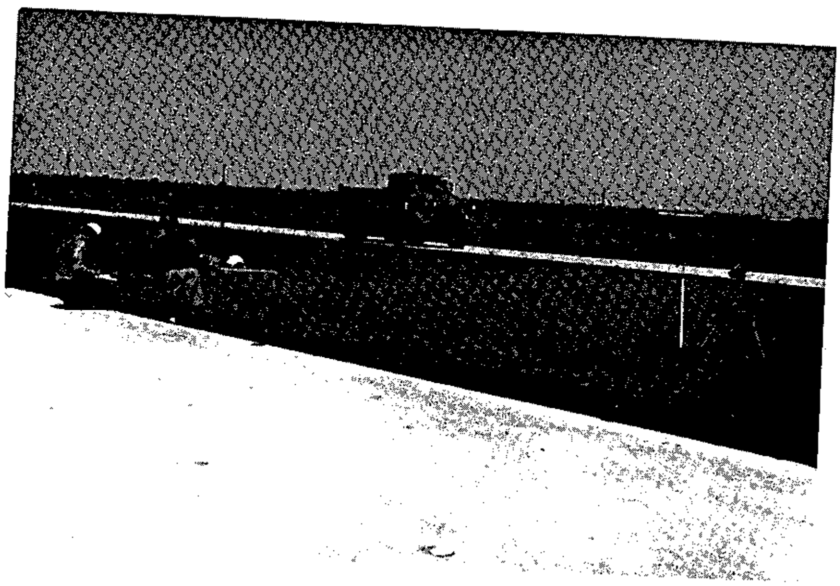


Figure XXXII
Test Site on I-5

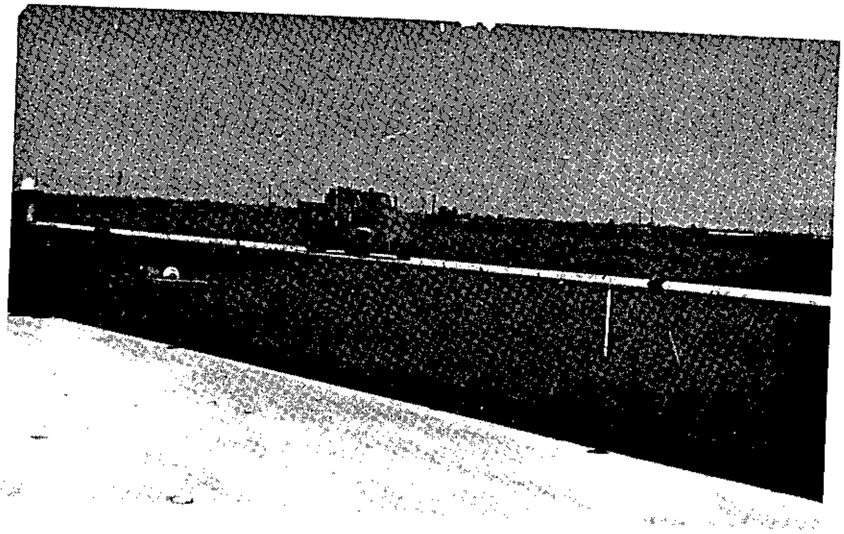


Figure XXXIII
Test Site on I-5

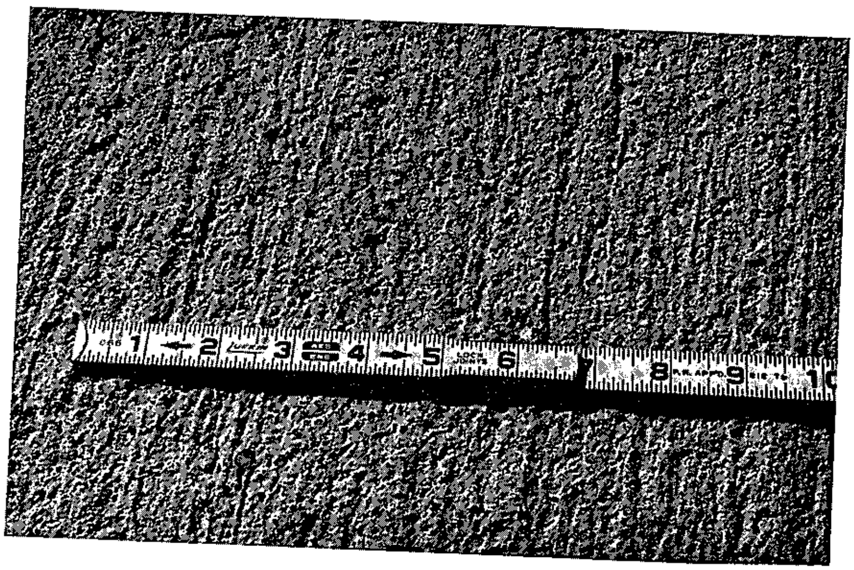
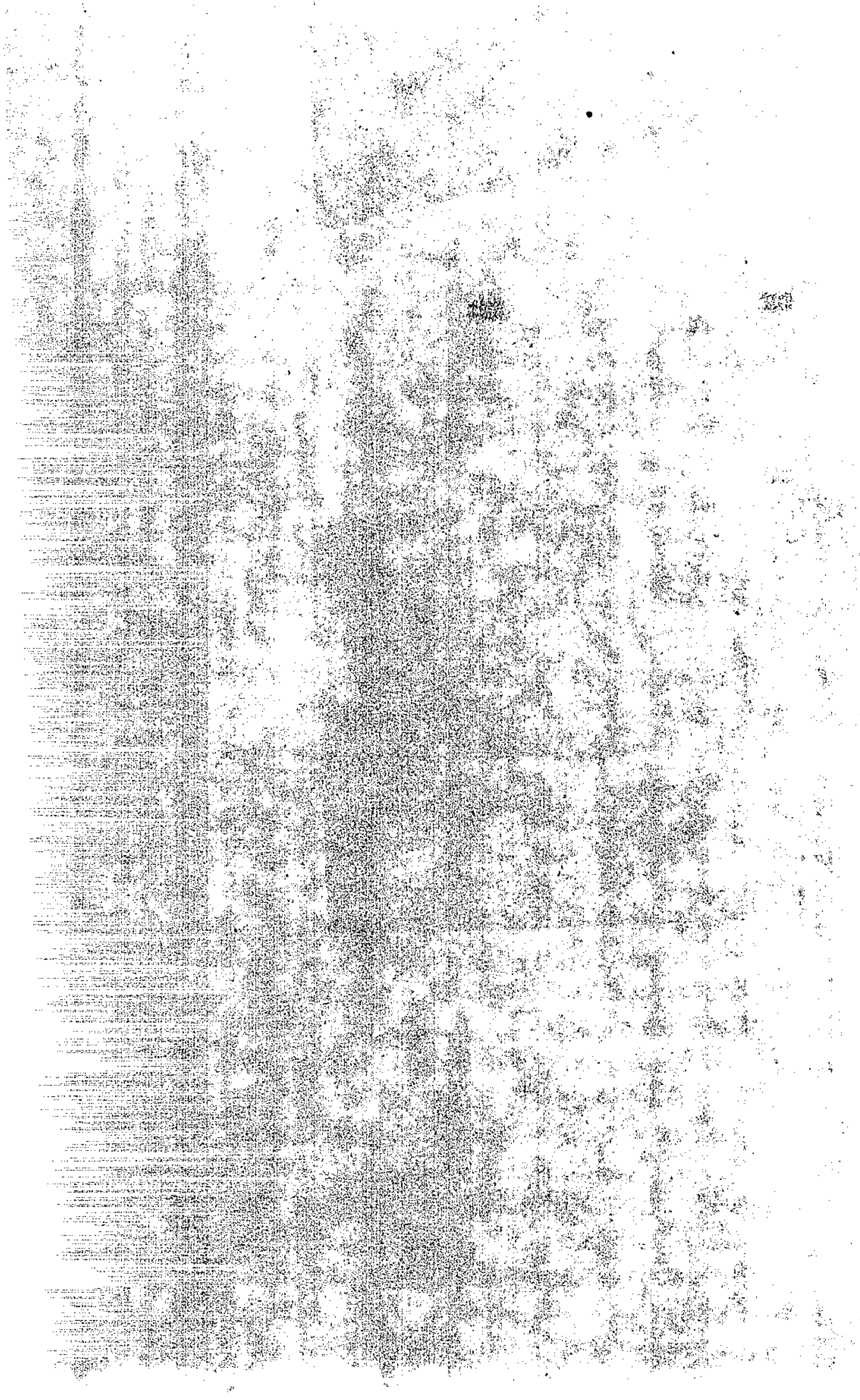


Figure XXXIV
Pavement Texture of Test Site on I-5



## DATA ACQUISTION AND ANALYSIS

Initial tests were performed to evaluate the completed modified truck on April 9 and 10, 1975, at the I-5 test site south of Sacramento. As a basis of comparison, tests were also performed on the Regular Truck. Noise measurements were made during the following operating modes and conditions.

1) Acceleration or cruise
2) Engine on or off
3) Northbound or Southbound
4) Various speeds

Background noise from airplanes and a train in one case invalidated some measurements. Due to inexperience of the personnel, there were other problems such as failure to turn the engine off or not accelerating at the correct distances.

Table 6 presents all the data collected except for a few measurements that were obviously incorrect as described above. These data are also plotted on Figure XXXV.

The test data and subjective field evaluations by the researchers indicated the following:

Table 6

SUMMARY OF DRIVEBY NOISE TESTS ON THE QUIET AND REGULAR TRUCK

(Tests performed on April 9-10, 1975) I-5 Test Site

Microphone at 50 ft. from ℄ of lane and 4.5 ft. above the pavement.

| Engine | | Speed | Mode | | Total No. of Eastbound and Westbound Runs | | $\bar{X}$ dBA of Eastbound and Westbound Runs | | |
|---|---|---|---|---|---|---|---|---|---|
| On | Off | MPH | Accel. | Cruise | Quiet | Regular | Quiet Truck | Regular Truck | Difference |
| | X | 15 | | X | 4 | 4 | 64.6 | 62.9 | +1.7 |
| X | | 15 | | X | 3 | 3 | 67.3 | 74.5 | -7.2 |
| X | | 15 | X | | 2 | 2 | 73.0 | 81.6 | -8.6 |
| | X | 35 | | X | 2 | 2 | 67.0 | 68.0 | -1.0 |
| X | | 35 | | X | 2 | 2 | 68.0 | 73.8 | -5.8 |
| X | | 35 | X | | 2 | 2 | 73.0 | 80.0 | -7.0 |
| | X | 55 | | X | 3 | 3 | 70.1 | 72.3 | -2.2 |
| X | | 55 | | X | 3 | 3 | 71.6 | 77.4 | -5.8 |
| X | | 50 | X | | 4 | 4 | 72.8 | 82.1 | -9.3 |
| SAE Test | | | | | | | | | |
| X | | 35 | X | | 3 | 5 | 75.9 | 81.7 | -5.8 |

## MODIFIED AND REGULAR TRUCK, DRIVE BY TESTS

TESTS PERFORMED, I-5 TEST SITE, 4-9 & 10-75

MICROPHONE 50 FT. FROM THE ℄ OF THE LANE
AND 4.5 FT. ABOVE THE PAVEMENT

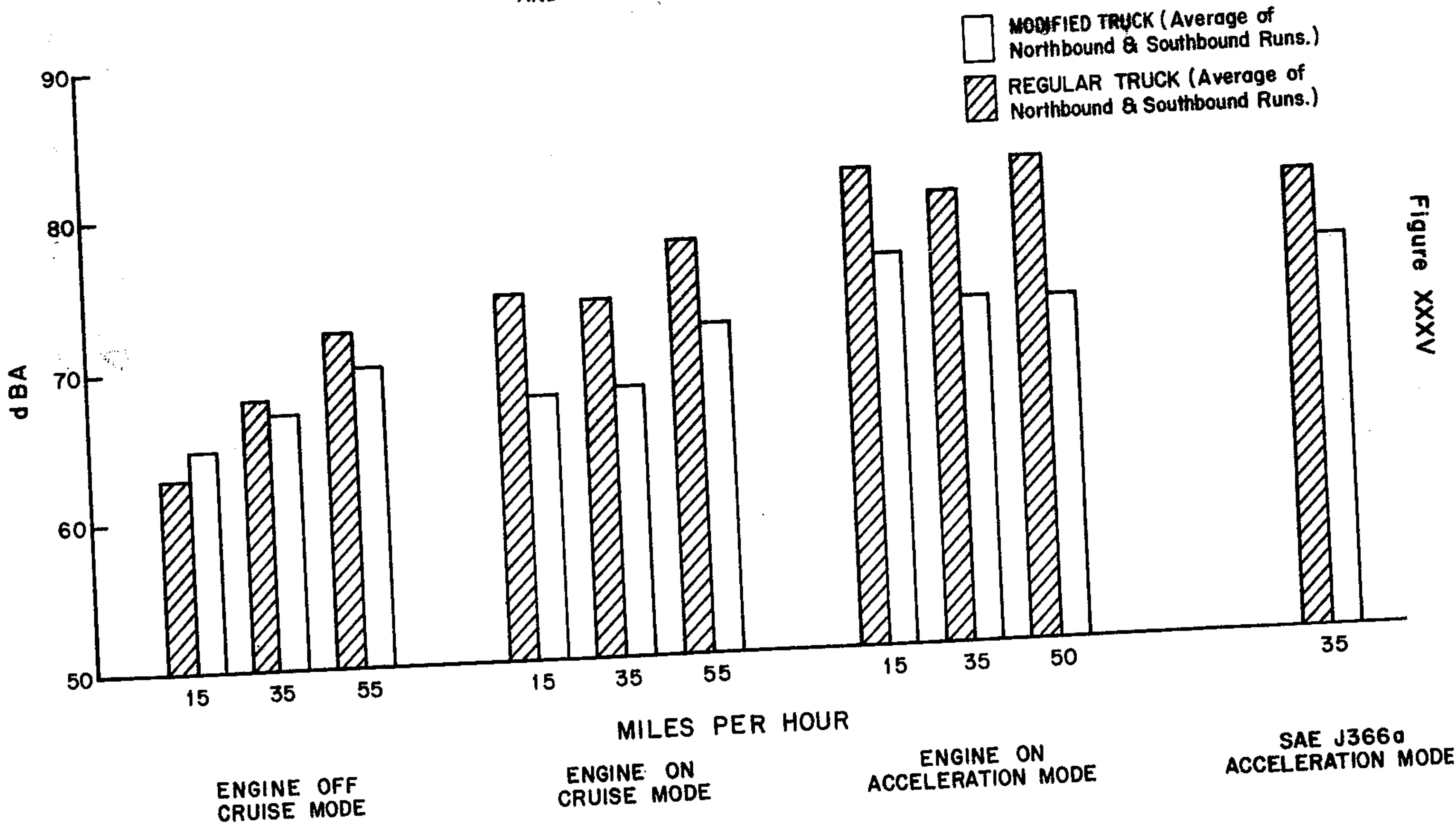



Figure XXXV

Engine Off - Cruise Mode

1. Noise due to tires, wind and mechanical parts.
2. Noise level increases with speed but the difference between the regular and modified truck is less than 2.5 dBA.

Engine On - Cruise Mode

1. Noise level of the regular truck is about 5 dBA higher than the modified truck.
2. Noise levels at 51 and 35 mph are about the same for the regular and modified truck but noise levels increase about 4 dBA at 55 mph.

Engine On - Acceleration Mode

1. Noise level of each vehicle is generally the same at 15, 35 and 50 mph with the regular truck about 6 dBA higher than the modified truck at all speeds.

SAE Tests

1. Regular truck is about 4 dBA higher than the modified truck.
2. Overall, the sound level of the SAE tests are about the same as the engine on acceleration tests at 15, 35 and 55 mph.

Overall

1. Sound level increases as the modes change from Engine Off, to Engine On, to Engine On-Acceleration for the modified truck.

A second series of tests were performed on December 16, 1975, at various speeds to evaluate effects of speed on the modified truck. Table 7 and Figure XXXVI display the data. Tests were performed at the I-5 test site. Background noise from airplanes invalidated some readings.

Table 7

QUIET TRUCK DRIVEBY TESTS AT 50 FEET, MODIFIED TRUCK

Microphone 50 Ft. From ℄ of Lane and 4.5 Ft. Above the Pavement

Tests Performed on 12-16-75

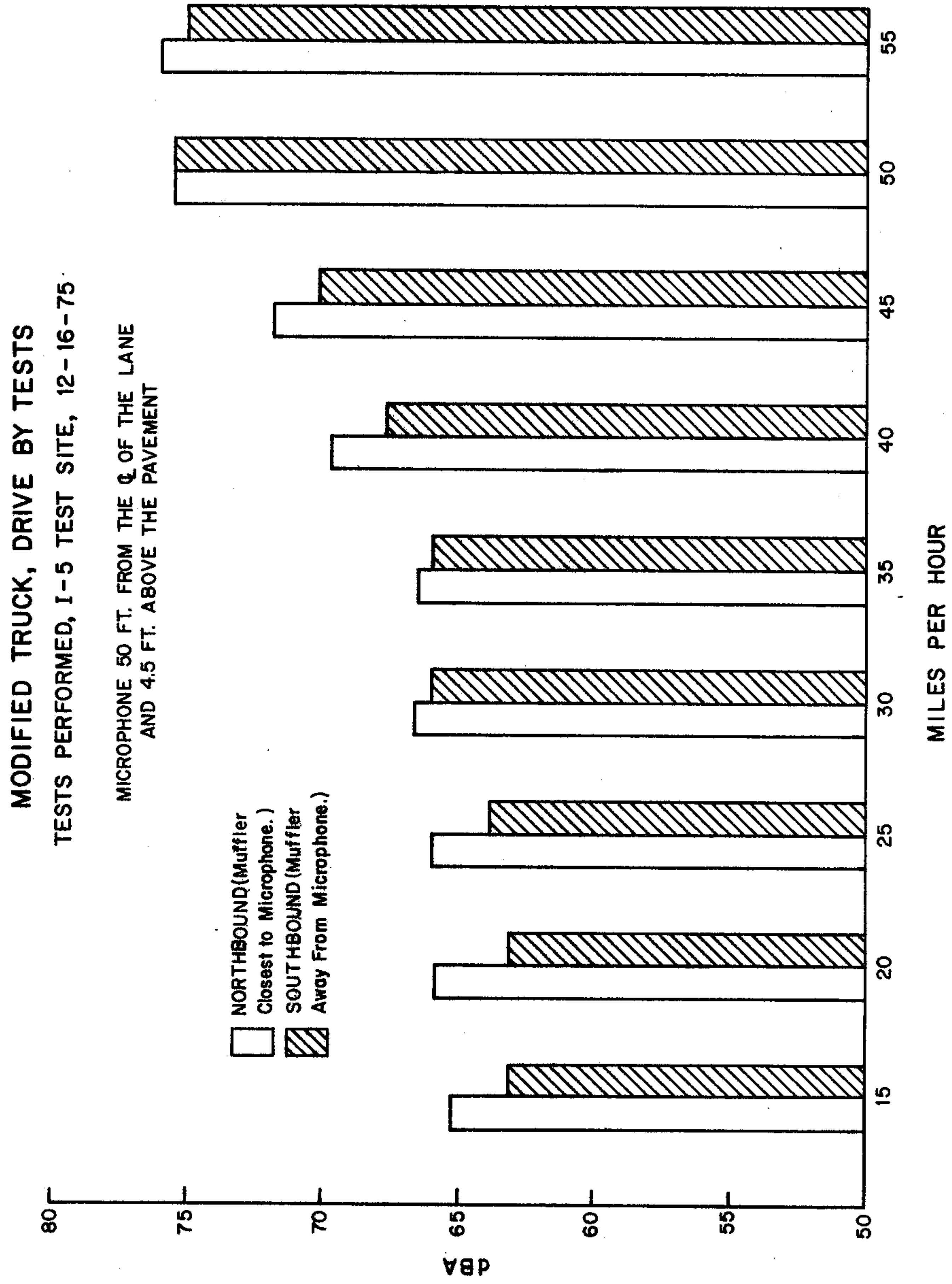
I-5 Test Site

| Speed MPH | Sound Level dBA Eastbound | Sound Level dBA Westbound |
|---|---|---|
| 55 | 77 | 76 |
| 55 | 75 | 74 |
| 55 | 77 | 75 |
| 55 | 76 | 74 |
| 55 | 75 | 76 |
| X̄ | 76.0 | 75.0 |
| 50 | 76 | 74 |
| 50 | 76 | 75 |
| 50 | 75 | 76 |
| 50 | - | - |
| 50 | 75 | 76 |
| X̄ | 75.5 | 75.5 |
| 45 | 72 | 72 |
| 45 | 71 | 70 |
| 45 | 74 | 69 |
| 45 | 72 | 70 |
| 45 | 70 | 76 |
| X̄ | 71.8 | 70.2 |
| 40 | 69 | - |
| 40 | 70 | 68 |
| 40 | 69 | 67 |
| 40 | 69 | 68 |
| 40 | 69 | 68 |
| X̄ | 69.7 | 67.8 |
| 35 | 67 | 66 |
| 35 | 66 | 66 |
| 35 | 67 | 66 |
| 35 | 66 | 66 |
| 35 | - | 66 |
| X̄ | 66.5 | 66.0 |
| 30 | 66 | 66 |
| 30 | 67 | 66 |
| 30 | 66 | 66 |
| 30 | 66 | 66 |
| 30 | - | - |
| X̄ | 66.6 | 66.0 |

Eastbound - Truck Muffler is closest to microphone

Westbound - Truck muffler is away from microphone

Figure XXXVI



The data indicated that the noise measurements on the eastbound runs (muffler closest to microphone) were generally about 1 to 3 dBA higher than those on the westbound runs. At speeds of 35 mph and lower, the noise levels are fairly constant for the eastbound runs (65-66.5 dBA). From 35 to 50 mph there is a sharp 10 dBA increase in noise level for the eastbound runs. There is the same general trend for the westbound runs but not as clearly defined.

Factors such as tire noise, wind noise, and engine noise contribute to the sharp increase in noise levels above 35 mph.

Figure XXXVII and Table 8 display the noise test data collected on the modified truck to evaluate the acceleration and deceleration modes following the SAE J366a procedures. These tests made on December 17, 1975, showed higher sound levels on the northbound than for the southbound runs for the acceleration tests (5 to 8 dBA) and deceleration tests (about 3 dBA). The acceleration runs were much higher than the comparable decleration runs. As expected, this indicated the modified truck was noiser during acceleration.

Another series of tests were attempted on December 17, 1975, at the California Highway Patrol Academy but were not completed due to transmission problems with the modified truck. The noise measurements that were made are shown on Table 9 and plotted on Figure XXXVIII. Truck speed did not have any significant effect on noise level for both the regular and modified truck at the low test speeds. The eastbound runs show higher noise levels than the westbound runs. In all cases, there is considerably less noise emitted from the modified truck (7 to 10 dBA).

Figure XXXVII

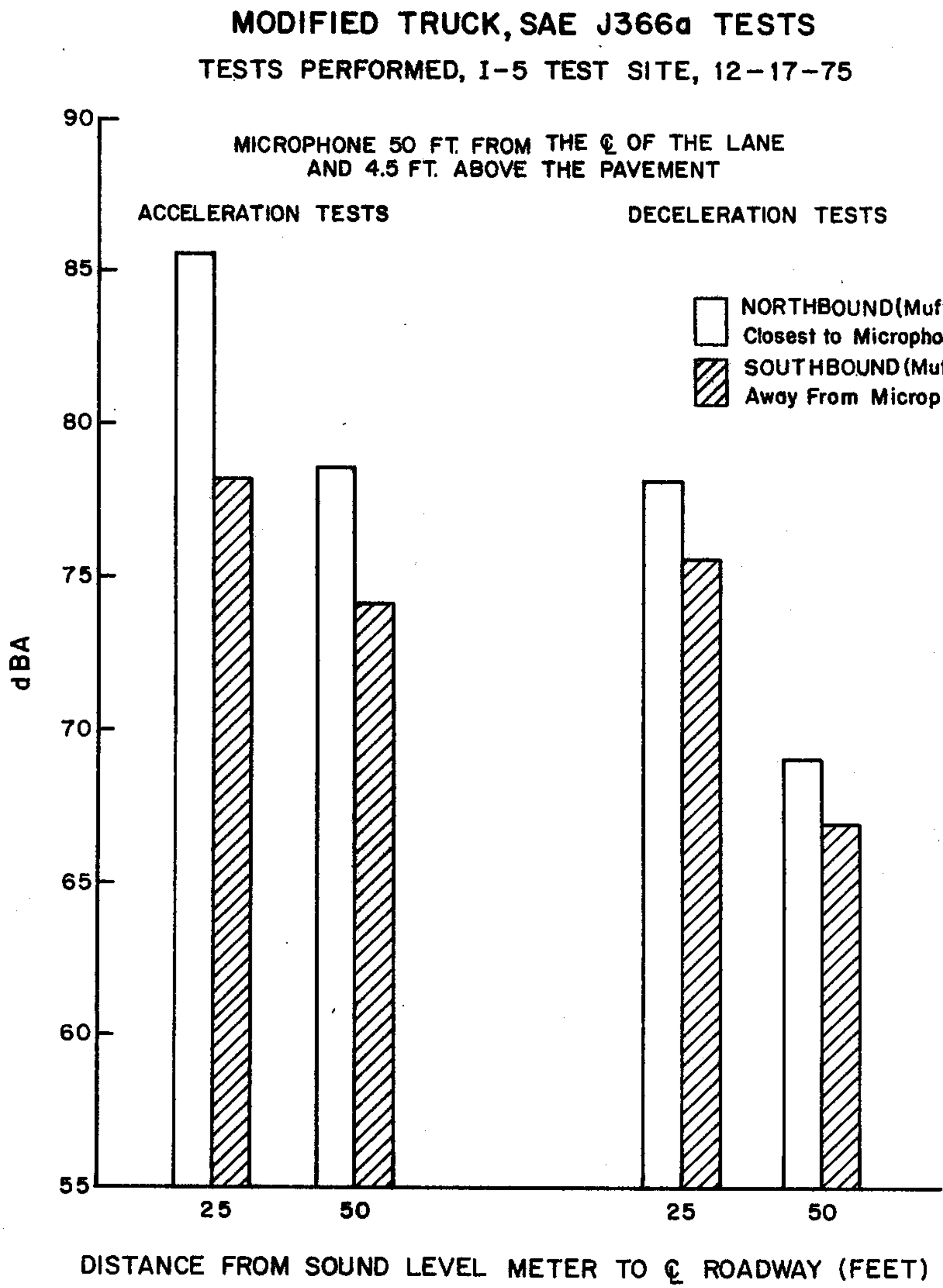


Table 8

MODIFIED TRUCK
TESTED ON 12-17-75

Distance from Sound Level Meter was 25 and 50 ft. from the ℄ of the roadway. The meter was 4.5 ft. above the pavement.

SAE J366a, Acceleration Tests

| | 25' | | 50' | |
|---|---|---|---|---|
| | WB | EB | WB | EB |
| | 77 | 84 | 74 | 79 |
| | 78 | 87 | 74 | 75 |
| | 76 | 86 | - | 75 |
| | 78 | - | 73 | 79 |
| | 78 | 85 | 72 | 79 |
| | 79 | 85 | 75 | 81 |
| | 80 | 86 | 76 | 81 |
| | 80 | 86 | 76 | 80 |
| | 78 | 86 | 73 | 78 |
| X̄ | 78.2 | 85.6 | 74.1 | 78.6 |

SAE J366a Deceleration Tests

| | 25' | | 50' | |
|---|---|---|---|---|
| | WB | EB | WB | EB |
| | 75 | 76 | 67 | 67 |
| | 75 | 78 | 66 | 70 |
| | 77 | 77 | 67 | 68 |
| | 76 | 81 | 68 | 70 |
| | 75 | 79 | 67 | 71 |
| X̄ | 75.6 | 78.2 | 67.0 | 69.2 |

Table 8 (con't.)

| Speed MPH | Sound Level dBA | |
|---|---|---|
| | Eastbound | Westbound |
| 25 | 66 | 64 |
| 25 | 65 | 63 |
| 25 | 67 | 64 |
| 25 | 66 | 64 |
| 25 | 66 | 64 |
| $\bar{X}$ | 66.0 | 63.8 |
| 20 | 66 | 64 |
| 20 | 66 | 64 |
| 20 | 66 | - |
| 20 | 67 | 63 |
| 20 | 64 | 62 |
| $\bar{X}$ | 65.8 | 63.2 |
| 15 | 66 | 64 |
| 15 | 66 | 64 |
| 15 | 66 | 62 |
| 15 | 64 | 62 |
| 15 | 64 | 64 |
| $\bar{X}$ | 65.2 | 63.2 |

Table 9

MODIFIED AND REGULAR TRUCKS

DRIVEBY TESTS 12-17-75

Microphone 50 ft. from ℄ of lane and 4.5 ft. above the pavement.

Tests at the California Highway Patrol Academy.

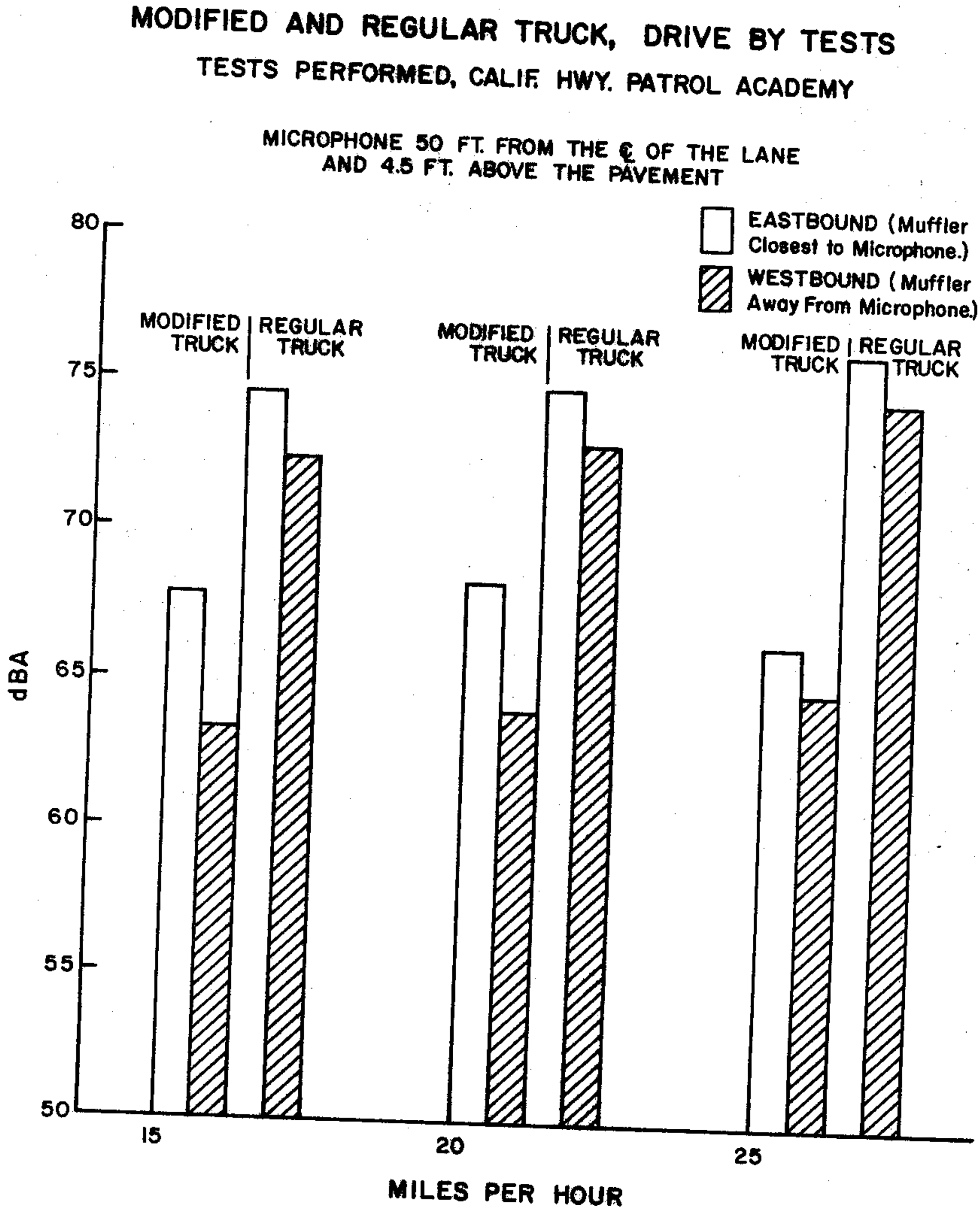
Measurements made in westbound and eastbound lanes.

| | 15 MPH | | | | 20 MPH | | | | 25 MPH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Quieted Truck 50' | | Regular Truck 50' | | Quieted Truck 50' | | Regular Truck 50' | | Quieted Truck 50' | | Regular Truck 50' | |
| | WB | EB | WB | EB | WB | EB | WB | EB | WB | EB | WB | EB |
| | 64 | 69 | 70 | 73 | 64 | 68 | 73 | 75 | 65 | 66 | 75 | 77 |
| | 64 | 68 | 71 | 77 | 64 | 68 | 72 | 75 | 64 | 66 | 75 | 76 |
| | 63 | 68 | 76 | 77 | - | 68 | 73 | 74 | 65 | 68 | 74 | 77 |
| | 61 | 66 | 72 | 72 | 64 | 69 | 73 | 75 | 65 | 66 | 74 | 76 |
| | 64 | - | 73 | 74 | 64 | 68 | 74 | 75 | 65 | 66 | 75 | 75 |
| $\bar{X}_1$ | 63.2 | 67.0 | 72.4 | 74.6 | 64.0 | 68.2 | 73.0 | 74.8 | 64.8 | 66.4 | 74.6 | 76.2 |
| $\bar{X}_2$ | 65.2 | | 73.5 | | 66.3 | | 73.9 | | 64.6 | | 75.4 | |

EB - Eastbound driveby, muffler closest to microphone.

WB - Westbound driveby, muffler away from microphone.

Figure XXXVIII



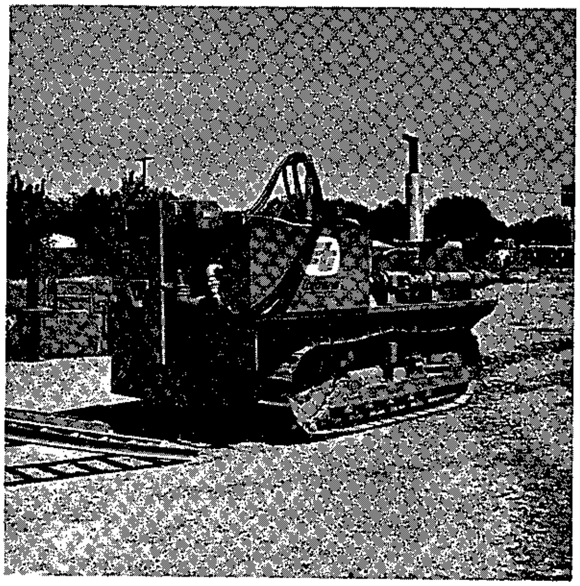
The data shown on Figures XXXVI, XXXVII and XXXVIII all show that the modified truck was quieter when the muffler was away from the measuring microphone. Differences as much as 7 dBA were measured depending on operating mode. This was believed due to the positioning of the exhaust outlet (Figure XVIII) rather than having the muffler on one side or the other. This may suggest that manufacturers use this configuration to gain some noise reduction off of highways.

## CONSTRUCTION EQUIPMENT (Drill Rig)

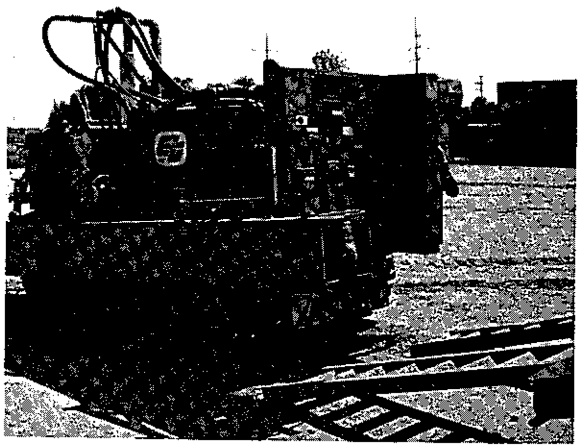
One of the objectives of this project was to apply the findings from the literature survey and experience gained from building a modified truck to quieting noisy construction equipment. A unique opportunity occurred during the later stages of this project when the high level of noise from the Transportation Laboratory Horizontal Drill Rig was brought to the attention of the researchers. One of the drill operators that recently retired was awarded additional retirement compensation due to a hearing loss which he attributed to the drill rig noise.

Figure XXXIX shows a photograph of the Horizontal Drill Rig used for construction and maintenance purposes. This section describes the steps taken to quiet the drill rig noise.

Figure XXXIX



Drill Rig
(back & side view)

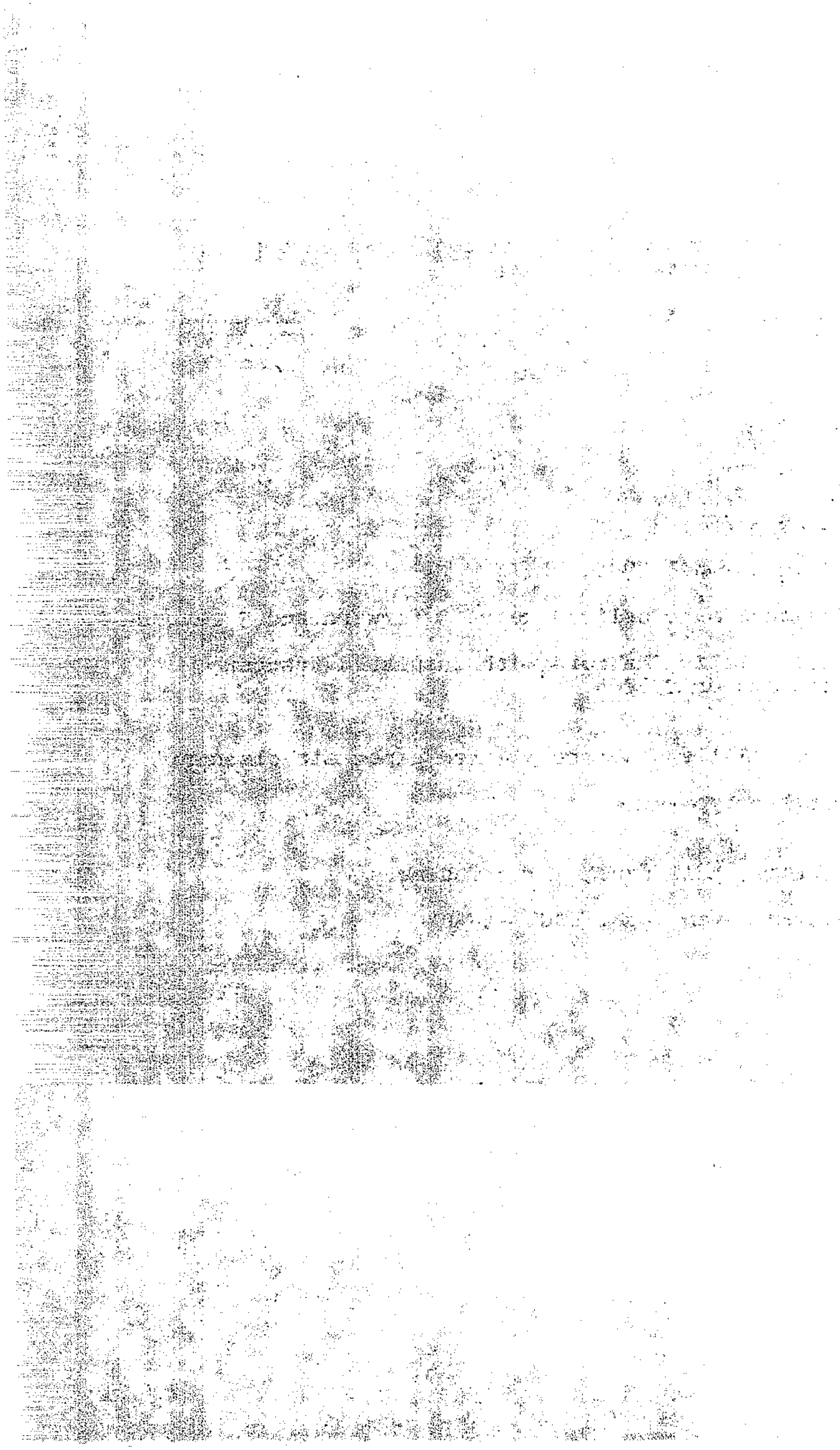


Drill Rig
(back & side view)

The following is a description of the engine and principle parts:

Geotechnical Drill Rig
CHC 34

| | | | |
|---|---|---|---|
| Engine Type | Allis Chalmers, Turbo charged, open combustion chamber, direct injection | | |
| | Automotive use | Variable load | Continuous load |
| HP @ RPM | 135(a)2600 - | 118(a)2400 - | 100(a)2200 |
| Cylinders | 6 | | |
| Cycle | 4 | | |
| CID | 301 cu. in. | | |
| Bore-Stroke | 3.875/4.25 | | |
| Gas or Diesel | Diesel, Model 2900, Mk.II | | |
| Transmission | Constant mesh helical gear, 3 forward and 3 reverse speeds | | |
| Exhaust System Muffler, Model & Make | Turbo, Allis Chalmers with insulated wrapper part number 256706 | | |
| Intake System | Turbo, Allis Chalmers pleated paper air cleaner | | |
| Cooling System Radiator | Tubular type core | | |
| Fan Type | 5 blade, pull type, Allis Chalmers | | |
| Hydraulic System Mfg. & Model | Vickers, van type, 1CC10-1-30 | | |



## Mitigation Measures

The initial examination of the drill rig indicated the absence of side panels around the engine area and an inadequate muffler. Noise measurements were performed before and after a new muffler and new side panels lined with sponge rubber were installed. The test data indicated that almost all of the noise reduction was achieved by the muffler. It appeared that the side panels were not doing an adequate job because too much open space was left which was needed for cooling the engine. This was determined by testing with the side panels on and off. Noise reductions due to these measures were 7 to 9 dBA at the various locations.

The next phase consisted of wrapping the muffler with fiberglass covered with metal wrapping. It was also noted that the hydraulic system was noisy and creating vibration in the control panel. To mitigate this problem, rubber isolation mounts were used and a second sheet metal panel (12 gauge), rubber mounted and lined with sponge rubber was installed. Noise reductions due to these measures ranged from 1 to 6 dBA. Analysis of the data indicated most of the noise reduction occurred when the secondary panel was installed. The second panel was most effective for the operator position behind the panel and to the position left of the panel. It did not help much at the other positions.

Figure XXXX shows a schematic of the drill rig and the various locations where noise measurements were made. These locations are the general areas where the operators work. Table 10 shows a summary of the noise measurements during the various mitigation steps.

Figure XXXX

## TRANSLAB HORIZONTAL DRILL RIG

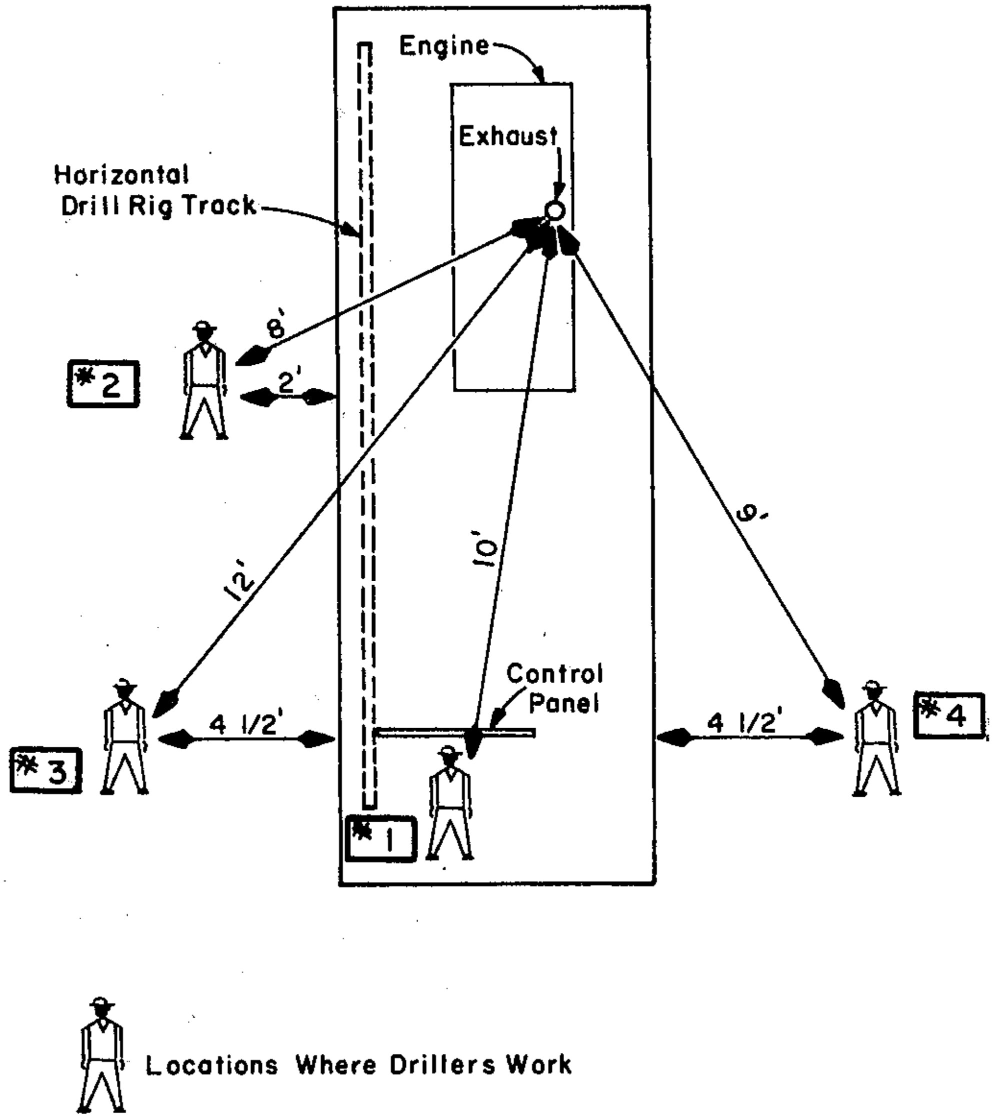


Table 10

Noise Measurements in dBA

| Location | Before Modification | | New Muffler + Engine Side Panels | | Wrapped Muffler + Insulated Control Panel | | Full Throttle With Drill Unit Operating | |
|---|---|---|---|---|---|---|---|---|
| | Full Throttle | Idle | Full Throttle | Idle | Full Throttle | Idle | Before Modification | After Modification |
| 1 | 97 | 75 | 89 | 72 | 83 | 70 | 104 | 87 |
| 2 | 98 | 83 | 89 | 76 | 88 | 75 | 98 | 89 |
| 3 | 95 | 78 | 86 | 78 | 82 | 68 | 94 | 83 |
| 4 | 95 | 79 | 88 | 75 | 86 | 73 | 93 | 87 |

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APPENDIX A

# EXTERIOR SOUND LEVEL FOR HEAVY TRUCKS AND BUSES

1. Introduction - This SAE Recommended Practice establishes the test procedure, environment, and instrumentation for determining the maximum exterior sound level for highway motor trucks, truck tractors, and buses. The Appendix contains the recommendations of SAE for maximum sound level.

2. Instrumentation - The following instrumentation shall be used, where applicable, for the measurement required:

2.1 A sound level meter which meets the requirements of International Electrotechnical Commission Publication 179, Precision Sound Level Meters, and ANSI S1.4-1961, General Purpose Sound Level Meters.

2.1.1 As an alternative to making direct measurements using a sound level meter, a microphone or sound level recorder or indicating meter, providing the system meets the requirements of SAE J184.

2.2 A sound level calibrator.

2.3 An engine-speed tachometer (see paragraph 4.1.1).

3. Test Site

3.1 A suitable test site shall consist of a level open space free of large reflecting surfaces, such as parked vehicles, signboards, buildings, or hillsides, located within 100 ft. of either the vehicle path or the microphone. See Fig. 1.

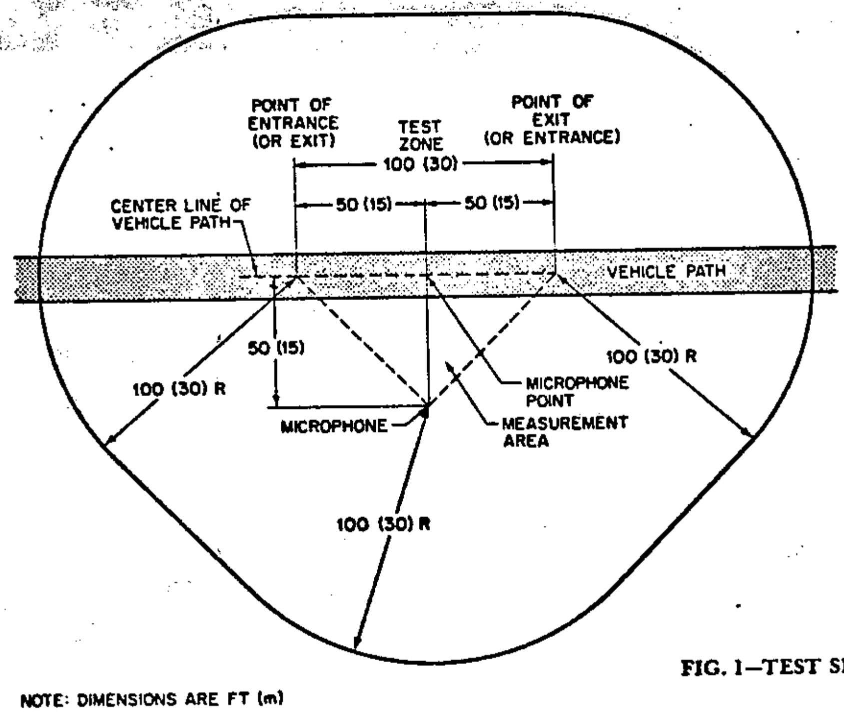


FIG. 1—TEST SITE (SEE PARAGRAPH 3). (VEHICLE MAY BE RUN IN EITHER DIRECTION)

3.2 The microphone shall be located 50 ft. from the center-line of the vehicle path and 4 ft. above the ground plane. The normal to the vehicle path from the microphone shall establish the microphone point on the vehicle path.

3.3 An acceleration point shall be established on the vehicle path 50 ft. before the microphone point.

3.4 An end point shall be established on the vehicle path 100 ft. from the acceleration point and 50 ft. from the microphone point.

3.5 The end zone is the last 40 ft of vehicle path prior to the end point.

3.6 The measurement area shall be the triangular area formed by the acceleration point, the end point, and the microphone location.

3.7 The reference point on the vehicle, to indicate when the vehicle is at any of the points on the vehicle path, shall be the front of the vehicle except as follows:

3.7.1 If the horizontal distance from the front of the vehicle to the exhaust outlet is more than 200 in, test shall be run using both the front and rear of the vehicle as reference points.

3.7.2 If the engine is located rearward to the center of the chassis, the rear of the vehicle shall be used as the reference point.

3.8 During measurement, the surface of the ground within the measurement area shall be free from powdery snow, long grass, loose soil, or ashes.

3.9 Because bystanders have an appreciable influence on meter response when they are in the vicinity of the vehicle or microphone, not more than one person, other than the observer reading the meter, shall be within 50 ft of the vehicle path or instrument, and that person shall be directly behind the observer reading the meter, on a line through the microphone and the observer.

3.10 The ambient sound level (including wind effects) coming from sources other than the vehicle being measured shall be at least 10 dB lower than the level of the tested vehicle.

3.11 The vehicle path shall be relatively smooth, dry concrete or asphalt, free of extraneous material such as gravel.

4. Procedure

4.1 Vehicle Operation - Full throttle acceleration and closed throttle deceleration tests are to be used. A beginning engine speed and proper gear ratio must be determined for use during measurements.

4.1.1 Select the highest rear axle and/or transmission gear ("highest gear" is used in the usual sense; it is synonymous to the lowest numerical ratio) and an initial vehicle speed such that a wide-open throttle the vehicle will accelerate from the acceleration point:

(a) Starting at no more than two-thirds of maximum rated or of governed engine speed.

(b) Reaching maximum rated or governed engine speed within the end zone.

(c) Without exceeding 35 mph before reaching the end point.

4.1.1.1 Should maximum rated or governed rpm be attained before reaching the end zone, decrease the approach rpm in 100 rpm increments until maximum rated or governed rpm is attained within the end zone.

4.1.1.2 Should maximum rated or governed rpm not be attained until beyond the end zone, select the next lower gear until maximum rated or governed rpm is attained within the end zone.

4.1.1.3 Should the lowest gear still result in reaching maximum rated or governed rpm beyond the permissible end zone, unload the vehicle and/or increase the approach rpm in 100 rpm increments until the maximum rated or governed rpm is reached within the end zone.

4.1.2 For the acceleration test, approach the acceleration point using the engine speed and gear ratio selected in paragraph 4.1.1 and at the acceleration point rapidly establish wide-open throttle. The vehicle reference shall be as indicated in paragraph 3.7. Acceleration shall continue until maximum rated or governed engine speed is reached.

4.1.3 Wheel slip which affects maximum sound level must be avoided.

4.1.4 For the deceleration test, approach the microphone point at maximum rated or governed engine speed in the gear selected for the acceleration test. At the microphone point, close the throttle and allow the vehicle to decelerate to one-half of maximum rated or of governed engine speed. The vehicle reference shall be as indicated in paragraph 3.7. If the vehicle is equipped with an exhaust brake, this deceleration test is to be repeated with the brake full on immediately following closing of the throttle.

4.2 Measurements

4.2.1 The meter shall be set for "fast" response and the A-weighted network.

4.2.2 The meter shall be observed during the period while the vehicle is accelerating or decelerating. The applicable reading shall be the highest sound level obtained for the run, ignoring unrelated peaks due to extraneous ambient noises. Readings shall be taken on both sides of the vehicle.

4.2.3 The sound level for each side of the vehicle shall be the average of the two highest readings which are within 2 dB of each other. Report the sound level for the side of the vehicle with the highest readings.

5. General Comments - Measurements shall be made only when wind velocity is below 12 mph.

5.1 It is strongly recommended that technically trained personnel select equipment and that tests are conducted only by qualified persons trained in the current techniques of sound measurement.

5.2 Proper usage of all test instrumentation is essential to obtain valid measurements. Operating manuals or other literature furnished by the instrument manufacturer should be referred to for both recommended operation of the instrument and precautions to be observed. Specific items to be considered are:

5.2.1 The effects of ambient weather conditions on the performance of all instruments (for example, temperature, humidity, and barometric pressure).

5.2.2 Proper signal levels, terminating impedances, and cable lengths on multi-instrument measurement systems.

4.2.3 Proper acoustical calibration procedure, to include the influence of extension cables, etc. Field calibration shall be made immediately before and after each test sequence. Internal calibration means is acceptable for field use, provided that external calibration is accomplished immediately before or after field use.

5.3 Vehicles used for tests must not be operated in a manner such that the break-in procedure specified by the manufacturer is violated.

6. References - Suggested reference material is as follows:

ANSI S1.1.1-1960 Acoustical Terminology
ANSI S1.2-1967 Physical Measurment of Sound
ANSI S1.4-1961 General Purpose Sound Level Meters
IEC Publication 179, Precision Sound Level Meters

Applications for copies of these documents should be addressed to the American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018.

## APPENDIX

The SAE recommends that a maximum A-weighted sound level of 88 dB when measured in accordance with the test procedure described above be used as a reference in the design and development of heavy trucks and buses.

An additional 2 dB allowance over the sound level limit is recommended to provide for variations in test site, temperature gradients, test equipment, and inherent differences in nominally identical vehicles.

## APPENDIX B

## Specifications for Construction Contracts

Suggested noise requirements for the California Department of Transportation Standard Specifications for construction contracts.

<u>History</u> After the passage of the Federal Environmental Policy Act in 1969 and the California Environmental Quality Act of 1970, the California Department of Transportation (Caltrans) made an effort to develop specifications to control construction noise. Caltrans and the contracting industry recognized the desireability of attaining reduced noise emissions from construction equipment. However, there were many disagreements on the details of implementing a specificaion.

The following industry comments were offered in 1971.

1. Sufficient lead time was required so that equipment manufacturers could retrofit or build new equipment to meet any proposed noise standards.

2. Apply specifications only when construction is being done in noise sensitive areas such as resorts and urban and metropolitan areas.

3. The proposed specifications could not be completely met with existing equipment and the contractors should be given a few years to allow the old equipment to wear out.

4. Allow higher noise levels when the ambient noise is high.

5. Make measurements at the right of way line.

6. Specify noise limits based on current equipment with reduced levels in future years.

7. Impact type noise should not be included in the specifications.

Comments - Federal and State laws presently limit noise emissions from operation of newly manufactured medium and heavy trucks. Regulations also cover air compressors and noise emissions from other equipment are being studied.

The disadvantage of specifying noise at the source is one of interpretation. Data from one construction machine is not necessarily applicable to several machines of the same type. Noise emission characteristics and mitigation measures are not known for all construction equipment and vary from one to another. Some construction equipment emits loud impact noise that is extremely difficult to control.

Another method of controlling construction noise is to specify maximum noise levels at the right of way line. This is an easier more practical method and protects the public but it does not minimize noise levels for the operators of the equipment. It also could create problems in metropolitan areas where right of way is restricted and equipment could be operating in close proximity to the right of way.

Noise Control Act - The Federal Noise Control Act (NCA) of 1972 (PL 92-574) established by statutory mandate is a national policy to promote an environment for all Americans free from noise that might jeoparize their health or welfare.

Under the NCA, the Federal responsibility is noise source emission control of products entering interstate commerce. The States and other political subdivisions retained authority to establish and inforce controls on environmental noise. This is to be accomplished by licensing, regulating, restricting the use, operation, or movement of noise sources and the level of noise permitted in their environment.

Specifications - In view of the past considerations previously mentioned, the current technology available in this area, and laws mandating noise control, the following specifications are proposed for Caltrans construction contracts.

Sound Control Requirements--Sound control shall conform to the provisions in Section 7-1.01N, "Sound Control Requirements", of the Standard Specifications.

The noise level from any of the Contractor's operations between the hours of 9:00 p.m. and 6:00 a.m. shall not exceed 80 dBA when measured at the right of way (RW) line. When the operations move close to the RW line a constant 50 feet distance between the equipment and measurement location outside the RW line may be established but in no case will exceed 50 feet beyond the RW line.

The noise level from any of the Contractor's operations between the hours of 6:00 a.m. to 9:00 p.m. shall not exceed 83 dBA when measured at the right of way line. Impact noise is excepted. When the operations move close to the RW line, a constant 50 feet distance between the equipment and measurement location outside the RW line may be established but in no case will exceed 50 feet beyond the RW line.

The noise level from the Contractor's operations involving impact noise shall not exceed 90 dBA between the hours of 6:00 a.m. to 9:00 p.m. when measured at the right of way line. When the operations move close to the RW line, a constant 50 feet distance between the equipment and measurement location outside the RW line may be established but in no case will exceed 50 feet beyond the RW line.

The above noise specifications for any contractors operations between the hours of 6:00 a.m. to 9:00 p.m. shall not apply if people are engaged in acitivites such as study, work, rest, play or inhabited buildings are more than 300 feet from the right of way line.

Said noise level requirements shall apply to all equipment on the job or related to the job including but not limited to earth moving, materials handling, stationary and impact equipment that may or may not be owned by the contractor. The use of loud sound signals shall be avoided in favor of light warnings except those required by safety laws for the protection of personnel.

Full compensation for conforming to the requirements of this section shall be considered as included in the prices paid for the various contract items of work involved and no additional compensation will be allowed therefore.

These proposed specifications should be reviewed and evaluated on a yearly basis. New noise standards can be promulgated as quieter equipment are manufactured, old equipment is replaced and methods for retrofitting old equipment is improved.

# APPENDIX C

## Specifications for Purchase of New Equipment

Motorcycles - Follow the State of California vehicle code (27202) specifying 75 dBA maximum if manufactured after January 1977.

Trucks - Follow the State of California Vehicle code (27204) 80 dBA maximum for vehicles with a 6,000 pound gross vehicle weight rating if manufactured after January 1977.

All Other Vehicles - Follow the State of California vehicle code (22205) specifying 80 dBA maximum if manufactured after January 1974.

Air Compressors - Follow the U.S. EPA regulations specifying 75 dBA maximum if manufactured after January 1, 1978 (capacity 75 and 250 CFM) and after July 1, 1978 (capacity over 250 CFM).

For other construction or maintenance equipment listed below a maximum 83 dBA specification is proposed. Noise measurements are made at 50 feet using the SAE J952b or equivalent procedure.

| | | |
|---|---|---|
| Frontloader | Pavers | Derrick |
| Backhoe | Saws | Pumps |
| Dozers | Vibrators | Generators |
| Tractors | Concrete Mixer | Jackhammers |
| Scrapers | Concrete Pumps | Pneumatic Tools |
| Graders | Crane | |

## APPENDIX D

### Guidelines for Quieting Construction and Maintenance Equipment

A maximum 86 dBA is proposed for all equipment powered with gasoline or diesel powered engines. Noise measurements are made at 50 feet using the SAE J952b or equivalent procedure. The following is a list cf such equipment but is not to be construed as all inclusive.

| | | |
|---|---|---|
| Trucks | Concrete Mixers | Graders |
| Frontloaders | Concrete Pumps | Pavers |
| Backhoes | Crane | Scrapers |
| Dozers | Derrick | Generatiors |
| Tractors | Pumps | Jackhammers |
| | | Pneumatic Tools |

The above noise limits on stationary equipment and others such as a jackhammer or pneumatic tools may be achieved by shielding which is not an integral part of the equipment.